A research collaboration

Australian Sustainable Energy

Zero Carbon Australia Stationary Energy Plan

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

THE UNIVERSITY OF MELBOURNE

ENERGY Research Institute

As the IEA has shown in its research, solar energy is now a serious global player for providing the world's energy. Australia has one of the world's best solar energy resource, especially suited for concentrating solar thermal power plants, which can dispatch electricity when it is needed. The Zero Carbon Australia Plan is based on up-to-date and sound information and provides quality insights on how a country well-endowed in renewable resources can transition to a solar and wind economy.

CÉDRIC PHILIBERT
RENEWABLE ENERGY DIVISION
INTERNATIONAL ENERGY AGENCY

With our natural advantage Australia can and should be positioning itself as a global renewable super power for future prosperity. This report will help shift the climate debate to focus on energy, security, affordability, export and of course opportunity. Beyond Zero Emissions offers a new and invigorating message that is much needed.

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KERNOT PROFESSOR OF ENGINEERING, UNIVERSITY OF MELBOURNE
PRESIDENT, AUSTRALIAN ACADEMY OF TECHNOLOGICAL SCIENCES AND ENGINEERING
FORMERLY CHIEF SCIENTIST OF AUSTRALIA

The Zero Carbon Australia 2020 plan shows that it is technically feasible and affordable to replace all fossil fuel electricity with 100% renewable energy given the willpower and commitment to do so. This is a cutting-edge science-based plan that should be read by every energy decision maker and politician in Australia.

MARK Z. JACOBSON
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The management of BrightSource Energy have had a long and extensive involvement in the solar thermal industry. At BrightSource's predecessor, Luz, they designed, developed, built and operated the nine SEGS parabolic trough plants in California that still operate today. Built in the 1980's, these plants were the best that could be built with the available technology at the time and certainly proved beyond any doubt that one could capture the sun's energy and convert it into steam for large scale electricity generation on a scale never before contemplated.

But, there were limits to this technology which resulted in low efficiencies and capacity factors, and high capital costs. Our team at BrightSource has now completely re-engineered the whole approach to solar thermal, utilising a centralised tower to effect a direct solar to steam design. By using flat glass mirrors that track the sun all day and through the seasons, our tower plants generate steam at 550°C and higher, allowing us to use standard Rankine cycle generation power blocks that are dry cooled. With far greater efficiencies, higher capacity factors, lower capital costs and the ability to operate the plant in hybrid mode and/or with storage, the BrightSource Luz Power Tower is the proven technology of today and well into the future for delivering firm, renewable power.

I certainly encourage and endorse the need for a holistic plan being developed for our generation portfolio in Australia going forward – one that properly takes into consideration our targets and desire to substantially increase the proportion of renewable generation capacity. The plan requires careful consideration of our "as is" situation, the desired "to be" at future dates such as 2020 and beyond, and a migration plan that will transform our generation portfolio over time to meet our renewable targets and achieve security of supply. Solar thermal power, as a firm, dispatchable power generation source, will be an integral and significant component of this plan and its deployment.

— ANDREW DYER, DIRECTOR, BRIGHTSOURCE ENERGY AUSTRALIA

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RENEWABLE ENERGY DIVISION, INTERNATIONAL ENERGY AGENCY

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STANFORD UNIVERSITY, USA

No doubt improved technologies for tapping usable energy from the sun, the winds, the tides, and the hot core of our planet will emerge as time goes by. But this report shows clearly that the solutions available now are, with our small population and enormous landmass, sufficient for Australia to move forward very quickly to tap renewable energy sources and minimize greenhouse gas emissions. We have the resources. We need the will.

— PETER DOHERTY
NOBEL LAUREATE, SCHOOL OF MEDICINE, UNIVERSITY OF MELBOURNE

This is an ambitious, technically feasible plan that should be looked at seriously.

— TIM FLANNERY
PROFESSOR FACULTY OF SCIENCE, MACQUARIE UNIVERSITY
AUSTRALIAN OF THE YEAR 2007

100 % renewable energy with zero emissions is achievable in Australia in about a decade if politics takes concerted actions... Moreover, Australia can become the initiator for a serious attempt to shift the world to a solar economy. This is the only promising strategy for climate protection and would provide societies around the world with solutions for climate protection, economic development, poverty reduction and conflict resolution. We need action now!

— HANS-JOSEF FELL
MEMBER OF THE GERMAN PARLIAMENT ALLIANCE 90
THE GREENS SPOKESMAN FOR ENERGY

To achieve a safe climate future we need an urgent, large-scale transition. The work of Beyond Zero Emissions shows that the technical transition is affordable and achievable. Now we need a social and political transition to get behind it.

— PROFESSOR CARMEN LAWRENCE
SCHOOL OF PSYCHOLOGY, UNIVERSITY OF WESTERN AUSTRALIA
FORMER PREMIER OF WESTERN AUSTRALIA

Over the past few decades the community in general and all sides of politics have come to accept the significance of the threat that greenhouse gas emissions from fossil fuel use has given rise to. Serious concrete action on changing our energy mix is all too slow in coming.

One of the challenges that those of us promoting a renewable energy future face, is that in the community and amongst decision makers, whilst there is widespread support for the idea of the renewable energy solutions, there is a lack of information on their level of technical and commercial maturity and their ability to deliver in short time frames. This is the information gap that the Beyond Zero Emissions study helps to fill in a very significant way.

The ZCA report analyses one particular scenario of renewable energy technology choice based on available solutions, in considerable depth. It successfully shows in detail that 100% renewable energy is both technically possible and economically affordable. Clearly other renewable energy technology scenarios are also possible, that only serves to strengthen the overall conclusion about viability. The group is to be congratulated for their efforts.

— ASSOCIATE PROFESSOR KEITH LOVEGROVE
HIGH TEMPERATURE SOLAR THERMAL GROUP,
AUSTRALIAN NATIONAL UNIVERSITY

The chips are down - there is no longer any doubt about our need to rapidly transition to a zero emission economy. The fate of Australia and the world depend on it. The Zero Carbon Australia strategy being launched by Beyond Zero Emissions provides the roadmap to the solutions. Let's hope it is adopted by responsible governments everywhere.

— PROFESSOR OVE HOEGH-GOLDBERG
DIRECTOR, GLOBAL CHANGE INSTITUTE, THE UNIVERSITY OF QUEENSLAND

"This is a bold and ground-breaking piece of work which should be a wake-up call to all those in government and industry who refuse to see beyond coal.

This is a very exciting report. It has academic rigour; it has also the hope of a generation and it has thousands of jobs waiting to happen.

We can and must aim to power Australia with 100% renewable energy as soon as possible if we are to truly tackle the climate crisis - and the great news is, that will bring huge benefits to us all, cleaning the air and creating jobs and investment from the suburbs to the farmlands.

This Zero Carbon Australia plan is an extremely valuable contribution which all in the parliament should be looking at very seriously"

— CHRISTINE MILNE
SENATOR FOR TASMANIA

"It's not the five per cent cut project or the 20 per cent cut project with a bunch of unachievable caveats. It's a zero carbon project and I think people actually want to be told a narrative, a story which is ambitious, which is aspirational, but also practical and I think that is what this project is about."

— NICK XENOPHON
SENATOR FOR SOUTH AUSTRALIA

It is difficult to imagine the Zero Carbon Australia plan being adopted in the context of Australia's current political and commercial culture and power cost structure. However, as an examination of the technical feasibility of achieving its goals as it seeks to shift this culture, it offers an interesting challenge for the imagination of policymakers and power suppliers feeling their way in to an uncertain future.

— KEITH ORCHISON, DIRECTOR, COOLIBAH PTY LTD
FORMER MANAGING DIRECTOR, ELECTRICITY SUPPLY ASSOCIATION OF AUSTRALIA

Every nation in the world should make a plan like this. If one can get a 100% renewable, zero carbon electricity system by investing 3% of GDP (and 10% of gross investment) for ten years, there is no good reason not to do it. Except, maybe, the straitjacket of old ways of thinking and doing.

This plan lays out a high solar-wind renewable future and then does more. It looks carefully at the materials requirements of such a future, an aspect of the matter too often left unaddressed.

Australia could be the first large economy to show the way.

— JOHN O. BLACKBURN
PROFESSOR EMERITUS OF ECONOMICS,
DUKE UNIVERSITY, USA

I strongly endorse the broad concept of such a solar and wind plan and applaud the work of the University of Melbourne and Beyond Zero Emissions. Our own work underway to calculate the feasibility of a 100% solar - wind plan for the United States has so far had the aim of testing technical feasibility, and the match seems to be 99-100%. We have considered the biomass backup options as well for CST plants but increased thermal storage also seems to work for a 100% solar - wind system for the USA. I have some differences in the discussion of CST technology used as an example, but the study is at an initial stage. The advent of such a comprehensive study in Australia will assist recognition of our own work directed to the USA case, and speed the market development of the CST and wind technologies to supply economical solar energy both day and night.

— DR DAVID MILLS
FOUNDER AND PAST CEO
SOLAR THERMAL POWER COMPANY AUSRA

Wind Power is now a serious player in international energy. Installing 8,000 megawatt-class turbines along with smaller wind turbines and other renewables where appropriate is achievable at a price the community can afford. Direct drive turbines such as the Enercon turbines are very suitable for a modern electricity grid where wind will be relied upon for a large proportion of overall electricity demand.

— DAVID WOOD
ENMAX/SCHULICH PROFESSOR OF RENEWABLE ENERGY
DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING
UNIVERSITY OF CALGARY, CANADA

That Australia enjoys an abundance of renewable energy resources is beyond question. The Zero Carbon Australia 2020 plan demonstrates that it is both technically feasible and economically affordable for Australia to realise the benefit of these resources and transition to a 100% renewable energy future. Australian politicians and decision makers with the vision and commitment to embrace this new path have the opportunity to play an important role in leading Australia to a sustainable low carbon future.

— SHARON MASCHER, ASSOCIATE PROFESSOR, CENTRE FOR MINING,
ENERGY AND RESOURCES LAW UNIVERSITY OF WESTERN AUSTRALIA

For decades, those opposing the transition to clean energy have claimed that it is not technically feasible. This report puts that argument convincingly to bed. There is no longer an excuse for inaction. Starting the transition now is our responsibility to future generations.

— PROFESSOR IAN LOWE
PRESIDENT OF THE AUSTRALIAN CONSERVATION FOUNDATION
EMERITUS PROFESSOR GRIFFITH UNIVERSITY

Beyond Zero Emissions have been in my building, Kindness House, for five years. The dedication of this remarkable team of individuals is astonishing. Most of all, I am impressed by their relentless pursuit of the truth, wherever it may lead. They have built their strategies cautiously, never letting the enthusiasm distract them from the goal of getting the right answers by asking the right questions.

They are a welcoming organization, drawing experts from a variety of disciplines, methodically searching for practical solutions to the challenges of reducing our massive carbon footprint. I am personally delighted to see the tens of thousands of hours they have invested in this important project, never once complaining about the lack of financial resources at their disposal. They have focussed their attention heavily on the carbon costs of stationary power, transport and building. I look forward to the time when they devote their formidable intellect and energy to the Livestock industry, where so much of our carbon share is squandered and emissions ignored. Beyond Zero Emissions is one organization I am proud to say I helped to incubate.

I urge every serious institution to listen to them attentively. These are serious people for serious times.

— PHILIP WOLLEN OAM
AUSTRALIAN OF THE YEAR VICTORIA 2007

Australians are capable of rapid change when the historical circumstances call for it. Indeed, we pride ourselves on being a resourceful people. The Beyond Zero Emissions team show how inventive and resourceful we can be. Their plan for a transition to 100% renewables is a powerful and cogent response to those who claim it can't be done. The reception this report receives will be a sign of how much Australians believe in their future and how much they take refuge in the thinking of the past.

— CLIVE HAMILTON
PROFESSOR OF PUBLIC ETHICS AND
AUTHOR OF REQUIEM FOR A SPECIES

The Zero Carbon Australia Stationary Energy Plan is a provocative and timely contribution to the climate change debate, and it deserves attention both here and abroad. The Plan demolishes a pile of conventional wisdom that Australian policymakers still seem unable to get past. The sorry history of Australian climate policy procrastination is littered with polluter-friendly analyses conducted by economic hired guns. Their work has been used to argue against action, or for illusory schemes that price carbon without reducing the greenhouse pollution billowing from Australian smokestacks and tailpipes. The effect has been to constrain debate and obscure from our view a very different vision—a rapid switch from fossil to renewable energy that makes economic and environmental sense. By highlighting one of many pathways to achieving that vision, the ZCA report sheds light where it is desperately needed.

— DR GUY PEARSE
RESEARCH FELLOW, GLOBAL CHANGE INSTITUTE, UNIVERSITY OF QUEENSLAND
AUTHOR OF HIGH & DRY AND QUARRY VISION

I get to work with people all over the world in the fight against global warming, a fight growing increasingly desperate as temperatures climb and rainfall patterns shift. Since Australia leads the world in per capita emissions, it makes sense that its transition planners would be thinking big. This transition obviously won't be easy or simple or cost-free, but given the alternatives it's very nice to know it's technically feasible!

— BILL MCKIBBEN
SCHOLAR IN RESIDENCE AT MIDDLEBURY COLLEGE, AUTHOR AND FOUNDER 350.ORG

This is exactly the type of initiative that we, the solar power industry, needs to propel our technology into the energy markets of Australia. SolarReserve's concentrated solar power towers with molten salt storage are the most reliable, stable form of clean, renewable energy, which is exactly what's needed to achieve the safe climate future proposed in BZE's Zero Carbon Australia roadmap. SolarReserve's solar thermal technology with molten salt storage; proven at Solar Two, the US Department of Energy's 10 MW pilot plant that operated for over 3 years in the 1990's, will not only aid in meeting Australia's renewable energy and carbon reduction objectives, but also have significant economic benefits, bringing green jobs and cutting edge technology.

Solar Reserve is willing, ready and able to deploy our molten salt power towers and fully supports the Zero Carbon Australia project.

— TOM GEORGIS
VICE PRESIDENT, SOLARRESERVE

The twin threats of peak oil and climate change are now real and escalating rapidly. They demand a radical re-think of our approach to energy, ending our fossil-fuel dependence and moving to sustainable solutions before oil scarcity and climate change impact cut off our options - and it has to happen far faster than our leaders are prepared to acknowledge.

Zero Carbon Australia 2020 is exactly the type of positive, rigorous technical analysis that is urgently needed to chart our path to a sustainable future - and convince Australia that there are far better alternatives to the complacent assumption that our high-carbon lifestyle can continue ad infinitum.

— IAN DUNLOP
FORMER CEO, AUSTRALIAN INSTITUTE OF COMPANY DIRECTORS
FORMER EXECUTIVE DIRECTOR OF THE AUSTRALIAN COAL ASSOCIATION

Renewable energy is the only way to go in the future. Enercon wind energy converters are designed to the newest standards to integrate with the modern high flexibility demands of electricity grids, providing sustainable reliable power to keep the wheels of daily life, household and industry turning. The Zero Carbon Plan outlines a technically achievable plan for generating all of Australia's energy from the wind and the sun. It can be a realistic goal if Australia gets immediately seriously committed with decision making from industry and government. We hope that its recommendations are taken up so that Australia can also be a player in the renewable energy economy that is already booming around the world.

— ENERCON GMBH

Success in restoring a safe climate depends on transforming the global economy by 2020. Every nation and every economy needs to act. The Beyond Zero Emissions group shows in their Zero Carbon Australia 2020 report how this can be done for Australia. The report charts a practical path—using only commercially available technology—to a zero emissions stationary energy sector. Let's hope that, very soon, every country has such a plan.

— LESTER R. BROWN, PRESIDENT OF EARTH POLICY INSTITUTE
AUTHOR OF PLAN B 4.0: MOBILIZING TO SAVE CIVILISATION

As a company involved in the development of solar plants all over the world, at Torresol Energy we support the Zero Carbon Australia Plan that sets the path for a future with clean, renewable energy.

Australia is one of the areas with better solar radiation and forms part of the international 'sun belt'. Besides, the country has excellent conditions for profiting from that solar radiation: large low-populated areas to build the plants and an industry that can support the technological development in the solar generation sector. In that sense, each of Torresol Energy's new projects introduces technologically advanced improvements to make Concentrated Solar Energy a manageable, economically competitive option and a real, viable, ecological and sustainable alternative to traditional energy sources.

Torresol Energy has three plants currently under construction. Among them, Gemasolar, with an innovative technology of central tower with molten salt receiver and thermal storage system, is the first commercial plant in the world of its kind. Due to this, the project has achieved considerable importance in the field of renewable energies as it opens the path to a new solar thermal power generation. Today, all of the analyses that have been carried out either by ourselves or by major international institutions show that tower plants with thermal storage is the type of technology that will be capable of generating reliable, manageable and renewable energy at the lowest costs. Therefore Australia could adapt this kind of technology in its renewable energy development plan that will allow the country to conserve the environment for future generations with a reliable energy source through utility scale baseload CSP plants.

— SANTIAGO ARIAS
CHIEF INFRASTRUCTURE OFFICER,
TORRESOL ENERGY

From the other side of the globe Protermosolar fully shares the vision of the realistic and feasible Zero Carbon Australia Plan. Spain is currently the country with the most intensive deployment of CST plants and their contribution to the grid stability and to the dispatchability of power supply has been fully demonstrated. Molten salt storage systems have been implemented in many Spanish plants providing predictable and reliable operation after sunset. Thus CST technologies could be considered as a real alternative to cover even the base load requirements of the electricity system.

Australia must profit from its high solar resource, the sooner the better. An effective boost to CST and to the other renewable technologies - as presented in this plan – will not only go in the right direction in terms of the transition to a new energy mix but it will also result in an excellent business for the Australian economy.

— DR. LUIS CRESPO
GENERAL-SECRETARY PROTERMOSOLAR
SPANISH ASSOCIATION OF CST INDUSTRIES

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Zero Carbon Australia
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Foreword

Twenty-eight billion is a big number. Measured in tonnes it is a very heavy load. This figure is the amount of sediment eroded each year from all our mountains and carried by all our rivers to all our seas. And it is the amount of carbon dioxide (CO_2) we pump into the atmosphere each year from burning fossil fuels globally – enough to cover Australia in a blanket two metres thick. In dollars, it is just a little more than the extra annual investment needed to reconfigure Australia's stationary energy system to have zero emissions in just 10 years time.

Each year the 28 billion tonnes of CO_2 we make induces heating. The oceans are now heating at the phenomenal rate of 300 trillion watts. In frighteningly human terms that is equivalent to detonating five Hiroshima sized A-bombs every second, every day of every year.

To make 28 billion tonnes of CO_2 we dig 7 billion tonnes of coal and suck countless gallons of oil and gas from the ground. In total we already excavate more rock from the Earth than nature does. With peak oil rapidly approaching, if not passed, BP's Deepwater Horizon catastrophe attests to the huge risks entailed in maintaining production.

The rate we consume energy to emit that CO_2 is 16 trillion watts. That is already about 1/3 of the energy released by plate tectonics - the process that pushes continents around the globe over geological time making mountains and earthquakes as it goes. On current growth trajectories we are set to surpass this amount of energy by 2060.

Each year we are adding a bit under 1% to the atmospheric CO_2 load, enhancing the greenhouse effect by a small fraction of a percent. By trapping just a tiny extra fraction of the incoming solar energy, we are heating not only the atmosphere, but also the oceans and land.

Such numbers give a very real sense that we humans are now operating as a geological change agent. But the scary thing is we have only just begun. Energy use is increasing exponentially, doubling every 34 years so that it will increase by 800% in a century. Curtailing energy growth will not be easy with 2 billion people already in energy poverty and 2 billion more added to the human number by mid century.

So how will we cater for our future energy needs?

One answer stares us in the face. Effectively converting about 0.06% of the solar energy that hits the land would meet the entire global energy demand.

But aren't there problems with renewable energy? Isn't it too expensive and unreliable? After all, the wind doesn't blow all the time and the sun doesn't shine at night.

Currently, advanced solar thermal power with molten salt storage, capable of producing power on demand day or night, is about four times more expensive than the cheapest coal fired power plants. But the cost of new technologies always reduces with large-scale rollout. The 2003 US-based Sargent & Lundy report anticipated solar thermal electricity costs would reach parity with coal fired power once 8.7 GW of capacity was installed – just a bit under Victoria's stationary energy capacity today.

So far, there has not even been modest stimulus for solar thermal power. The Global Financial Crisis is partly to blame, but political will is the resource in shortest supply. The BP Deepwater Horizon oil spill may have changed that.

So what if we were to try to build a 100% renewable energy system to power the Australian economy in just 10 years? How could we possibly do that, and what would it cost?

That is the challenge outlined in Australian Sustainable Energy – Zero Carbon Australia Stationary Energy Plan.

Zero Carbon Australia outlines a coherent and thoroughly researched blueprint showing how 100% renewable energy is achievable using technologies that are commercially available today: wind power and concentrating solar thermal with molten salt storage. It goes through the options, costs and benefits, confirming that a 10 year transformation of the stationary energy sector is achievable and affordable. This will also add huge stimulus to the new green economy and create jobs.

Zero Carbon Australia demonstrates that both cost and variability can be readily addressed, and exposes as myth the frequent argument that we need coal, gas or nuclear to provide baseload electricity. This is achieved by first smoothing power output across the grid via geographically dispersed production, and secondly providing dispatchable "back up" power from the molten salt storage at solar thermal power plants. Our nation continent, stretching across climate and time zones, appears ready made for this.

Zero Carbon Australia provides a big vision - Australia as a renewable energy powerhouse. But 28 billion tonnes of CO_2 is a big load, and getting bigger. Therefore a big vision for an alternative energy system is precisely what is needed.

Zero Carbon Australia is an extraordinary and pragmatic roadmap to a new and more sustainable energy system in Australia, and ultimately our region. I recommend it to all who are truly interested in securing Australia's energy future.

Mike Sandiford

Professor of Geology
Director, Melbourne Energy Institute
University of Melbourne

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Executive Summary

The Zero Carbon Australia 2020 Stationary Energy Plan (ZCA2020 Plan) is a detailed and practical roadmap to decarbonise the Australian stationary energy sector within a decade.

Current levels of greenhouse gases in the atmosphere are already sufficiently high to carry the climate system past significant tipping points. They pose an unacceptable risk of dangerous and irreversible changes to the world's climate, to biodiversity, and therefore to human civilisation. These changes directly affect Australia's food and water security, and increase the risk of regional instability.

Using a global carbon budget approach, recent work by the German Advisory Council on Global Change demonstrates that, to have a two-in-three chance of keeping global warming to less than 2°C above pre-industrial temperatures, developed nations with the highest per capita rates of emissions, such as the United States and Australia, would need to decarbonise their economies by 2020. There is increasing consensus that the 2°C threshold is too high and beyond a 'safe boundary', and that atmospheric carbon dioxide must be reduced from the current level of around 390 parts per million (ppm) into the range of 300 to 350 ppm.

For these reasons a timeline of ten years is recommended. Ten years is a meaningful timeframe for planning purposes, as it requires immediate action, whereas longer and less ambitious goals lead to half-responses and delay. Over this ten year period, fossil fuel generating assets will be retired as new renewable energy infrastructure is brought on line and securely integrated into the electricity supply system.

A group of dedicated individuals with experience and expertise in relevant energy industry disciplines, many of whom work in the fossil fuel energy industry, collaborated to develop the Zero Carbon Australia 2020 Stationary Energy Plan.

Only proven and costed technologies are used in the ZCA2020 Plan. Wind power and concentrating solar thermal (CST) with molten salt storage are the two primary technologies used, providing approximately 40% and 60% of the energy mix respectively. These key energy sources are backed up by a 2% annual contribution from crop waste biomass and hydroelectricity. Detailed modelling was undertaken to ensure that the new renewable energy supply can meet all demand projected under the ZCA2020 Plan, 24 hours a day, 7 days a week, 365 days a year.

When compared to other nations, Australia's renewable energy resources are amongst the best and the most profitable to develop. Thus, these resources offer a strategic advantage for all Australians as we prepare to compete in the future carbon-constrained global economy. The investment required to transition Australia's stationary energy sector to renewables is a stimulus equivalent to just 3% of GDP over ten years, to build a zero-emissions energy system that will last for at least 30-40 years.

The ZCA2020 research team also found that moving to 100% renewable energy by 2020 is well within the financial and industrial capability of Australia's economy. The raw materials, and manufacturing and construction labour needed to implement the transition are small when compared with those employed every day within Australian industry. For example, 80,000 construction jobs will be required at the peak of the ZCA2020 Plan installation, equivalent to only 8% of Australia's present construction workforce. This is easily achievable given that in the period immediately prior to the Global Financial Crisis, new construction jobs were increasing at a rate of around 50,000 per year. Furthermore, the jobs created by the new renewable energy economy will more than offset job losses in the fossil fuel industries.

In narrow economic terms the ZCA2020 Stationary Energy Plan does not impose a long-term cost on the economy above business-as-usual. That is, the net present costs for both scenarios calculated for the period 2010-2040 are approximately equal, at roughly $AU500 billion. This calculation ignores savings from transport fuel costs and possible carbon pricing. The ZCA2020 Plan is able to achieve this low cost, because the pipeline of renewable energy projects in the plan contributes to the rapid reduction in the cost of renewable energy. Cost reductions from increased cumulative capacity of these technologies are realised, as well as avoiding future rising costs of fossil fuels for power stations. Adoption of the full ZCA2020 Plan provides significant economic benefits, eliminates all dependence on foreign energy sources, and positions Australia to lead in the 21st century renewable energy economy.

Decisive leadership is now needed from government, business, academia and the wider community for this transition to begin.

The Stationary Energy Plan is the first in a series of six plans making up the ZCA2020 Project. Future reports will cover the sectors of Transport, Buildings, Land Use and Agriculture, Industrial Processes and Replacing Fossil-Fuel Export Revenue.

ZCA2020 Stationary Energy Plan Detail

The stationary energy sector accounts for almost 55% of Australia's CO_2 equivalent emissions, with all fossil fuels accounting for over 70% of Australia's emissions.

The ZCA2020 Stationary Energy Plan describes how to repower Australia's stationary energy sector using 100% renewable sources by 2020. The authors acknowledge that the Plan detailed herein is not the only way that Australia could achieve zero emissions from the stationary energy sector. While ongoing innovation will indeed make it even easier and cheaper to meet the zero emissions target, the option presented here is available right now.

Enercon E-126 turbines in Belgium. Image: Steenki

The ten-year timeframe has been mapped out taking into account the need for initial growth of the renewable energy industry. The timeframe could be accelerated with continued growth in later years or delayed if policy action is too slow However the report demonstrates that such a rapid transition is within Australia's capacity.

There are a variety of policy mechanisms that could facilitate implementation of the ZCA2020 Plan, with funding provided from any mixture of public and private sources. It is beyond the scope of this report to recommend any particular financing or policy mechanism.

Key features of the Plan include:

Increased Electricity Use

Australia's annual electricity demand increases by over 40%, from 822 PJ/yr (228 TWh/yr) in 2008 to 1,170 PJ/yr (325 TWh/yr) in 2020. While this is more electricity demand than would be required under business-as-usual demand growth, it is demonstrated that with a combination of energy efficiency and fuel-switching measures, this is in fact sufficient to replace all fossil fuel use, including transport and heating.

Reduced Overall Energy Requirements

Total delivered energy use under the plan is reduced by more than half, from 3,915 PJ/yr (2008) to 1,660 PJ/yr (2020), while maintaining the same level of energy services, including transport, heating and cooling, industrial energy use and so on.

This is achieved through a combination of energy efficiency measures, and by switching energy services currently provided with oil and natural gas, mostly for transport and heating, with far more efficient electrical systems.

For instance, due to the inefficiency of internal combustion engines, less than 20% of the fossil fuel energy consumed by the transport sector is actually converted into useful vehicular motion, once stop-start inefficiencies are factored in. On the other hand, electric rail and electric cars convert 80-90% of electrical energy into motion.

Similarly, space heating with efficient heat pump systems uses a small amount of electricity to "pump" ambient heat - a renewable resource - from outside. Typically, heat pump systems for domestic and commercial buildings will use between one quarter and one third of the energy used by natural gas or resistive electrical heating systems to provide the same amount of heat.

A minor allowance is made for biogas and biofuels to meet energy demands that cannot be electrified, though this is kept to a minimum.

Flatter Electricity-Use Profile

Australian electricity and natural gas usage fluctuates considerably from day to day and between seasons. This means that at present the energy generation and distribution infrastructure is under-utilised. The ZCA2020 Plan employs measures to flatten this profile on both a daily and seasonal basis so that infrastructure is more effectively used and infrastructure investors can achieve suitable economic returns.

Proven and Costed Renewable Energy Technologies

The Plan relies only on existing, proven, commercially available and costed technologies. The Plan found that wind and concentrating solar thermal (CST) power with molten salt heat storage are the most appropriate, cost effective, commercially available, and scalable technologies for deployment in Australia.

"Better-than-Baseload" Electricity Generation

Storing the sun's energy as heat in the form of hot molten salt allows CST plants to provide power that is "better-than-baseload". Similar to a hydroelectricity dam, CST plants with heat storage can dispatch electricity as needed at very short notice. This is achieved by using the heat from the stored molten salt to produce steam as necessary.

Achievability

The Plan examines the achievability of the required transformation, including labour and resource requirements and manufacturing capacity, and concludes that there are no resource constraints that prevent the transition to 100% renewable energy.

Electricity Generation Technology Details

The Plan provides 100% of Australia's electricity needs using the following renewable energy sources geographically dispersed around an improved national grid. This geographic diversity is a major contributor to the consistency of the ZCA2020 power supply. Detailed modelling using real-world data on a half-hourly timescale has shown that the proposed generation mix is capable of meeting 100% of electricity demand. The system is in fact able to generate at least 25% *more* power than the projected 325TWh/yr demand.

Concentrating Solar Thermal (CST) Power with Molten Salt Storage supplies 60% of Electricity Demand

Enviably, Australia has the best solar resource of any developed country, and concentrating solar thermal power is recognised as the optimal technology to exploit this. The Plan provides CST power towers with molten salt storage, such as those available from Torresol and Solar Reserve. Power towers offer the dual advantage of continued high performance in winter, and higher operating temperatures year-round. With fully integrated molten salt heat storage, from which steam can be produced on demand, these plants provide 24-hour electricity production. Crop-waste biomass firing is used during extended periods of concurrent low solar and wind availability, as described below. Industry scale-up and cost reduction trajectories have been detailed by the U.S. Department of Energy and Sargent & Lundy Consulting LLC. Consistent with these, after a capacity of 8,700 MWe is installed globally, solar thermal power towers will provide electricity at a cost that is competitive with conventional coal power at 5-6 $AU cents/kWh.

Proposed National Renewable Grid - see Part 5 for detail

One ZCA2020 CST module consists of a net 217 MWe turbine, with a mirror field and molten salt system sized to provide thermal energy for 17 hours of storage. Air-cooling of the power cycle is used instead of water cooling in order to minimise water requirements. These solar thermal plants are capable of running at a 72% annual capacity factor - more than the annual operating capacity of most large black coal power plants operating in Australia today. Twelve solar sites around Australia were chosen, each with installed capacity of 3,500MW per site.

Wind Supplies 40% of Electricity Demand

Wind power is generally the cheapest renewable energy source to deploy and is technologically mature. Australia however, currently has less than 2,000 MWe of wind turbine capacity installed. The Plan provides 48,000 MWe of new installed turbine capacity running at an average annual capacity factor of 30%. This consists of 6,400 7.5 MW wind turbines spread out over 23 geographically diverse locations. Detailed simulations have shown that 40% wind power can be readily integrated with the CST-based electricity supply grid. For example, during periods of high wind speeds, wind generated electricity is dispatched to the grid first, while the sun's energy is used mainly to heat salt for storage. Conversely, when wind speeds are low, the hot molten salt at CST plants is used to produce extra steam for the turbines and hence make up for the lull in wind generation. Based on detailed studies from the U.S.A., it is projected that at least 15% of the installed wind capacity will always be producing power, with the same reliability as conventional 'baseload' power.

Biomass and Hydroelectricity Backup

Biomass and hydroelectricity are used as contingency backup for up to 2% of annual demand. Pelletised crop waste biomass is provided as a backup heat source for the CST plants to accommodate periods of extended cloud cover in winter. This is similar to the way in which natural gas is used to backup some existing CST plants. In both cases, the steam system and other power generation infrastructure of the CST plants function without regard to the source of heat: sun, combusted biomass, or combusted natural gas. Adequate backup can be provided by processing just 13% of waste straw residue from Australia's annual wheat crop. Pelletisation increases the energy density and cost effectiveness of the transport of the biomass. Australia's existing hydroelectricity systems have also been factored in to provide backup, though at a discounted rate to account for future drought periods.

Electricity Transmission Infrastructure

The ZCA2020 Plan provides upgraded electricity grid infrastructure connected to an optimal selection of renewable energy plant sites. Sites for wind and solar power generation were chosen on the basis of data available from NASA and Australian Government bodies. Emphasis was placed on selecting sites with high year-round energy availability so that both winter and summer peak electricity demands are met.

Electrical transmission links are upgraded in order to strengthen the Australian grid and connect the new renewable energy installations. New interstate connections enable greater import and export capability between the geographically diverse renewable energy resources. The Plan provides 500kV alternating current links to connect new power stations near populated regions where the power is to be used locally. Meanwhile efficient High Voltage Direct Current (HVDC) links are provided for low-loss long-distance transmission to connect specified solar installations and for interstate connections to areas of high electricity demand. The Plan costings also allow for supply of 4,475 MW of offgrid electricity to load centres without grid access.

Achievability and Employment

Implementation of the plan would require a rapid ramp-up of projects and industry. The ten year timeframe takes into account that this will not happen overnight, and would see most of the proposed infrastructure completed in the second half of the decade. Mid-term goals are to have 15,000 MW of wind and 5,000 MW of CST operational by 2015. This requires fast-tracking existing projects and putting in place the right policies to stimulate new projects.

The labour resource requirements for the implementation are dwarfed by Australia's existing industrial capacity. The Plan would require a peak of 80,000 construction workers by 2016, out of an existing workforce of almost one million. Prior to the Global Financial Crisis of 2008, the construction workforce was growing at the rate of 50,000 new jobs per year. Similarly in manufacturing, modelling has allowed for 50% of the manufacturing of wind turbine components and CST heliostat mirrors to be done onshore. This would create up to 30,000 new jobs, out of Australia's existing manufacturing workforce of one million which is projected to decline under business-as-usual. The Plan would create a further 45,000 ongoing jobs in operations and maintenance of the renewable energy infrastructure, which would more than offset the loss of around 20,000 jobs in the domestic fossil energy supply sector.

The raw materials required by the Plan are primarily concrete, steel and glass, none of which are constrained by supply. The Plan would require the equivalent of only 7% of Australia's current concrete production, while sourcing steel and glass would require some increase in either domestic production or imports. The manufacturing of heliostats and wind turbine components would require the setting up of several new factories of a similar size to ones that already exist overseas. For example, it is feasible that the production of 600,000 heliostats per year could be done in a single factory, as there are already car factories in Australia and overseas with the capability of producing 300,000 to 500,000 cars per year.

Required Investment and Economics compared to Business-As-Usual

The ZCA2020 plan requires a total investment of $AU370 billion over the period 2011-2020. Annual investment, averaging $AU37 billion per year, will be lower in initial years and higher as the pace of construction ramps up. Importantly, the up-front annual costs of construction need only be paid by investors, not by the Australian public. As with any energy infrastructure project, up-front capital costs will be paid back over time through energy sales. Therefore the figure of $370 billion is not an expense to the economy without return. Rather it is a strategic investment that secures Australia's zero-emission future and results in significant savings in future years.

Compared to Australia's annual GDP of $AU1.2 trillion, the investment for ZCA2020 represents 3% of GDP over the ten years. Though the up-front investment required by the Plan is significant, maintaining business-as-usual (BAU) is not without its costs either. BAU requires $AU135 billion for ongoing capital investments in energy infrastructure for the period 2011 to 2020, and then continues to pay for increasingly expensive fossil fuels in later years, with $AU300 billion in fuel costs. Although the ZCA2020 Plan's up-front investment is substantially higher than BAU, the Plan's low ongoing costs result in dramatically reduced expenditures over the long-term. Calculating net present costs on a longer timeframe (2011-2040) demonstrates that the ZCA2020 Stationary Energy Plan is about the same cost as the BAU scenario.

These savings expand when the broader economic benefits of the Plan are included. The use of electricity to power transport instead of oil realises fuel cost savings of nearly $AU1,170 billion. Lastly, in the event that a carbon price is implemented, an estimate of the savings made by avoiding potential CO_2 emission charges shows that the Plan avoids an additional $AU370 billion, raising total savings to $AU1,550 billion. Taking these costs into account realises a very rapid economic payback of only a few years.

This report also compares the ZCA2020 Plan costs to other public and private expenditures – for example, the annual ZCA2020 investment is equal to what Australians spend each year on insurance. This demonstrates that the scale of the projects described within this report are well within the capacity and capability of the Australian economy. More detailed economic modelling and policy recommendations are beyond the scope of the ZCA2020 Stationary Energy Report. Future work will include a separate financing and policy document to be produced at a later date.

As a benchmark for gauging the economic impact of the Plan, a preliminary analysis has been done based on one possible funding scenario where the investment is paid for solely through electricity retail revenue. If the proposed

BrightSource Solar Thermal Power Tower

infrastructure was funded with revenue from electricity prices at a standard rate of return for regulated assets, it would require a price rise of around 6.5c/kWh by 2020, equivalent to the existing premium for GreenPower today. This should not be taken as a recommendation of the ZCA2020 Plan, but it does provide a useful indication of the costs involved. This price increase would cost approximately $AU420 per household per year, or $AU8 per household per week, by 2020, and is a similar electricity price rise to what may be expected in Australia's business-as-usual electricity market. There are of course various policy options that could fund the Plan in different ways and would not require electricity price increases. Also, further detailed design to the Plan in later versions may decrease this price, as more detailed modelling and information comes to hand.

Summary

The following chapters show in detail how the transition to a Zero Carbon Australian economy can be achieved using technology that is commercially available today. There are no technical barriers to this deployment. Implementing the proposed infrastructure in ten years is well within the capability of Australia's existing industrial capacity. ZCA2020 outlines a decisive and achievable transition blueprint for a 100% renewable energy future which would position Australia as a leader in the emerging global renewable energy economy. What is required to make this happen is leadership through action from policymakers and society, with firm decisions made quickly that will allow this transition to occur.

Part 1

Introduction and Overview

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The Zero Carbon Australia 2020 Stationary Energy Plan outlines a technically feasible, practical, and economically attractive transition to 100% renewable energy in Australia in ten years. The plan is a rational and necessary response to the risk of major climate change.

As governments continue to grapple with the problem of how to shift to low-carbon societies, the evidence mounts that only a rapid transition to a zero-carbon economy can ensure climate and energy security for us all. Mitigating climate change in an incremental manner ignores the potentially catastrophic effects we face if global warming "tipping points" are passed. Moving to a zero-carbon economy requires concerted efforts across all national governments and across multiple sectors including Stationary Energy, Transport, Building Efficiency, Industrial Processes and Land Use.

Many different factors shape action to mitigate climate change. Societal and political barriers are quite different from technical barriers. This report is aimed at demonstrating the technical and financial feasibility of rolling out a 100% renewable energy system in Australia over the next ten years. Importantly, only commercially available technology is specified, to show that such a roll-out could start today. This report does not address the political and social impediments to beginning such a Plan. It is aimed at concluding the debate about whether renewable energy has the capability to keep the wheels of industry turning, in order to enable the social and political changes that will lead to the transition to 100% renewable energy. The 2020 timeframe is motivated by the best available climate science. While any delay to the roll-out of such a ten-year 'decadal plan' could still see a 100% renewable sector achieved at a later date, this comes with greater risk of exceeding safe limits within the Earth's climate system.

This report focuses on the Stationary Energy sector in Australia. Subsequent reports will address the other carbon emitting sectors of the economy. The ZCA2020 Stationary Energy Plan allows Australia to play a responsible, constructive and leading role in promoting decisive action for climate protection around the world. For the remainder of this document, unless otherwise defined, the ZCA2020 Stationary Energy Plan will be referred to as "the Plan" or the "ZCA2020 Plan".

There are a number of potential paths to a zero-emissions stationary energy system. This Plan offers one possible solution based on renewable resources, using existing proven and reliable technologies, such that the costs and liabilities of the Plan can be rigorously assessed. In this regard, the Plan concords with an emerging view that national scale renewable systems are not only technically and economically viable, but are likely to accrue significant benefits to the nations that first implement them.

"[t]his goal is achievable, affordable and transformative."
U.S. VICE PRESIDENT AL GORE, ANNOUNCING HIS PROPOSAL TO RE-POWER AMERICA WITH CLEAN ELECTRICITY IN TEN YEARS[1]

"We know the country that harnesses the power of clean, renewable energy will lead the 21st century"
U.S. PRESIDENT OBAMA[2]

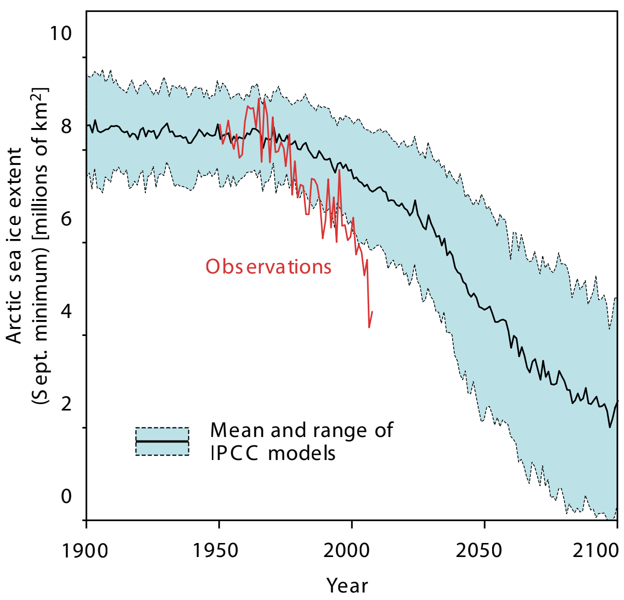
1.1 Why Zero Emissions?

Present atmospheric levels of CO_2 are at 390ppm[3], well above the pre-industrial levels of 275 to 285 ppm (AD 1000-1750)[4]. Furthermore, atmospheric CO_2 concentration has been growing rapidly for the last 40 years [note 1]. Many climate scientists now believe that CO_2 levels must be reduced from today's concentrations to avoid triggering dangerous "tipping point" mechanisms[6,7] [note 2].

Tipping points are serious because once they are passed, a return to a normal climate situation may be impossible. For example, if global average temperatures increase by 4°C , the huge carbon stores in the northern circumpolar permafrost zone (estimated at 1,672 gigatonnes) may be vulnerable to irreversible release[8]. Figure 1.1 shows that the current rate of loss of summer arctic sea ice is exceeding worst-case IPCC predictions.

Many scientists have stated that the maximum safe level of atmospheric CO_2 concentration is 350 ppm or less—a level significantly below the present atmospheric concentration of 390 ppm[note 3]. It is not too late—a rapid and decisive reduction in CO_2 emissions can return us to safe atmospheric levels with a reasonable probability of avoiding dangerous tipping points. However, this can only be

FIGURE 1.1
Arctic Sea Ice Extent—observed loss versus IPCC forecasts [9]



achieved through the implementation of urgent, purposeful action by governments to quickly reduce anthropogenic carbon emissions to zero.

"If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted .... CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm."

HANSEN ET AL, 2008[6]

"... any reasonably comprehensive and up-to-date look at the evidence makes clear that civilization has already generated dangerous anthropogenic interference in the climate system. What keeps me going is my belief that there is still a chance of avoiding catastrophe."

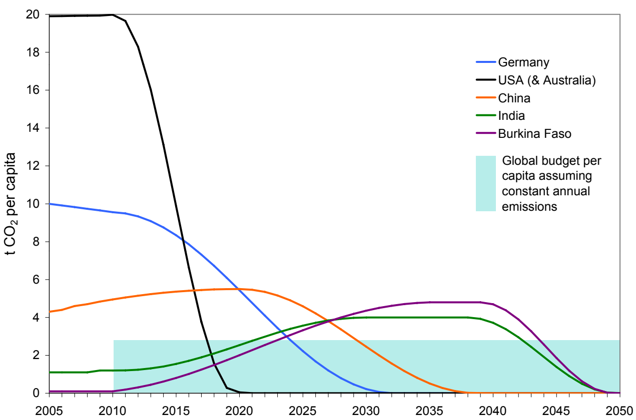
JOHN P. HOLDREN, ENERGY AND ENVIRONMENT EXPERT AT HARVARD UNIVERSITY, PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AND PRESIDENTIAL SCIENCE ADVISOR TO BARACK OBAMA[10]

1.2 Why Ten Years?

The Plan looks not only at how to implement a zero-greenhouse gas emission energy sector, but also how to achieve this within a ten year timeframe, from a technical perspective. It is recognised that this is needed to properly address the threat of severe and potentially irreversible climate change.

The premise of a ten year timeframe to achieve zero emissions echoes several leading academics and public figures. In a recent report from the German Advisory Council on Global Change (WBGU), Prof. Hans Joachim Schellnhuber (Director of the Potsdam Institute for Climate Impact Research) indicated that, in order to have a two-in-three chance of keeping global warming below 2°C over pre-industrial levels, and using a global per-capita carbon budget approach, it would be necessary for the USA to reduce emissions to zero by 2020[9]. An extension to this would be that other rich countries, with the highest per-capita emissions, such as Australia[12], would need to pursue the same goal. As Figure 1.2 depicts, the "global budget per-capita" (the blue block in the background) shows that the maximum per-capita emissions allowed across all populations of the world would need to be limited to around 110 tonnes of CO_2 per-capita (2.75 tonnes per-capita per annum over a period of 40 years).

FIGURE 1.2
Carbon budget 2010—2050: Emissions paths per capita for selected countries (adapted)[11]



As such, countries with high per-capita emissions (such as the USA or Australia [note 4]) have less than ten years to cut their emissions to zero. At the current Australian emissions rate of about 20 tonnes per-capita per annum, our emissions budget would run out in five years. If instead we begin reducing emissions sooner, we could extend the budget to ten years. As a country with high per-capita emissions, Australia has the opportunity to be a catalyst for other countries (particularly countries with high total emissions but low per-capita emissions, such as China and India) by inspiring action on climate change and developing renewable energy industries.

A transition in ten years may seem challenging, but the world has seen remarkably fast economic transitions in the past; the restructuring of the United States economy during the Second World War is a notable example[13]. A ten year transformation period has also been nominated by Al Gore[14]. In his 2008 speech calling for America to move to 100% renewable energy within ten years , Al Gore said: "To those who say ten years is not enough time, I respectfully ask them to consider what the world's scientists are telling us about the risks we face if we don't act in ten years. Ten years is about the maximum time that we as a nation can hold a steady aim and hit our target."[14]

There are many additional reasons for Australia planning immediate and deep cuts to emissions. Global warming has the potential to create irreversible ecological change, and Australia is at particular risk of biodiversity reduction[15]. With our agricultural and water systems also at particular risk, climate change threatens our national security.

"Global average temperature increases of 1.5 or 2.0°C above pre-industrial levels will likely lead to a massive loss of biodiversity worldwide. ... The more effectively the rate of climate change can be slowed and the sooner climate can be stabilised, the better are the prospects that biodiversity loss will be lessened."

SUMMARY OF A REPORT TO THE NATURAL RESOURCE MANAGEMENT MINISTERIAL COUNCIL COMMISSIONED BY THE AUSTRALIAN GOVERNMENT, 2009[16]

There is widespread recognition that those who lead the renewable energy race will reap significant economic benefits. Already, several Australian renewable energy technology firms have moved offshore to take advantage of more supportive and forward-looking regulatory environments. These include the now multi-million dollar corporations Ausra (now French-owned) and Suntech (now China-based). The DESERTEC program is pressing ahead with plans to build a vast network of solar thermal plants across North Africa, the Middle East and Europe[17] while Spain will have 2.5 gigawatts (GW) of solar thermal power connected to the grid by 2013.[18] In terms of renewable resources, Australia has all the natural advantages of the DESERTEC proposal, with none of its multi-national political impediments.

China has begun to invest heavily in renewable energy, doubling its wind power capacity every year for the last 5 years, now having 25 GW as of 2009. China has a target of 150 GW of wind by 2020, but if it continues its current rate of installation it will reach 150 GW by 2015—five years ahead of schedule. This scale of growth is impressive and actually accounts for one third of the total global wind power growth[19,20].

As these and other countries take actions which reduce their reliance on coal, Australia has the opportunity to move beyond its 'quarry vision',[21] which sees the success of our economy strongly tied to fossil fuel exports, and look instead to reap the economic benefits of being among the leaders in zero emissions technology innovation.

"The credit crunch has been brutal for solar start-ups in the West, but not for Chinese firms with access to almost free finance from the state banking system. They have taken advantage of the moment to flood the world with solar panels, driving down the retail price from $4.20 per watt last year to nearer $2 in what some say is a cut-throat drive for market share ... We may soon be moving into a phase of history when ill-prepared countries cannot be sure of obtaining energy—whatever the price."

AMBROSE EVANS-PRITCHARD [22]

By choosing to become a leader in the race towards zero emissions, Australia has the opportunity to secure its food, water and energy supplies for the future, and build a new and robust economy as a global renewable powerhouse. These arguments all promote the case for immediate action.

"I think that the word "now" has to creep into the vocabulary of people in public policy."

S DAVID FREEMAN, US ENERGY ADVISOR AND FORMER HEAD OF TENESSEE VALLEY AUTHORITY [23]

1.3 Guiding Principles, Assumptions and Project Methodology

A zero emissions target—not a low emissions target. The ZCA2020 Project is based on a zero emissions methodology underpinned by a set of guiding principles. These principles relate to the use of proven technology solutions and the achievement of social equity goals with minimal disruption to food, water and energy supplies.

The Plan differs from other emissions reductions plans in that, from the outset, it seeks a target of zero emissions within ten years. Most other transition plans aim to move towards a low emissions economy over a period of indeterminate length. A zero emissions plan is not simply an accelerated low emissions strategy. *The point of a rapid transition to a zero emissions economy is not to just proceed further along the same path that will take us to a low emissions economy over 50 years or so.*

With this in mind, the ZCA2020 working group has framed the development of the whole Project within the following set of guiding principles to provide clarity of direction and transparency of purpose.

- **Proven and Reliable Solutions**. A plan for transition to a zero emissions economy beginning now requires us to use the best of what is now available. There have been major advances in renewable energy technology over recent years, and it is possible to move to a zero emissions economy without waiting for further technologies to be developed[22]. Consequently, the Plan considers only technological solutions that are already commercially available from existing companies which offer the technology at a multi-megawatt scale, and have moved beyond small-scale demonstration and pilot projects.
- **Implementation Flexibility**. While the Plan only considers commercially proven technologies at the outset, the ZCA2020 working group leaves open the option of subsequent incorporation of new and innovative technologies as they become commercially available, if they will reduce the cost of the transition and/or they have fewer associated environmental or social impacts. Example technologies that the ZCA2020 working group anticipates may become commercially available during the 10 year transition period include arrays of Australian National Universities' 500 m^2 SG4 concentrating solar thermal Big Dishes,[24] and Carnegie Corporation's CETO III Wave Technology[25,26].
- **A Socially Equitable Solution.** The ZCA2020 Project will seek to ensure that social equity in Australia is maintained or enhanced during the transition to a zero emissions economy. In particular, this solution will continue to provide equitable access to energy for all Australians today, while ensuring that the costs and burdens are not deferred to future generations.
- **Transition Fuels.** Whereas a long-term low emissions plan may recommend the use of natural (or petroleum) gas as a transition fuel, such a 'double transition' is not considered because it necessarily ties Australia to continued fossil fuel emissions beyond the Plan's timeframe, and would see money that could otherwise be spent on renewable generation capacity diverted into fossil fuel infrastructure.
- **Technology Sequencing.** As with the idea of transition fuels, investment in so-called 'transition technologies' will only serve to divert funding and attention from developing true zero emissions solutions. An example would be the development of more efficient petrol driven cars at the expense of investing in an electrified transport system that can be powered from a renewable energy grid.

- **Minimal Impact on Food, Water and Energy Supplies.** The transition to a zero emissions economy should aim to do so without compromising Australia's food, water and energy security.

1.4 Summary of Technology Choices

While the choices of energy technologies are detailed with references in Part 2 of the report, they are summarised here to aid the reader in understanding why the guiding principles outlined above led to the chosen technology mix. There are commonly held perceptions that renewable energy has a limited future because "the wind doesn't always blow and the sun doesn't shine at night". The aim and scope of this report is to show that this is not an issue, and to demonstrate the feasibility of 100% renewable energy in Australia within the next ten years. Instead of focusing on various negative aspects of the technologies we have not chosen, the authors wish to show the positive aspects of the renewable technologies that are already available to replace fossil fuels.

The conclusions relating to technology choices are as follows:

- Wind, solar photovoltaics and concentrating solar thermal with storage are commercially proven, scaleable solutions that together can ensure reliable, 24-hour renewable energy supply.
- Biomass and hydro are commercial renewable options that are limited in their scaleability due to other environmental considerations. They are better suited to supplying backup and balancing power to wind and solar. Biomass is also needed for its carbon content to replace non-energy-related chemical carbon requirements.
- Wave, tidal and enhanced geothermal power are technologies that are on the horizon, but as yet have not overcome all technical hurdles nor have they been demonstrated at scale.
- Carbon capture and storage (CCS) is similarly an unproven technology, that is not expected to be commercially available within the ZCA2020 timeframe. It is also not a zero-emissions solution, as even should it be demonstrated at scale, proposed projects are not expected to capture 100% of fossil fuel plant emissions.
- Nuclear power is highly unlikely to be viable in Australia over a ten-year period, as countries that already have a nuclear power industry experience implementation times for nuclear plants in the order of 10-19 years for single reactors.

1.5 The ZCA2020 Project and the Stationary Energy Plan

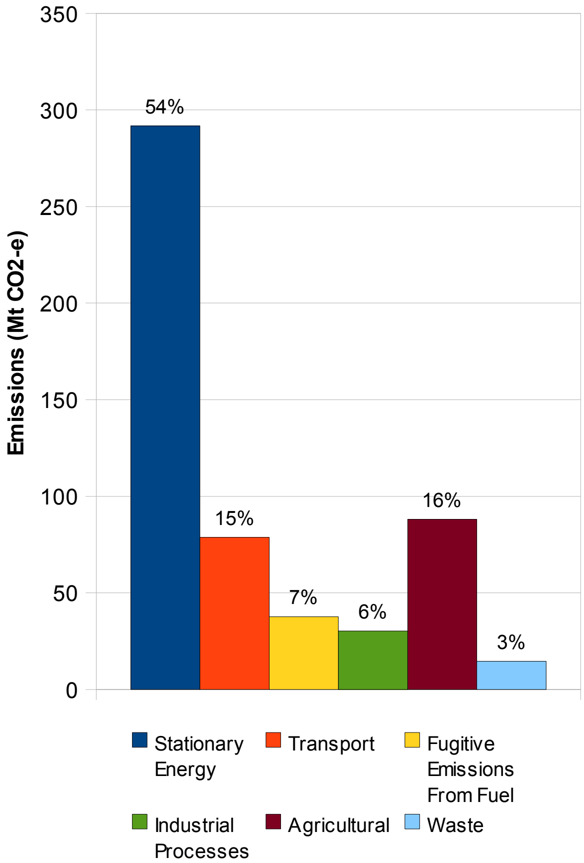
The ZCA2020 Project consists of six inter-related reports, each addressing a specific Plan. The ZCA2020 Stationary Energy Plan is the first and most urgent of these, since 50% of Australia's emissions are generated by the stationary energy sector.

The complete set of ZCA2020 reports to be produced are:

- Report 1: The ZCA2020 Stationary Energy Plan addresses the re-powering of Australia's stationary energy sector with zero emissions technology
- Report 2: The ZCA2020 Buildings Plan considers measures to improve energy efficiency, and hence reduce the demand for stationary energy
- Report 3: The ZCA2020 Transport Plan is concerned with powering private and public transportation with renewable electricity
- Report 4: The ZCA2020 Industrial Processes Plan addresses measures to reduce emissions from industry
- Report 5: The ZCA2020 Land Use Plan considers changes to agriculture, forestry and other land use practices to minimise emissions
- Report 6: The ZCA2020 Plan for Replacing Coal Export Revenue focuses on Australia's large fossil fuel exports.

The reports will be inter-related and complementary. As an example, the design of the stationary energy supply

FIGURE 1.3
Australian Greenhouse Gas Inventory 2007[27]



system (Report 1) must include projections of demand and efficiencies from Reports 2, 3 and 4. Furthermore, emissions reductions achieved in the stationary energy sector will have flow on effects in other sectors (Reports 2, 3 and 4) because, for example, electricity will become a low emissions energy source relative to gas. The Stationary Energy Plan is released in Version 1.0 form prior to the release of the other five components of the final report, in order to allow for discussion and feedback at the earliest opportunity. The remaining five reports of the ZCA2020 Project will be completed following the release of this report. Ultimately, each report will be combined into a single document to form a comprehensive Plan for reaching zero emissions in Australia over a ten year period.

1.6 Structure of the Stationary Energy Plan Report

The structure of the Plan is as follows:

- **Part 2** describes the design of the proposed stationary energy system (including the implications of the size and pattern of projected demand), an overview of the available zero-emissions technologies, and the rationale for the choice and weighting of these technologies.
- **Part 3** provides a blueprint for the installation of the 100% renewable electricity infrastructure, including specifications, proposed locations, costs and installation timelines.
- **Part 4** shows energy modelling on real-time meteorological data that demonstrates the reliability of the Plan's specified grid.
- **Part 5** shows how the new renewable energy infrastructure integrates into an upgraded grid to ensure reliable supply of electricity. It addresses the significant upgrades to transmission networks that will be required in order to transition to 100% renewable energy.
- **Part 6** describes the resourcing of the transition, in terms of mobilising the material and human resources required within the ten-year timeline.
- **Part 7** compares the investment for the Stationary Energy Plan with the Business-as-Usual case, putting the scale of the financial investment into context with Australia's other present day expenditures.

The basis for the energy demand estimates used within the Stationary Energy Plan are derived from work already undertaken on the remaining ZCA2020 reports. These remaining five reports are currently in development and therefore it is possible that the projected stationary energy demand may change from the estimates in this initial version of the Plan. Nevertheless, the same design principles would apply to the proposed stationary energy system when updated demand figures become available. Similarly, although the current figures for costing are well-informed estimates, it is feasible that the figures in later versions of the Plan may be higher or lower, depending on updates relating to technologies and proposed efficiencies.

1.7 The ZCA2020 Working Group

The concept of a plan to achieve zero-emissions energy in ten years originally came from Beyond Zero Emissions, motivated by the scientific evidence that atmospheric concentrations of greenhouse gases are already too high. BZE put together an enthusiastic expert team of engineers and scientists with relevant industry and academic backgrounds who worked pro-bono to develop the plan.

As one of the project leaders Patrick Hearps, from The University of Melbourne's Energy Institute, recruited a team of University researchers and alumni, doubling the capacity of the project. The Melbourne Energy Research Institute has reviewed the plan, and publishes it as part of its "Australian Sustainable Energy" series.

1.7.1 The Future of ZCA2020

The ZCA2020 project is an ongoing initiative. It is a collaboration of pro bono contributors, and more people with relevant expertise and interests are welcome to contribute. The current publication is Version 1.0 of the Stationary Energy Plan. Future work includes not only the other ZCA2020 reports, but updated versions of the Stationary Energy Plan that take into account more in-depth analysis, updated figures on energy projections, modelling with improved data, and any new technological developments.

In the meantime, updates to the Plan will be available online.

It is not the intent of the ZCA2020 Stationary Energy Plan to comment or recommend any particular financial or policy mechanisms that would lead to the roll-out of the proposed transition. There are a range of policy instruments that can be used, which should all be judged by their effectiveness in achieving a desired outcome. The Plan demonstrates one potential outcome. However, future work will also involve a separate publication discussing financial and economic policies in the context of the ZCA2020 plan.

Footnotes

1. *The absolute growth rate of CO_2 in the atmosphere has increased substantially: the first 50 ppm increase above the pre-industrial value was reached in the 1970s after more than 200 years, whereas the second 50 ppm occurred in about 30 years. In the 10 years from 1995 to 2005, atmospheric CO_2 increased by about 19 ppm; the highest average growth rate recorded for any decade since direct atmospheric CO_2 measurements began in the 1950s*[5].
2. *While we normally tend to think of climate as having its own inherent equilibrium, the concept of a "tipping point" mechanism*[7] *breaks this rule, creating a situation where large scale climate systems can finally switch into a different state, which is qualitatively different from past history, and recovery may be impossible. "Tipping point" mechanisms include positive feedback, phase transitions with hysteresis, and bifurcations.*
3. *Hansen recommends that atmospheric CO_2 concentration be reduced to 350 ppm at most (but preferably less) to preserve a planet similar to that on which civilisation developed, and to which life is adapted*[6]*. Schellnhuber et al base their strategy on keeping temperature rise below a "guardrail" of 2°C rise above 1990 levels*[9]*. They do not specify a particular concentration of atmospheric CO_2, but strongly suggest that we should return to pre-industrial levels of atmospheric CO_2 (280 ppm) to avoid the risks of untested long term climate conditions.*
4. *Australia and USA have virtually the same per capita emissions—Australia 19.00 tonnes per capita per annum, USA 19.7 tonnes per capita per annum (2006 data)*[12].

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Part 2

Designing the ZCA2020 Stationary Energy Plan Supply System

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2.1 Overview of the ZCA2020 Stationary Energy Plan Supply System

Part 2 presents a broad overview of the design of the ZCA2020 Stationary Energy Plan (the Plan). It begins with a description of Australia's current stationary energy sector, then outlines what Australia's energy demand will look like in 2020 under the Plan's implementation of efficiency upgrades and fuel-switching. Strategies for flattening demand peaks are discussed, and, finally, the commercially available renewable technologies that will meet this demand are introduced.

The renewable energy infrastructure proposed (further detailed and costed in Part 3) will be sized to supply a 2020 grid electricity demand of 325TWh/yr, more than 40% higher than today's electricity consumption. This is greater than would be expected under Business-As-Usual growth, and is more than capable of meeting future electricity needs. However, with further investment in energy efficiency and fuel-switching, to be detailed and costed in future ZCA2020 reports, it is projected that this will be sufficient to replace not only current electricity, but oil and gas that is currently used for transport and direct heating, thereby replacing all fossil fuel use.

Australia's current energy consumption is approximately 3,915 PJ/yr, while the grid electricity component of this is 228 TWh/yr (822 PJ/yr). Under the Plan, total energy consumption will halve by 2020 without reducing the provision of energy services. To achieve this, grid electricity requirements will increase to 325TWh/yr. This new requirement has two major parts:

- improved energy efficiency technologies reduce the electricity requirements for current services by one third across the residential, commercial and industrial sectors. This brings Australia energy efficiency into line with other modern, developed economies.;
- a fuel-switch from transport oil, heating gas, and industrial use of fossil fuels to highly efficient renewably-sourced electricity. This reduces Australian consumption of *energy* dramatically, though of course leads to an increase in *electricity* demand.

Seasonal energy demand variation, and ways of flattening demand curves, are also examined in detail. In particular, the strong peaking influence of Victorian cold weather gas demand can be mitigated through a large-scale rollout of building insulation and integrated photovoltaic technology in Victoria.

In order to meet the new demand curves, the ZCA2020 Plan recommends the following commercially-available generation technologies:

- **Concentrated Solar Thermal (CST) Power Towers with molten salt heat storage**: meeting 60% of electricity demand throughout the year;
- **Wind power**: meeting the remaining 40% of demand;
- **Crop-waste biomass and hydroelectricity**: providing backup for 2% of the demand, when simultaneous lulls in solar and wind cause shortfalls in supply;
- **National Grid**: flattening demand peaks and integrating CST, wind and backup energy sources, to provide reliable supply.

Concentrating solar thermal with molten-salt-heat-storage technology provides the capability to store the sun's energy as heat, rather than as electricity. Electricity can then be generated either at a constant rate ('baseload') or as required to meet peak demand. Cost-effective storage of the sun's energy as heat means that CST can reliably provide electricity during cloudy periods and at night. Overseas, Concentrating Solar Thermal electricity generation already operates at utility scale, providing efficient energy storage and 24-hour electricity supply.

In Australia, a wide geographical distribution of generation assets under the Plan allows lower-cost wind power to be integrated with CST.

In rare extended periods of low sun and wind across Australia, crop waste biomass-firing provides an additional source of heat at the CST plant sites, and/or existing hydro is used. Historical system performance and weather forecasts are used as tools to manage the system during such periods.

Lastly, solar PV is likely to reach "grid parity" between 2015-2020, and an allowance is made for small scale solar PV and solar hot water to provide 10% of energy by 2020.

A life-cycle emissions analysis of this system demonstrates that wind and CST have rapid energy pay-back periods, and vastly superior emissions profiles compared with alternative technologies such as carbon capture and storage (CCS). Moreover, unlike technologies such as enhanced geothermal and CCS, all the technologies relied upon in the Plan are commercially available today.

2.2 Analysis of Current Australian Emissions and Energy-Use Trends

2.2.1 Australian Greenhouse Gas Emissions

Australia currently generates the highest per-capita emissions of greenhouse gases amongst OECD countries[1] As shown by Figure 2.1, approximately two-thirds of Australia's total greenhouse gas emissions result from fossil fuel combustion in the stationary energy and transport sectors.

As shown by Figure 2.2, close to 90% of the emissions from the Stationary Energy Sector arise from the combustion of coal. Other emissions associated with the use of fossil fuels in the Stationary Energy Sector are related to industrial processes and fugitive emissions, including leakage from natural gas distribution networks and methane released during coal mining[1].

Treasury modelling predicts that under Business As Usual (BAU), Australia's greenhouse gas emissions will continue to rise[2]. The same modelling also predicts that any reductions in greenhouse gas emissions under CPRS type legislation (5-15% reductions), will depend substantially on importing permits from other countries. Given this predicted dependence on exporting Australian carbon emissions offshore, it is difficult to see when and how, under current government policies, the Australian economy will make any significant move away from its reliance on fossil fuels.

FIGURE 2.1
Australia's projected cumulative emissions by sector 2005 to 2050

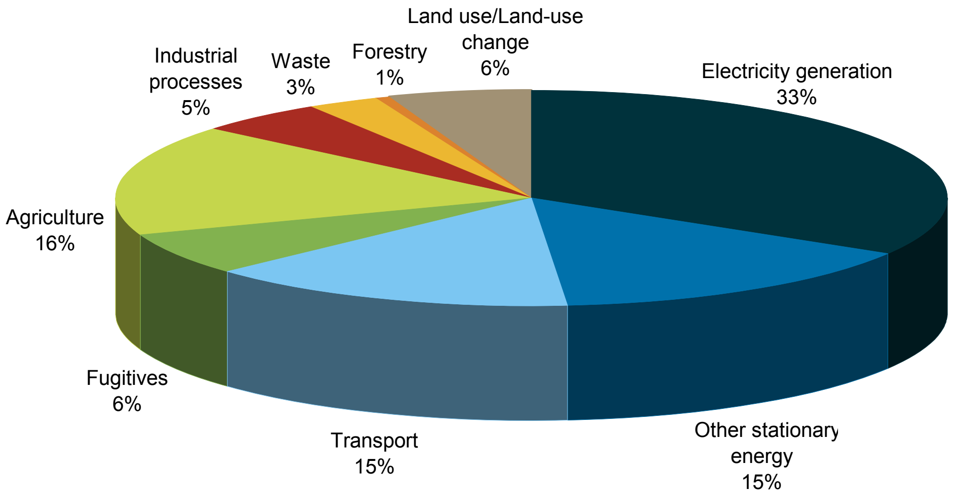
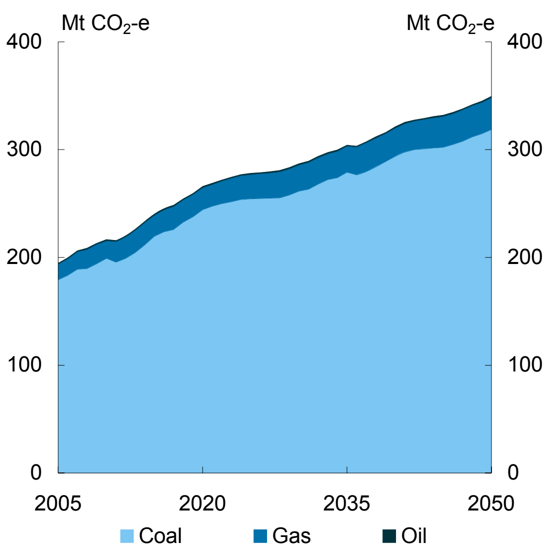


FIGURE 2.2
Australia's projected stationary energy emissions by fuel source[2]



Source: Treasury estimates from MMRF and MMA (2008).

2.2.2 Current Australian Energy Consumption

Figure 2.3, sourced from Geoscience Australia, reveals important relationships between Australian energy supply and utilisation. The relative width of the lines represents the size of the energy flows.

Coal (shown in blue in Figure 2.3) is an inefficiently-used fuel. 2,050 PJ/yr of coal is burned in Australia to produce only 750 PJ/yr of electricity[3]. Even then, about 7% of this is "parasitic" consumption used onsite by the power stations themselves[4]. This means that only 700 PJ of useful, end-user coal-fired electricity makes it to consumers. The remaining 1,350 PJ/yr, or 66% of the resource[3], is lost in the electricity generation process. This lost energy is rejected into the environment via vaporisation of cooling water or when coal-fired power stations 'blow steam' at periods of low demand. Water used in the coal-fired generation of electricity is unavailable for other uses such as for growing food. A typical 500 MW coal-fired power station requires around 8.3 billion litres of water per year[5].

In Australia, natural gas (shown in pink in Figure 2.3) currently supplies more end-use energy than any other fuel used in the Stationary Energy Sector, even coal. This energy is largely consumed for industrial and residential heating.

Australian passenger and freight movements are currently powered primarily by the burning of 300 million barrels per year of oil and LPG[3] in inefficient internal combustion engines. Oil (shown in black in Figure 2.3) is a growing expense which, under BAU, will cost the Australian economy ~$1.3 trillion (2010 dollars) between 2010 and 2040 (see Part 7—Economics). Oil imports have grown since Australian domestic oil production peaked in 2000. Domestic oil production is now in decline and this is projected to continue. Forty percent of the crude oil consumed in Australia is imported, adding $15.7 billion to the 2007/2008 current account deficit[6].

FIGURE 2.4
Australia's projected oil supply-demand balance [8]

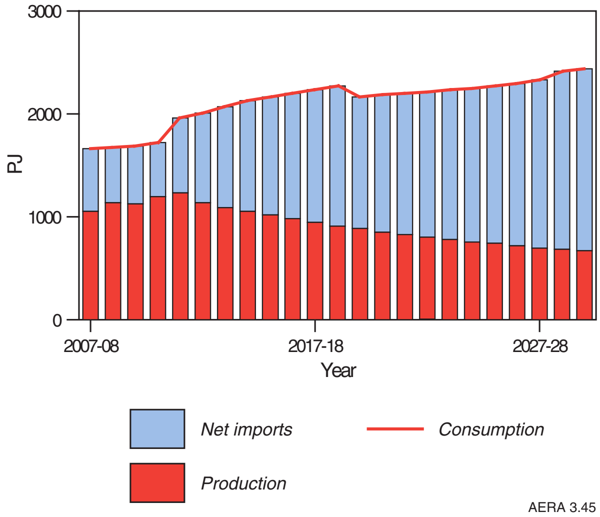


FIGURE 2.3
Australian Energy Flows 2006-2007[3]

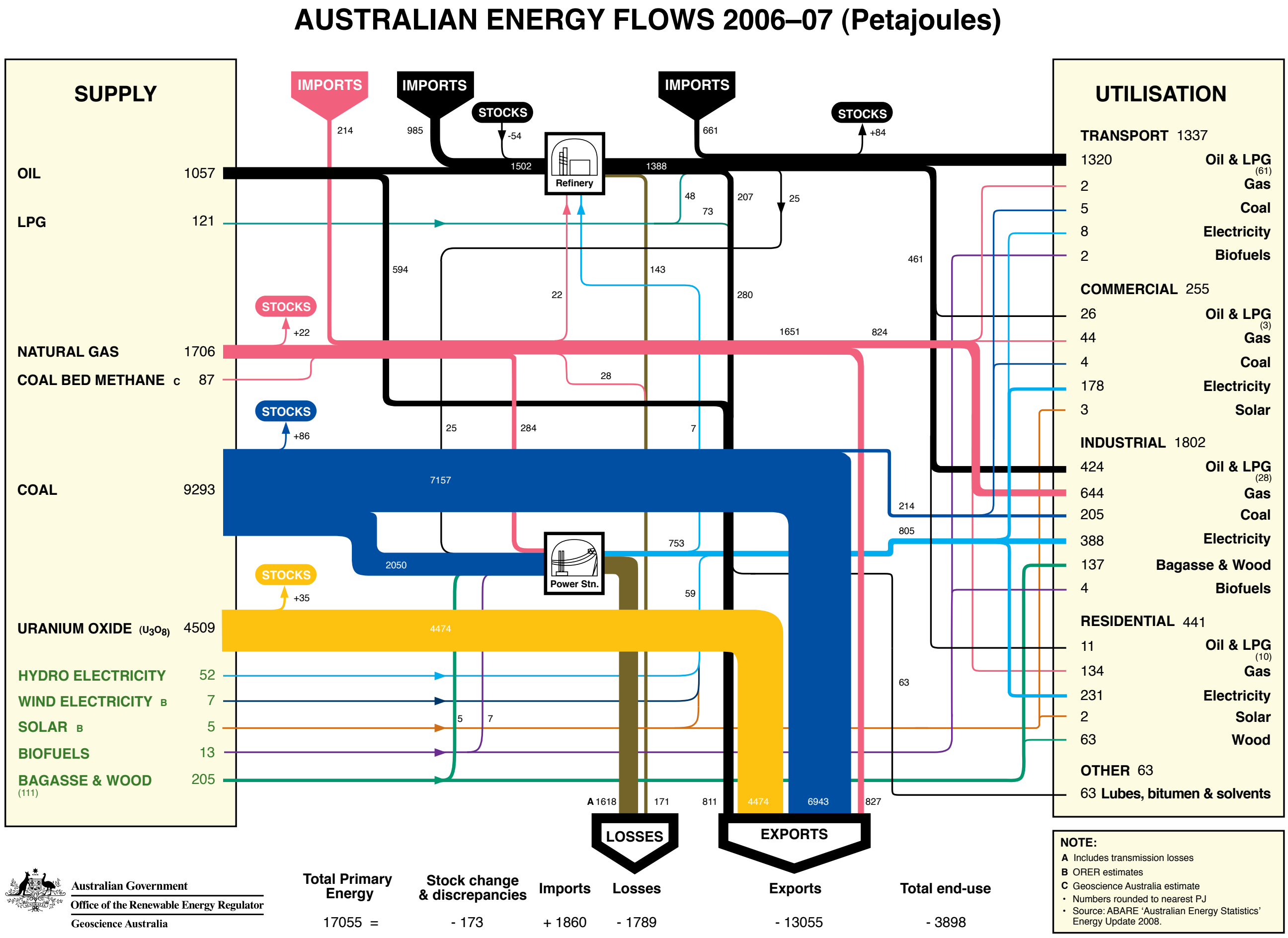
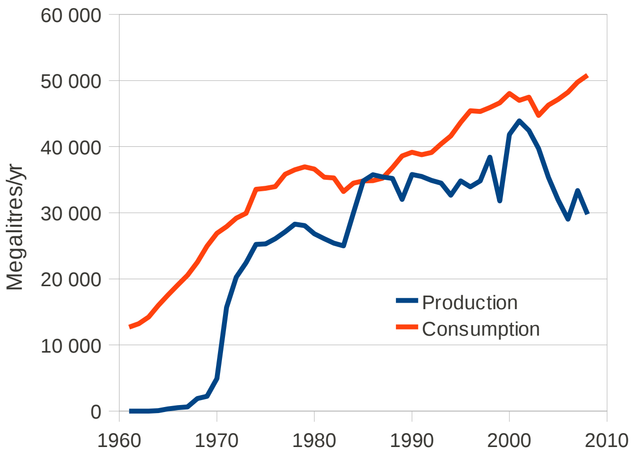


FIGURE 2.5
Australia's Oil Production and Consumption 1961-2008. Data from ABARE[7]



Moving away from oil as a transport fuel has the additional benefit of improving Australia's energy security. A number of studies support the conclusion that global oil production is currently peaking, leading to supply/demand price spikes in the near future[9,10,11].

Due to the inefficiency of the internal combustion engine, less than 20% of the fossil fuel energy consumed by the Transport Sector is actually converted into useful vehicular motion, once stop-start ineffeciencies are factored in. On the other hand, electric rail and electric cars convert 80-90% of electrical energy into motion—and the electrical energy can be derived from 100% renewable sources. This presents a massive opportunity to improve energy-use efficiency, eliminate the vast cost of oil imports, and reduce the carbon-intensity of Australia's transport system to zero.

2.3 Australian Energy Demand in 2020 under the Plan

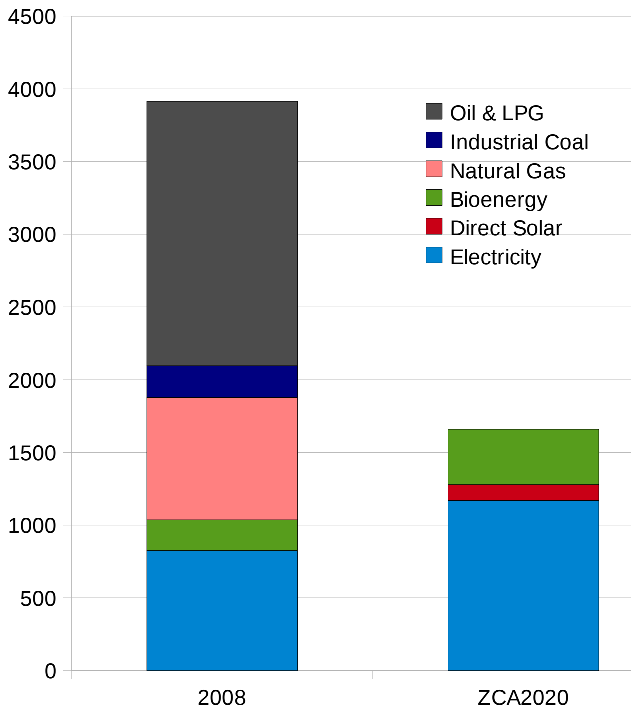
The ZCA2020 Plan proposes a complete phase-out of all fossil fuels (natural gas, oil and coal), starting from 2011. By 2020, total Australian energy consumption is reduced to less than half of Business As Usual (BAU) projections. This is the result of moving to a higher efficiency, zero carbon, electricity-based energy system that applies negative pressure on energy costs in the long term[12]. Detailed modelling of this energy transition can be found in Appendix 1, though a short summary is presented in the following text.

Figure 2.6 illustrates the impact of the transition from present-day energy sources to ZCA2020 Plan sources.

Under the ZCA2020 Plan, total energy consumption is reduced to less than half of BAU, from 3,915 PJ/yr (2008) to only 1,660 PJ/yr (2020). How is such a dramatic fall possible?

Under the Plan, oil and LPG production ceases and the inefficient internal combustion engine is replaced with a combination of electrified heavy and light rail, electric vehicles, and some range-extending biofueled hybrid-electric vehicles. These efficiency improvements mean that the 1,217 PJ/yr currently used in transport, primarily oil-

FIGURE 2.6
Australian Energy Sources: Present and Under ZCA2020



(Note: In Figure 2.6, "End-use" coal shown on the chart represents coal that is used only for metallurgical smelting and process heat. Coal currently used for electricity production falls into the "electricity" section of this barchart.)

fuelled, can be replaced with two far smaller energy inputs: first, 180PJ/yr (50TWh) of additional renewable electricity generation capacity for electrified transport, and secondly, just over 50PJ/yr of liquid biofuel to support non-electrified transport services (approximately 5% of the total).

Natural gas is completely phased out and replaced with efficient electrically-driven devices. Natural gas space-heating, for example, is replaced with high efficiency electric heat pumps. As with oil, natural gas consumed for transportation is replaced by additional electricity generation capacity. Certain industrial applications, however, cannot be electrified. Methane, for example, is used directly as a feedstock for the production of chemicals such as methanol and ammonia-based fertiliser. For these purposes, the plan proposes 50 PJ/yr of biogas.

Energy used in the refining of petrol, mining of coal and in the manufacture of liquefied natural gas (LNG), is excluded from the total future energy requirements. This is because the ZCA2020 Plan assumes zero domestic demand for fossil fuels, and assumes that Australia will not be servicing overseas demand for any LNG, petrol, or other fossil fuels.

Locally-collected solar energy for heating water, indoor spaces, and other purposes increases from 3 PJ/yr (currently) to 110 PJ/yr. This includes household solar hot water systems and the use of direct solar energy for industrial processes and other commercial consumption. Onsite solar energy use is modelled by reducing the requirements for grid-delivered electricity.

Lastly, the deployment of energy efficiency programs reduces the end-use energy demanded by traditional services (i.e. not including newly electrified transport and space heating/cooling) in the commercial, industrial, and residential sectors by 20% over the period 2011—2020. This translates to a 33% reduction in per-capita electricity use for these services when population growth is taken into account. This 20% reduction in demand has been modelled conservatively, and deeper analysis in later reports is likely to identify greater energy savings within each sector.

In summary, and as shown by Figure 2.7, though total *energy* demand is reduced by 50% under the Plan, total *electricity* demand increases by 42% from 2008-2020 because of the electrification of transport as well as residential, commercial, and industrial heating. This increased electricity demand is supplied through the renewable generation system that forms the centerpiece of the Plan.

Under the ZCA2020 Plan, total annual grid electricity demand is 325 TWh.

- 152 TWh/year is required for the continuation of current end-use electricity functions (after a 20% reduction from current levels due to efficiency, and other reductions outlined in Appendix 1 such as onsite solar).
- 123 TWh/year is required after the shift from gas to electricity for heating. Improved insulation minimises the winter peaking effect of this shift.
- 50 TWh/year is required for the electrification of transport. The transport component is inherently less volatile than current end-use functions, and in fact can contribute to load levelling due to EV smart charging capability.
- Onsite solar PV and solar hotwater displaces 30TWh/year that would otherwise be required from the grid.

FIGURE 2.7
Total electricity demand including fuel switch and transport electrification

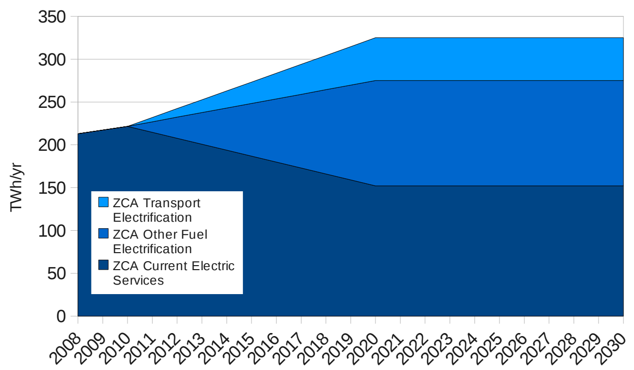


FIGURE 2.8
International comparison of primary energy consumption per capita (GJ, 2007).

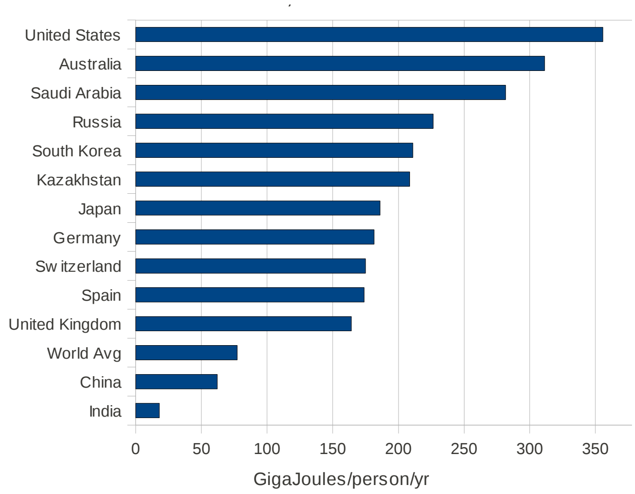
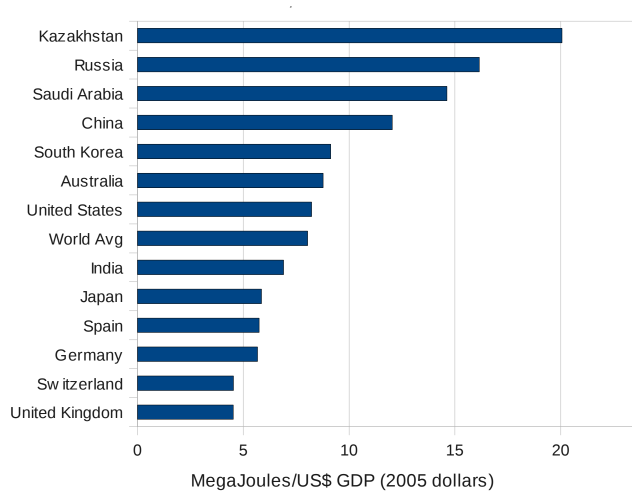


FIGURE 2.9
World energy intensity (MJ / $US GDP, 2005).



2.3.1 Energy Efficiency Measures Employed to Reduce Overall Energy Demand

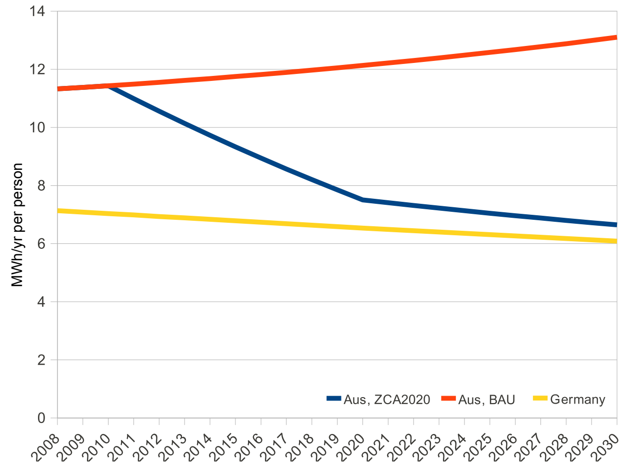
Australia has an energy intensive economy compared to other modern economies worldwide. Many European countries have significantly lower per capita primary energy consumption (Figure 2.8). High energy consumption is not necessarily linked to higher wealth or quality of life. Countries like Kazakhstan and China have a higher energy intensity (MJ/$GDP) than Australia and are poorer countries with lower living standards.

Increasing energy efficiency, and thereby reducing overall demand, is the most cost-effective way to reduce carbon dioxide emissions in Australia. Our current per-capita energy consumption is significantly higher than energy-efficient countries such as Germany. In fact, even after the Plan's 20% improvement in commercial, residential and industrial energy efficiency, Australian per-capita electricity consumption is still above that of Germany (Figure 2.10), not inclusive of the extra electricity for oil and gas replacement. Ongoing per-capita efficiency gains of 1-1.3% per year after 2020 keep total demand steady at least to 2040, while allowing for population growth.

This 20% improvement in energy efficiency can be achieved largely through targeting 'low-hanging fruit': technologies that are easily implemented with rapid payback periods. Examples include upgrades to the latest appliances and machinery, and measures as basic as insulation of buildings and piping. These 'low-hanging fruit' improvements can be implemented without negative effects on service levels or quality of life, and can realise per-capita efficiency gains of 3.5-4% per year.

As shown in Figure 2.7, total electricity demand will continue to rise as electricity steadily replaces oil and gas. This will in fact result in higher total per-capita electricity consumption than even the Business-As-Usual scenario of 2% growth per year. From 2020 to 2040, the Plan caps total electricity consumption at 325TWh/yr by continuously deploying ever-improving efficiency measures.

FIGURE 2.10
Per capita electricity consumption



Such improvements in energy efficiency appear realistic and achievable when compared with experiences in other developed economies—such as the aforementioned Germany. Germany is a comparable modern economy with car manufacturing and energy-intensive metal refining industries, including five aluminium smelters[14]. It provides a good example of what can be achieved through strong energy efficiency measures: Germany and Australia have similar per capita GDP[15], but Germans currently use about 36% less end-use delivered electricity than Australians (7.2 MWh of electricity per capita is used in Germany compared to 11.2 MWh per capita in Australia)[16].

Germany plans to improve its use of energy still further, with an additional absolute cut of 8% from current net energy levels between 2010 and 2020 and a further 9% cut during the decade after that[17]. This will be achieved through the implementation of Germany's National Energy Efficiency Action Plan which includes such measures as:

- rapid implementation of smart metering;
- increased investment in energy efficiency for public buildings;
- new guidelines emphasising energy efficiency in government procurement processes;
- long-term, low-interest loans for retrofitting of old residential buildings;
- subsidies for new low energy houses;
- employment of specialised energy managers within municipal governments;
- demand management projects to foster energy saving actions by consumers;
- improved energy consumption labelling on motor vehicles, equipment and products in general[18].

Australia's record on energy efficiency is poor, as shown in Figure 2.8. This has resulted from the absence of effective government policies to provide incentives for investment in energy efficiency. Consequently, there is room for dramatic improvement in energy efficiency in Australia[13].

Given Germany's plans for the future, and Australia's current laggardly performance in energy efficiency, rapid improvements are feasible and will be cost-effective. Coordinated measures and policies can ensure both short-term and long-term gains in efficiency, and prevent negative rebound effects[19].

2.3.2 Buildings: Energy Efficiency and Retrofitting

The cost of electricity in Australia has historically been low compared to other developed nations, allowing lowest-initial-cost building practices and inefficient design to persist as the norm. Given a growing awareness that these practices are unsustainable, the ZCA2020 Sector Report 2—"Buildings" will be developed to correct this. It will include detailed and costed proposals for:

- a building efficiency retrofitting program, including insulation, double glazing and draught-proofing;

- phasing out the use of gas for domestic, commercial and industrial space and water heating, by moving to electric heat pumps and solar water heating. (Heat pumps use around one third of the energy of other forms of space heating);
- the phased replacement of gas used in cookery with induction cooking and high efficiency electric ovens (gas stove tops are 30-40% efficient[20] at heating food while induction cooktops are generally 80-90% efficient[21] at heating food).

For the purposes of the ZCA Stationary Energy Plan, a projection of a 20% improvement in energy efficiency (i.e. 20% reduction in total energy use) for the buildings sector is modelled. Preliminary work analysing the retrofitting Australia's existing housing stock indicates that this is likely to prove conservative. The preliminary Residential Retrofit report, a prelude to a full Building sector analysis, shows that total energy use could be reduced by 60%, and grid electricity consumption by 36%, through the measures outlined above.

Up to four and a half million homes would be fitted with rooftop mounted solar photovoltaic systems, reducing the requirements for grid electricity. Solar PV systems in this analysis are considered similar to a form of energy efficiency, by offsetting grid demand and reducing daytime peak power requirements.

There is ample evidence that many simple initiatives to reduce energy consumption are cost negative in the short term[22]. iGrid, a collaboration of leading Australian research institutes including the CSIRO, recently pointed to energy efficiency as the most economical method of reducing power consumption, with an effective energy "cost" that is substantially below that of conventional power sources[23]. Despite their higher construction expenses, energy efficient buildings more than pay for themselves in both cost and energy savings over their lifetime [24] [25]. Analysis undertaken by the Australian federal government also supports this finding[26].

The Empire State Building in New York provides a compelling case for retrofits in the commercial sector. It is currently undergoing a comprehensive retrofit program to reduce energy consumption by 38%. It will require a $13.2 million incremental investment, but will save $4.4 million per year in energy bills. Measures include retrofitting 6,514 individual glass windows with triple-glazing, inserting an inert gas in between glazing panels, as well as upgrading the heating and cooling equipment and introducing more effective energy management systems. Once complete, peak electricity requirements will be reduced by 3.5MW[27].

2.3.3 Transport Electrification and Mode Shift to Public Transport

The ZCA2020 Sector Report: Transport will include detailed costings of:

- replacement of the present petroleum-fuelled fleet with electric vehicles, comprising 'plug-in, battery swap' models and plug-in hybrid-electric vehicles, using liquid biofuels to extend the driving range;
- the design of future personal transport vehicles, fostering and encouraging development and roll-out of a range of lower cost zero-emission electric vehicles;
- a general shift from private cars and trucks to electric passenger trains, passenger trams, freight trains and cargo trams;
- additional energy savings from reductions in average

FIGURE 2.11
Residential energy efficiency, based on preliminary analysis from ZCA2020 Buildings sector report.

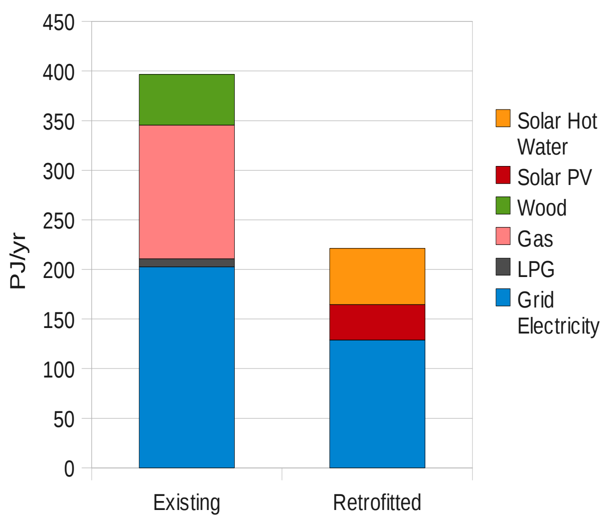
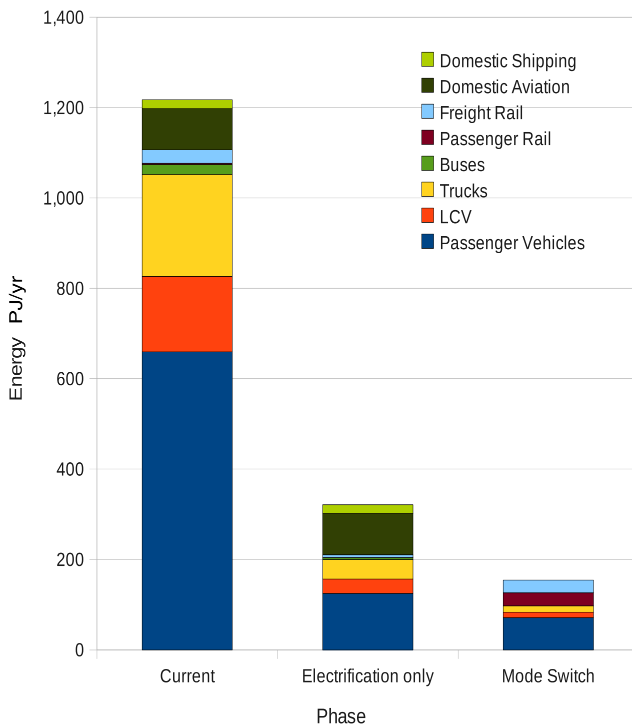


FIGURE 2.12
Energy savings from comprehensive transport electrification and modal shift. Data in Appendix 1



High-speed train in Shenzhen, China[28]

distances travelled, achieved through better urban planning, localised access to services and a range of other policy settings.

Figure 2.12 shows the reduction in energy consumed by the transport sector upon completion of the electric conversion in 2020.

Current annual domestic transport energy consumption is 1217PJ, mainly oil (international transport not included). Analysis indicates that this can be reduced to 320PJ by electrifying 95% of land-based modes of transport, both passenger and freight. A further modal switch to electric light & heavy rail would reduce this to 160PJ, just under 45 TWh/yr of electricity. Allowing for population growth, 50TWh has been allocated for electric transport in 2020 (See Appendix 1 for details).

These figures are based on a switch to efficient, electric light & heavy rail of

- 50% of urban passenger-kilometres
- 25% of non-urban passenger-kilometres
- 50% of urban freight tonne-kilometres
- 80% of non-urban freight tonne-kilometres
- all domestic passenger and freight air and shipping

International air & shipping is beyond the scope of this analysis for Australia.

The Plan proposes a large scale upgrade of public transport services, supplemented with a smaller-than-current private vehicle fleet, consisting of electric, battery swap and plug-in hybrid electric vehicles. Where plug-in hybrid vehicles exist in the fleet, The Plan proposes that they use green biofuels instead of petrol or diesel fuel. However, The Plan recommends a focus on development and rollout of zero-emission electric vehicles, rather than that of low emission fossil-fuel-powered vehicles. Additional energy savings can be accessed by reducing average distances travelled through better urban planning and localised access to services. A renewed emphasis on cycling infrastructure will encourage the use of bicycles in urban areas.

The modal shift from private passenger vehicles to shared electric rail vehicles has the capacity to reduce the private car fleet by around 50%. The average car will travel 8000km p.a. instead of the 15,000km travelled today. ZCA2020 aims for Australia to have six million pure electric, plug-in hybrid electric and battery swap electric vehicles by 2020.

Electric Car Production Capacity and Jobs

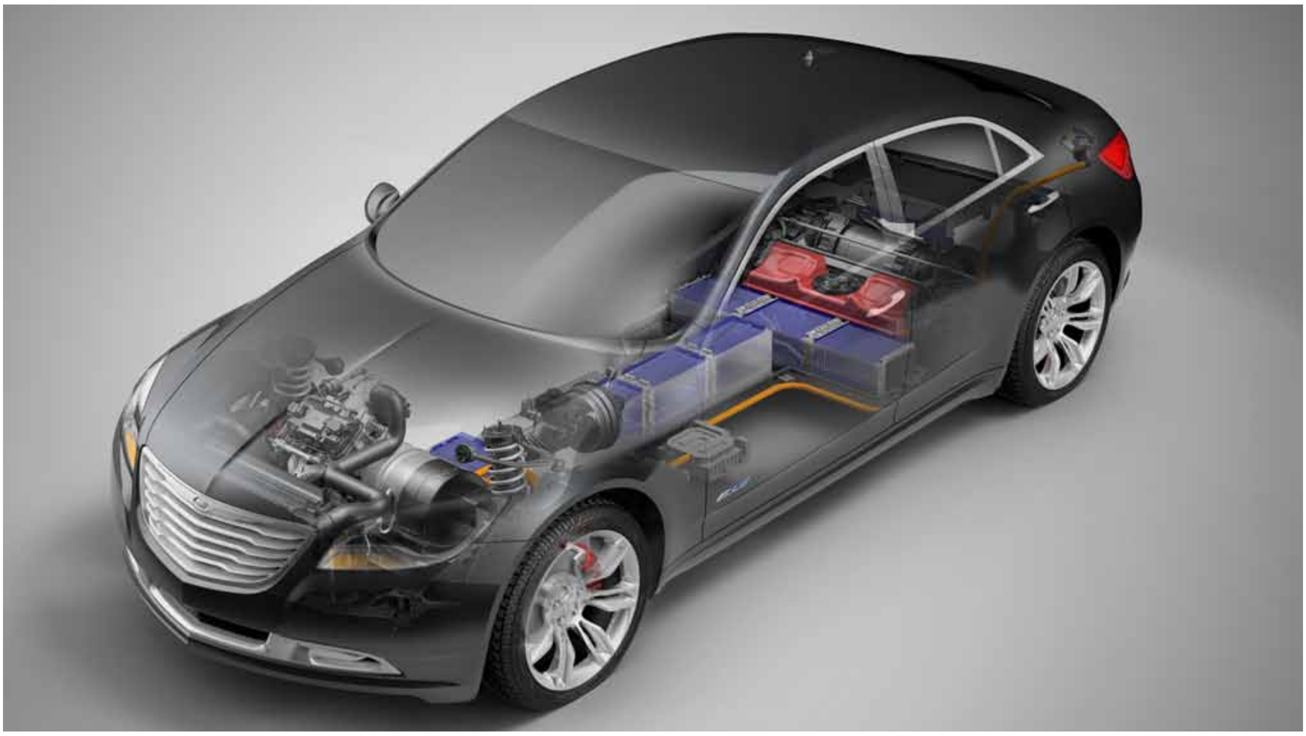
The introduction of 6 million new vehicles in 10 years may seem a challenge, but Australians currently purchases around 1 million new vehicles every year[29]. Demand for new vehicles is therefore strong enough to drive the introduction of appropriately-priced zero emission vehicles. The Australian fleet currently numbers some 12 million private vehicles. The Plan does not attempt to replace all 12 million vehicles, as it anticipates vast improvements to public transport, higher fuel prices, and hence reduced demand for private vehicles. Nevertheless, the capacity exists to deploy 10 million electric cars over the 10 year implementation period. Whether these are sourced from overseas or domestic manufacturing is an economic matter for which the Plan does not recommend any particular solution. An example is given below of the capability of Australia's domestic car manufacturing capacity, to demonstrate the feasibility of the transport shift.

Mass car manufacturing has been a prominent industry in Australia since 1931, beginning with General Motors and Ford, then Toyota, Nissan and Mitsubishi. Three domestic manufacturers remain. As of December 2009, none of their plants were running at full capacity. Toyota is currently producing 100,000—160,000 cars p.a., running 2 shifts and 223 production line days. This could easily be increased to 3 shifts and enough production line days to produce 300,000 cars per annum[30]. To achieve the required production of electric vehicles, the remaining plants would need to increase production to 3 shifts, creating more employment and a combined capacity at the three plants of 900,000 cars p.a.

Although the technology of the plug-in electric vehicles is considerably different from that of an internal combustion engine, the overall production of the car is the same[31]. For this reason, the required tooling changes in the plant would be comparable to those required for the Toyota Hybrid Camry. The manufacture of this hybrid vehicle in Australia was initiated by a $35 million Government grant in July 2008. Just 18 months later in December 2009, the car began production, from a plant designed with the capacity for every vehicle built to be a hybrid vehicle.

At the beginning of World War II, Holden was transformed from a struggling automotive manufacturer to a produceer of high volumes of cars, aircraft, field guns and marine engines[32]. Increased production to 900,000 vehicles per annum across the three existent auto plants is certainly achievable in the twenty-first century, and would allow the production of six million plug-in electric vehicles by 2020.

FIGURE 2.13
Range-extended Electric Vehicle Drive System[39]



Charging

Most cars are stationary for up to 22 hours a day. Car batteries are charged passively during this time, as cars can be left plugged in. When a correlation of high wind speed and solar incidence across the geographically diverse grid occurs, charging electric cars would be used as a means of absorbing "excess" power. In this case the dumped power is useful, both to society and to electricity consumers, rather than being an inconvenience to be managed, as would otherwise be the case for an electricity supply system without adequate energy storage.

The plug-in electric vehicles would be charged at standard domestic single phase sockets (240V/10amps). Full recharging of the national electric vehicle fleet's batteries would require 14.5 GWhr/day, and so could theoretically occur in just over one hour if 14.5 GW grid power was available. The ZCA2020 grid is capable of delivering this charging rate, because it is specified to transmit up to 60 GW with near full wind output. However, this "rapid recharge", would only occur rarely, when low electricity demand coincided with high wind and/or solar output. In the normal charging scenario, vehicles are plugged in (at work or at home) and slow charging can take place over the whole 22 hours, with a required average of only 650 MW battery charging power supply.

"It is all about the batteries...for our hybrids and plug-in hybrids, ten years and 150,000 miles is not an issue at all"
NANCY GIOIA, FORD MOTOR COMPANY[31]

Net Cost

The transformation of transport away from its present mode to the proposed ZCA2020 mode will be cost negative, as capital investment in infrastructure and vehicle stocks give way to lower operational costs. The electrification of the vehicle fleet would present a number of advantages, both in economic costs and in environmental impact[34]. Electrification of the vehicle fleet is beneficial, primarily due to the efficiency of electric motors transforming stored electrical energy to motion. A battery electric vehicle fleet can get up to 5 times more work (motion) per unit of energy input than a fleet of vehicles powered by internal combustion engines (in kms of travel)[35]. That is, an internal combustion engine car such as the Honda Civic or the Toyota Camry might achieve 0.28 to 0.52 km/MJ of input energy, while an electric vehicle can achieve 2.18 km/MJ[36] electrical-outlet-to-wheel. There will, however, be some additional infrastructure investment and operational costs required to support this change. There will be variations depending on the specific model implemented, but solutions outlined by Better Place and other significant movers in the sector are in three principal categories:

- Charge points—these will need to be located in all areas that electric cars are likely to be parked for extended periods (i.e. work and home);
- Battery swap stations—conceptually similar to petrol stations, these will be used to replace depleted batteries;
- Increased electrical generation and distribution requirements.

The requirement for swap stations will likely be lower than petrol stations as they will only be needed when cars exceed the range of a single battery charge in one day.

The overall increase in peak demand and system capacity requirements, caused by additional load on the network, is subject to debate, which centres on the issue of when charging of the batteries will take place. Detractors claim that charging an electric vehicle fleet would require massive increases in power generation capabilities[37]. Instead, the timing of car charging can be controlled to take advantage of lower cost, off-peak power, peak solar generation times or when the wind output is very high and demand relatively low. This will cause zero or minimal increase in peak demand, and may even result in reductions in electricity prices due to increased utilisation of existing infrastructure.

Another argument against the use of electric vehicles regards concerns about the cost and relatively short lifespan of the battery. These concerns are being addressed by developments being made in lithium ion technologies[38] and in the use of next generation lead acid battery technologies such as those from Firefly, a spin-off from Caterpillar[39]. The high cost of the battery is also partially offset by the reduced complexity of the vehicle, and cost reductions are expected to continue. Overall there is a strong argument that even with substantial capital requirements, these costs will eventually be entirely compensated by the substantially lower fuel costs and operational costs for electric cars.

2.3.4 Industrial Energy Reductions

Report 4 on Industry will include proposals for significant efficiencies across Australian industry. For example, a 19% reduction in energy use in the aluminium smelting process, from an average of 14.8 MWh/tonne[40], can be achieved by using a new Chinese process (or equivalent) requiring less than 12 MWh per tonne[41].

Industrial Case Study—Alumina refining energy replaced by solar thermal co-generation. In Part 3 of this report, a single case study has been carried out using solar thermal with molten salt storage as a direct co-generation supplier of process steam and electricity to a large industrial user—the Gladstone Alumina Refinery.

Industrial gas use—Switching gas-fired furnaces to electric furnaces. Approximately 36% of all natural gas consumed in Australia is used by industry, making it the largest consumer in the country. Within industry, gas is the second most used energy source behind electricity. Natural gas is used in many processes, including heating and incineration[42].

The ZCA2020 Plan incorporates the switching of industrial heating loads from natural gas and other fossil fuels to electricity. This can be achieved with existing, proven technology such as electric resistance heating, electric arc furnaces, induction and di-electric heating. Super-critical water oxidation is a proven process for destruction of chemicals, and able to replace incineration. These processes are highly efficient and cleaner than the alternative fossil fuel combustion techniques, and are detailed further in Part 3.4.1 of this report.

Switching of coal for iron smelting. The steel works at Port Kembla and Whyalla respectively use 3Mt and 1Mt of coal p.a.[43], equating to 110PJ of coal energy. This is primarily used for smelting of iron ore, and cannot simply be replaced with electric heating. The Direct Reduced Iron (DRI) process, coupled with Electric Arc Furnace steel smelting, provides an alternative to this. DRI is already used to produce a significant quantity of the world's smelted iron, and is inherently more efficient. Syngas (carbon monoxide and hydrogen), sourced from waste-to-energy or biomass, can be used as a reducing agent in place of coal[44]. Electric Arc Furnace steelmaking is growing rapidly, and is already used to smelt over a million tonnes of scrap iron in Australia. The process is well suited to receiving DRI as a feedstock, which can then be smelted with electricity. An allowance of extra electricity and syngas from biomass has been accounted for in the Stationary Energy ZCA2020 demand scenario to continue smelting the 7.7Mt of steel per annum produced in Australia[45], with the 110PJ of coal removed from the ZCA2020 energy demand scenario. The Industrial Processes working report will present details of this process, including the required investment.

2.4 Proposed Pattern of Demand under the ZCA2020 Plan

This section describes the finer details of energy demand in Australia, as it varies both daily and through the seasons. In particular, the ZCA2020 Plan will see a shift of peak demand from summer to winter, and a decline in overall seasonal demand variability. The section contrasts today's highly variable demand profile, characterised by large spikes in demand that require the construction of expensive reserve plants, with the demand profile flattening brought about by the building upgrades and transport technologies of the ZCA2020 Plan. The Plan promises to significantly reduce the need to construct the underutilised peaking plants of today.

2.4.1 Seasonal Variation and Shift of Demand from a Summer Peak

Under the ZCA2020 Stationary Energy Plan, peak electricity demand will move from summer to winter in most Australian states because of phased replacement of gas fired space heating with electric heat pumps. Seasonal variation in energy demand will also be "flattened", by reducinging Victoria's "winter-peak" gas demand, the dominant factor in seasonal energy use variability. Heating-related efficiency measures will initially be tackled in Victoria, before rolling out efficiency programs Australia-wide. These energy efficiency measures will lower energy demand generally and in particular will mitigate energy demand spikes during hot weather. The energy demand profile will be further smoothed using smart-grids in combination with an electric vehicle fleet and demand-negating, small scale PV.

Implementation of the ZCA2020 Plan has an effect on both the overall energy demand and its variability. The present overall energy demand (supplied by electricity, gas, and liquid automotive fuels) is shown in Figure 2.14. Under the ZCA2020 Plan, there is a reduction both in total energy demand, and its variability. This reduced variability is both long term and short term.

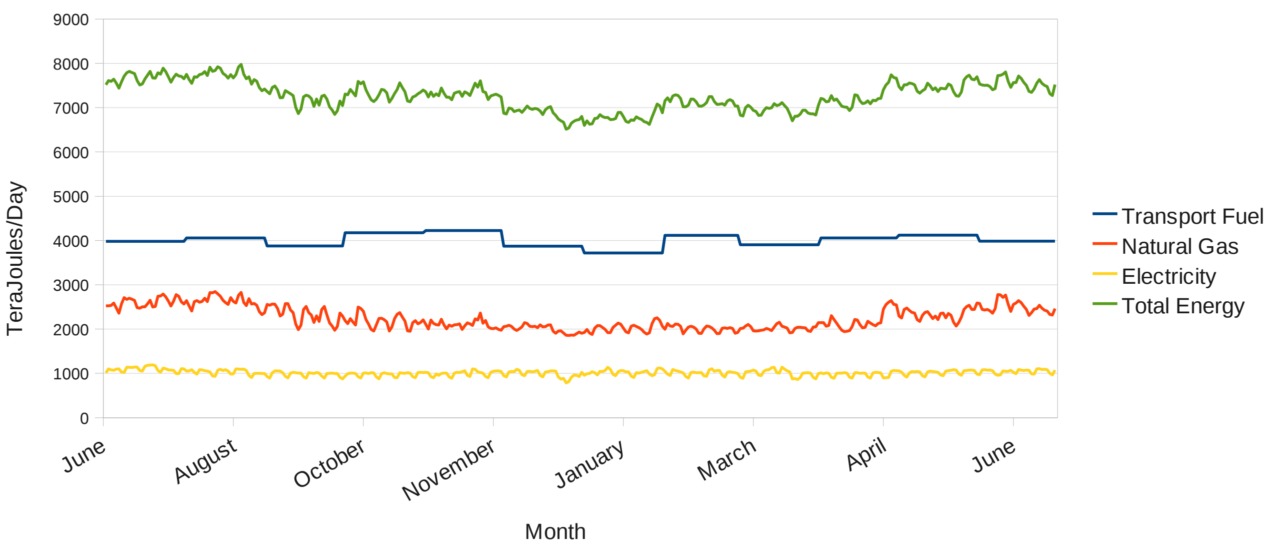
Peak Electricity Demand Will Occur in Winter in Most Australian states

At present, peak electricity demand periods in most Australian states occur during hot summer days. However, as the profile of Australia's total delivered energy shows (Figure 2.14), winter is the period of greatest total energy demand, primarily due to natural gas use. As natural gas is phased out, energy efficiency measures are implemented, and as the remaining temperature-dependent demand (i.e. space heating) is then supplied by methods derived from renewable electricity, peak Australian electricity demand will shift from summer to mid-winter. Efficiency measures such as improved insulation will also lower the demand for electricity for cooling in summer.

Reducing Seasonal Variation in Demand

Analysis has shown that the seasonal variation of the current Australian energy demand profile is heavily influenced by demand in Victoria, due to temperature-dependent gas demand (mainly for gas fired space heating) or the "winter peak" gas demand[46]. Gas consumption in other states can be assumed to be constant year round by comparison. Furthermore, while industry is the largest user of natural gas by total volume (as shown in Section 2.2.2), the seasonal variation in industrial gas usage is quite

FIGURE 2.14
Current (2007-08) Australian seasonal energy demand profile



SOURCE: AEMO [46]

small compared to the seasonal variation due to space heating in workplaces and businesses[46]. When an industrial facility is using gas to heat processes to high temperatures, for example 300˚C, it makes little difference whether the starting temperature is 30˚C in the summer or 15˚C in the winter. However, when tens of thousands of homes and businesses begin to switch on their natural gas heaters at the onset of the winter months, this results in considerably greater gas consumption. This is demonstrated in Figure 2.16 which presents Victoria's seasonal gas consumption, where winter gas demand is more than twice the summer gas demand.

A concentrated effort to flatten the Victorian winter gas usage peak would yield major gains in flattening the Australian energy demand profile over the year. The flattening would be achieved primarily by thermal insulation of Victorian commercial buildings and households. This can reduce heating loads by a factor of 2-4. A program of replacing gas furnace heating with heat pumps would further reduce space heating energy demand by a factor of 4, given an 80% efficiency for gas furnaces and 320% seasonal average efficiency for heat pumps[47]. It is therefore reasonable to assume that given widespread implementation of heat pump and building efficiency improvement in Victoria, "winter peak", space heating requirements could be reduced by around a factor of 10. Note: further flattening of the energy demand peaks, due to reduced air conditioner load during hot weather (as a result of improved insulation) is not modelled but would give further benefits.

2.4.2 Baseload and Peaking under Current Electricity Supply

The current electricity supply system typically groups generator types into "Baseload", "Intermediate", and "Peaking" generating plants.

- "Baseload generators" are designed to operate continuously at high output. Coal plants are almost always operated as baseload plants.
- "Intermediate generators" (or "load following" generators) are designed for faster startup and shutdown, but have higher operating cost. Intermediate generators provide "spinning reserve", which can react quickly to the variability of load and sudden unscheduled generation outages. Natural gas and hydroelectric power plants are typically operated as intermediate plants.
- "Peaking Generators" are held in reserve for periods of unusually high demand, but are the most expensive to operate. Some of these may operate for only a few hours per year[48].

Fossil fuel power stations are often claimed to be superior to renewables because of their capacity for 'baseload' power and energy supply security. However, the fact is that they represent an expensive and inflexible response to energy demands. Currently, Australia has an average power demand of 24,000 MW, which doubles to over 48,000 MW during peak periods. Currently, meeting peak demand is a more pressing issue for the Australian grid than meeting baseload generation[49].

The impact of short term peaking demands for NSW is shown in Figure 2.15. Almost one third of the annual wholesale cost of electricity comes from a few price spikes. These spikes have an extremely high cost (over $1000 per MWh, as opposed to a typical Australian wholesale electricity price of $30-40 per MWh[50]). These price spikes are passed on to

FIGURE 2.15
Current wholesale electricity market volatility[51].Price spike events offer opportunities for Demand Side Response (DSR) instead of building low-utilisation peak generating capacity.

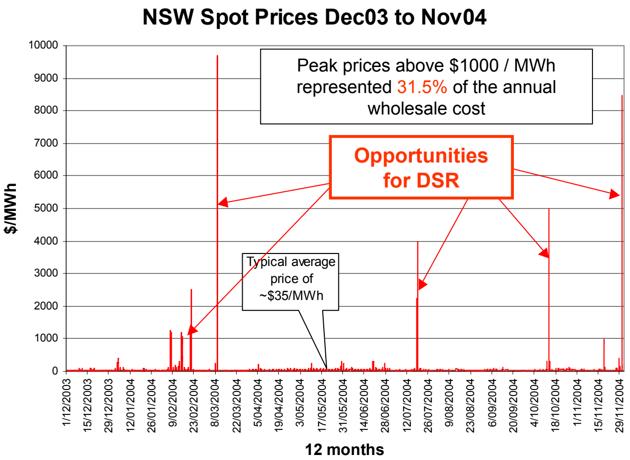
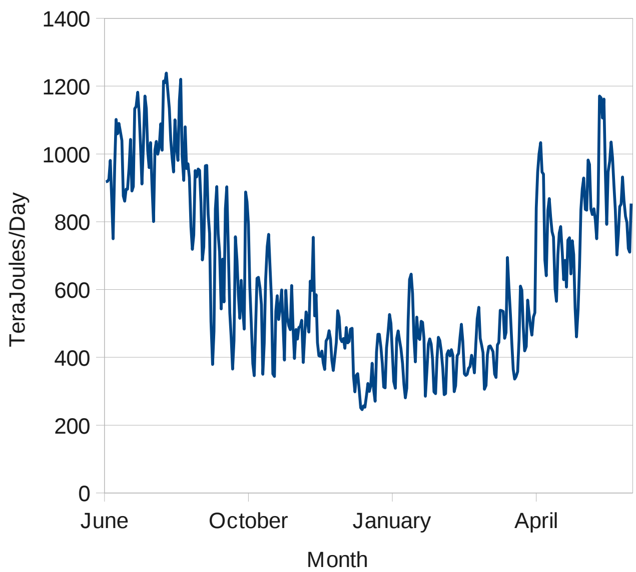
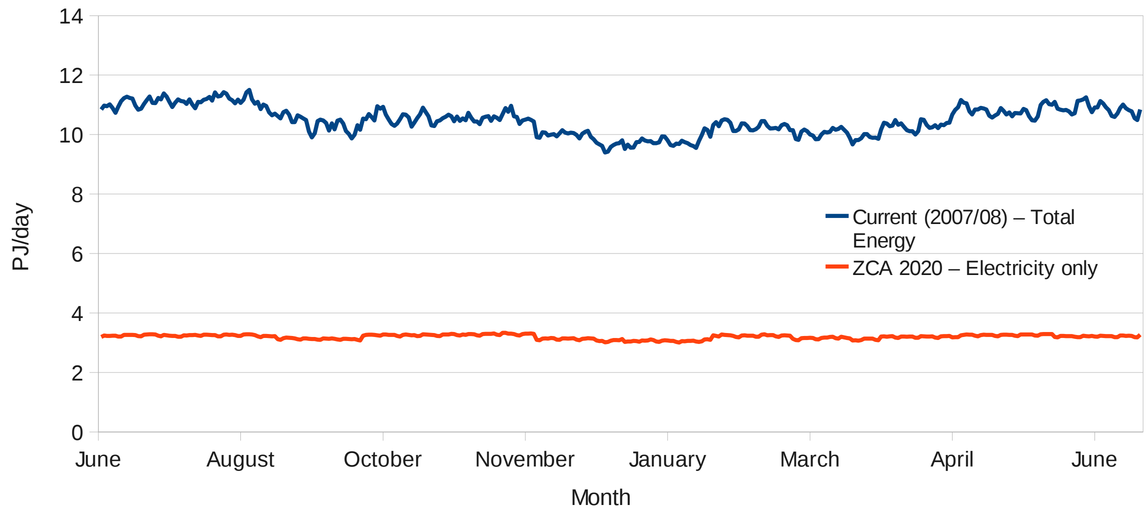


FIGURE 2.16
Victorian gas consumption—Winter 07 to Winter 08



SOURCE: AEMO[46]

FIGURE 2.17
Australian seasonal energy profile—Current (2007/8) (total 3915 PJ/yr) vs Projected ZCA2020 electricity (1170PJ/yr)



consumers, who currently have limited options for adjusting their energy use to avoid using energy during these 'peak price' events.

A recent example of this problem is outlined in the "2009 State of The Energy Market" report by the Australian Energy Regulator (AER). The report indicates that certain companies, who own peaking units, can exploit high demand events such as peak demand caused by extreme heat, to charge up to $10000 per MWh (over 150 times the normal wholesale electricity price[50]).

2.4.3 Flattening Electricity Demand Peaks

As outlined above, short-term electricity demand spikes (which are mainly due to air-conditioner load during hot weather) account for one third of the current retail price of electricity. Reducing short-term demand spikes yields high returns in minimising the overall capital and operating costs of the electricity supply system. Under the ZCA2020 Plan, improved insulation and the use of 'smart meters' assists in levelling short term spikes in electricity demand.

For example, well insulated houses with smart metering combined with advanced forecasting for smart grid operation can be preheated to 24 °C with electricity during lower demand periods, then allowed to slowly cool to 19°C over six hours or so. Virtual elimination of the energy demand spikes could be achieved by a large scale rollout of Building Integrated PV (BiPV). Buildings that are retrofitted with high performance insulation, passive ventilation and energy efficient devices can reduce their heating and cooling energy needs by 50-75%, with BiPV meeting much of the remaining demand[47].

The electric-transport fleet can also be useful in managing short term peaks, as off-peak charging of electric vehicles (nonessential deferred load) can be used to smooth peaks. Battery recharging of the transport fleet can occur during windy periods (or during coincidence of sunny and windy periods) when excess electricity is available, and during night-time hours when electricity demand is low, and the distribution network has spare capacity. Further detail on this measure will be available in Report 3 on Transport.

Under the ZCA2020 Plan the 'peakiness' of the pattern of demand is much reduced. This is due in part to the reduced volatility of domestic electricity use resulting from the measures described above, and further detailed in the later Report 2 on Buildings. However, it is important to note that there is also a substantial reduction in the proportion of electricity use that is subject to significant peaks.

2.5 Choosing Feasible, Cost Effective Zero-Emissions Solutions

This section details the specific zero-emission solutions that have been selected for use in the Plan. It describes why these technologies have been chosen, highlighting their advantages within the context of Australia's geography, resource availability, and demand curves. The electricity generation technologies that form the centrepiece of the Plan include a combination of wind turbines and concentrating solar thermal power towers with molten storage to meet the bulk of demand, with a small quantity of biomass and hydroelectric backup. Lastly, the life-cycle emissions of this system are analysed to demonstrate the rapidity of the expected CO_2 payback.

These technologies are all commercialised and ready for deployment today.

2.5.1 Australia's Solar Resource

Australia's solar resource is equal to the world's best. Figure 2.18 shows the annual average solar exposure, which is greater than 6 kWh/m²/day (2,200 kWh/m²/year) over much of the continent.

Australia has many sites with superior solar incidence, and less pronounced seasonal variations than overseas sites where extensive use of large scale solar power is planned and operating. Table 2.1 shows monthly solar incidence figures for three international sites which already have operational large-scale solar power plants (the Mojave Desert, California, and Granada and Seville in Spain) and three possible Australian sites — Mildura, Carnarvon and Longreach.

This demonstrates the excellent solar characteristics of Australia's proposed sites. Mildura, one of the sunnier places in Victoria, has a similar annual average insolation (5.9kWh/m²/day) to the Spanish/U.S. sites (5.8-6.9kWh/m²/day), with a less significant ratio from summer to winter (1.8:1 vs 2.4:1) than the Spanish sites. Further north, Australia's other sites become much better than overseas. This will make the economics of solar power in Australia even more favourable, as more energy can be obtained and sold from any given solar power installation.

2.5.2 Concentrating Solar Thermal Power—The Most Suitable Large-Scale Solar Technology

Two large scale centralised solar technologies are available:

- Concentrating Photovoltaic Solar (CPV); and
- Concentrating Solar-thermal Power (CST).

Both of these technologies can play a valuable role in a future zero emissions economy.

Choosing between large-scale CPV and large scale CST. Central dish and power tower CPV systems (for

FIGURE 2.18
Daily Direct Normal Irradiation solar exposure—annual average. From DLR[52]

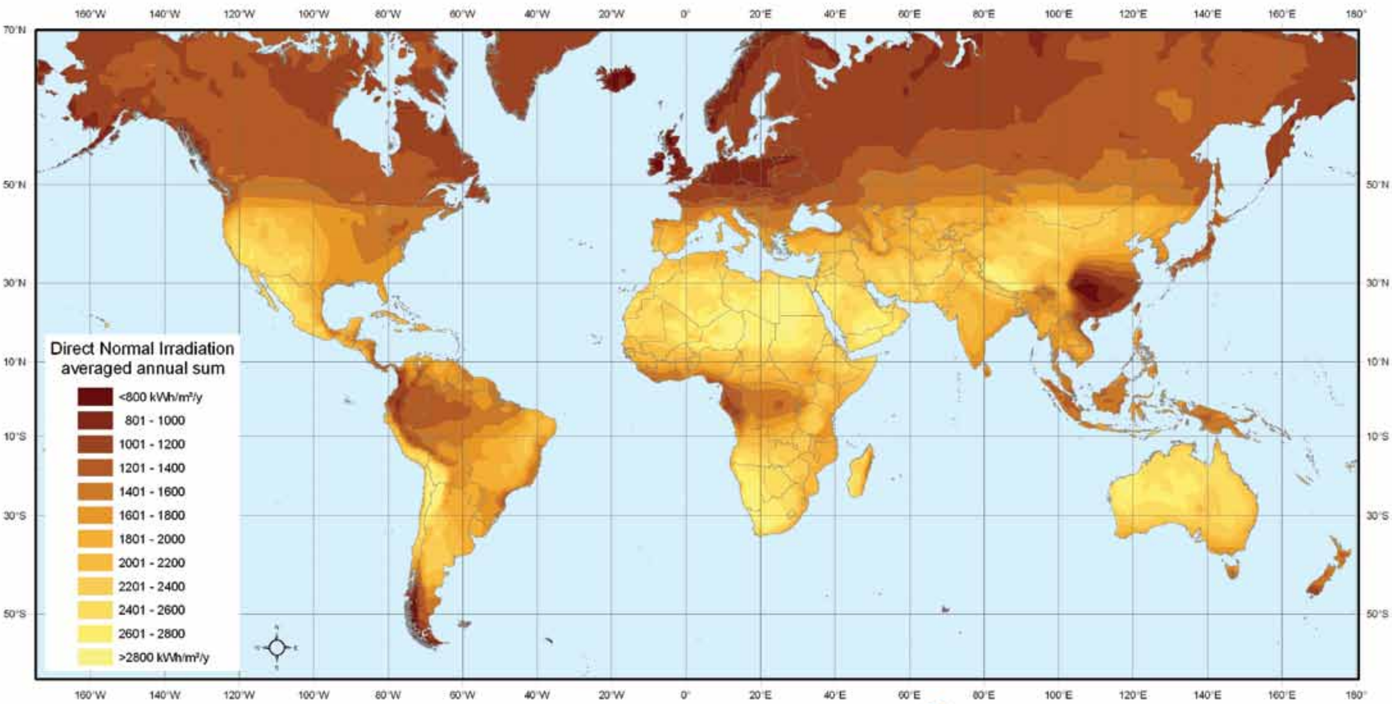


TABLE 2.1
Comparison of solar resource (Direct Normal Irradiation, kWh/m²/day) in Spain, southern U.S. and Australia. Data from NASA[53]

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Max-Min Ratio
Mojave Desert USA	5.29	5.62	7.03	7.95	8.32	8.55	7.87	7.50	7.03	6.37	5.90	5.25	**6.90**	**1.6:1**
Granada Spain	4.36	4.96	5.68	5.71	6.33	7.93	8.80	7.57	6.08	4.60	3.96	3.64	**5.81**	**2.4:1**
Seville Spain	4.62	5.30	6.14	6.24	6.79	8.32	9.26	8.42	6.74	4.92	4.26	3.94	**6.25**	**2.4:1**
Mildura Australia	7.52	7.10	6.71	5.76	4.56	4.13	4.25	4.92	5.62	6.49	6.89	7.17	**5.92**	**1.8:1**
Carnarvon Australia	9.63	8.80	8.27	7.13	6.42	6.33	6.66	7.72	8.78	9.57	9.98	8.25	**8.26**	**1.6:1**
Longreach Australia	6.63	6.36	6.63	6.54	6.38	6.61	7.05	7.30	7.54	7.05	7.18	7.13	**6.87**	**1.3:1**

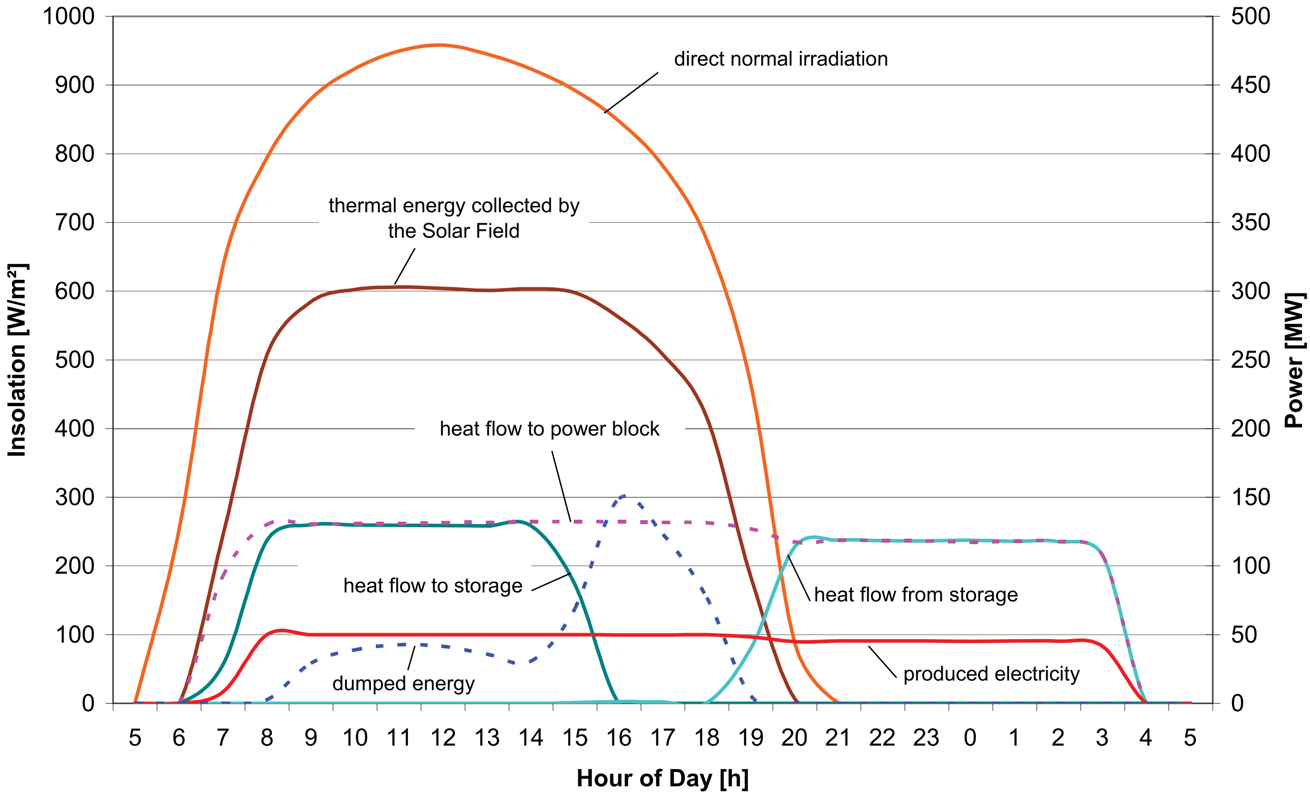
example, those developed by the Australian company, Solar Systems) are fast increasing in efficiency and reducing in price. These technologies will benefit from the development of multi-junction silicon cells by the space industry and National Renewable Energy Laboratories (NREL). Solar Systems' CPV systems currently utilise 34% efficient central receivers, however 40% efficiency has already been proven in the laboratory and up to 60% is achievable[54].

However, the ZCA2020 Plan grid design requires a fully dynamic, dispatchable generation source to complement wind power, which remains the cheapest way of generating renewable energy[55,56] (See Section 2.5.4 for more on wind power). Hence, large scale CST is more suitable than large scale CPV, as CST can be readily built with integrated commercially available storage. Central receiver CPV plants can only produce energy for reasonable costs during on-sun hours. The cost of producing energy from Molten Salt Storage based CST Power Towers is the same during sun hours and non-sun hours. And when the plants are positioned in sunny locations, they have the ability to generate electricity at full capacity 24 hours a day in summer, spring and autumn[57].

Solar Millenium's Andasol 1 & 2 solar thermal with storage plants in operation in Granada, Spain[63].

FIGURE 2.19

Energy flows in the Andasol 1 power plant on a typical summer day[65]



CST is a utility scale, proven and reliable technology, currently experiencing an exponential growth in global installed capacity. CST operates by concentrating sunlight to a focus, and using the resultant heat to create steam, which drives a turbine to generate electricity. For the last 20 years there has been over 350 MWe of CST operating globally[58]. A further 2,275 MWe of CST is to be commissioned and dispatching electricity into the Spanish grid by 2013[59]. In the U.S., the Californian Energy Commission has received applications for 4,800 MWe of CST projects in that state alone[60]. In addition, suitable land for 100,000 MW of CST is under assessment by the Bureau of Land Management across six states. As of June 2009, the BLM has received 158 active solar applications, with a projected capacity to generate 97,000 MWe of electricity[61]. There are solar thermal projects in various stages of development in Italy, United Arab Emirates, Algeria, Israel, Morocco and Egypt[62].

In Spain, 150 MWe of CST plants with molten salt storage are already in operation[60]. These plants—Andasol 1, Andasol 2 and Extrasol 1, each have an output capacity of 50 MWe. Built by Solar Millennium AG, they use parabolic trough technology coupled with molten salt thermal storage. A portion of the heat collected during the day is stored in a high-temperature molten salt tank, and used to continue despatching electricity for the equivalent of 7.5 hours, if operating at full 50 MWe output capacity. If ramped back to lower output overnight, the plants can operate for longer than 7.5 hours if necessary. Their flexibility means they can take advantage of the best power peak prices throughout the day[64]. This is shown in Figure 2.19. During sunlight hours, enough energy is collected by the mirror field to run the 50 MWe turbine and also fill the hot molten salt storage tank. As the sun goes down, energy is drawn out of the hot salt tank, continues to generate steam for the turbine, and the salt is cycled back into the cold tank[65].

Which CST Technology?

There are four major CST technologies available. These are described and compared on the following page. To aid understanding, one important feature of solar collection is explained first.

The Projection Effect – more wintertime energy from elevation tracking solar collectors

One of the key differences between the different solar collection technologies is whether they track the elevation of the sun (two-axes tracking) which varies with seasons, as well as the east-west daily path of the sun. When the sun is low in the sky in the winter time, beams of light hitting a horizontal surface are spread out over a larger area, compared to a surface at right angles to the sun's rays. This is known as the 'projection effect'. Systems which track the sun's elevation can collect more than twice as much energy per square metre of mirror surface in the winter than systems which remain horizontal, the exact ratio depends upon the latitude of the site. Radiation received on a horizontal surface is known as Global Horizontal Insolation (GHI), where as radiation measured on a surface facing directly towards the sun is called Direct Normal Insolation (DNI). DNI has a higher wintertime value than GHI.

A horizontal surface receives less radiation per m^2 than a surface perpendicular to the sun's rays. To put it another way, a horizontal collection system requires more mirror surface (i.e. paying for more glass, steel etc) to collect the same amount of energy as an elevation-tracking system.

Parabolic trough and linear fresnel systems do not track the sun elevation, so suffer significantly lower energy collection in the winter months. Heliostat and paraboloidal dish systems do track sun elevation, with heliostats or dishes spaced further apart to allow for shading. A dish is a near-perfect solar receiver, as it is always pointed directly at the sun. Heliostats bounce light at an angle onto a central receiver tower, and only approximate the performance of a dish. They therefore do lose some energy compared to a dish, but still have a much greater wintertime collection than a trough or fresnel system.

Chosen Technology: Power Towers with Molten Salt Storage

The ZCA2020 Plan recommends the use of the first of these technologies— CST power towers, with heliostat mirror fields, using molten salt as a working fluid and storage. It is recognised that other CST technologies may end up forming part of a final mix, especially in initial years of deployment, however power towers are recommended for their technical advantages, and for the ease of specifying the proposed Australian system with a single technology.

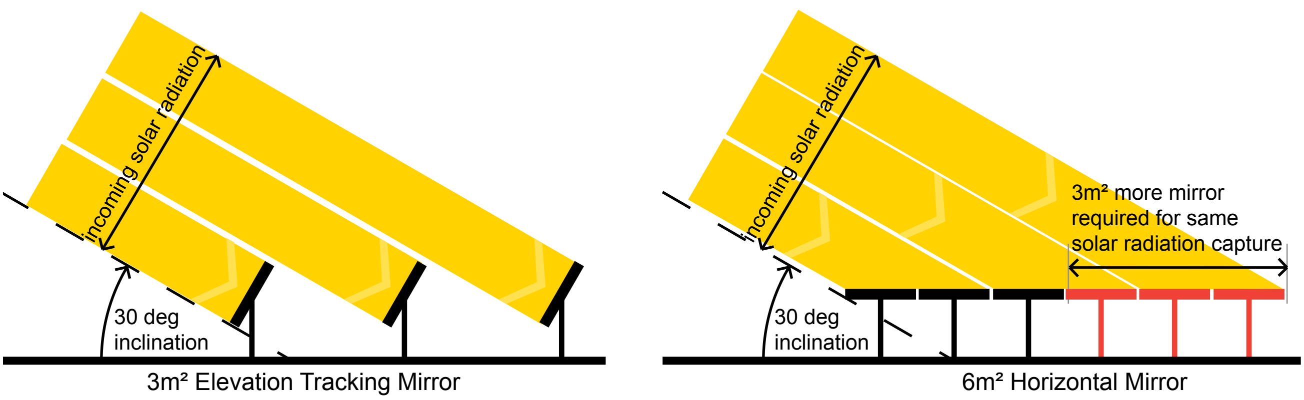
Heliostat mirror fields have the advantages of:

- They track the sun on two axes, so have a significantly higher collection efficiency than single-axis systems (trough & fresnel).
- They are simpler and more cost effective to manufacture and install on a large scale than curved collectors like dishes and troughs.

Central receivers have the advantages of:

- Lower re-radiative losses. Power Towers involve one central receiver tower, one turbine and one set of tanks, all contained physically in a very small area, there is no need to transport a working fluid throughout the field. Dish-based systems, by contrast, though having higher optical efficiency than towers, typically require relatively complex and expensive fluid transport between dishes and a centrally located electrical generator. Trough and Linear Fresnel plants both require kilometres of piping back and forth due to their line focussing arrangement.
- Achieving temperatures in the range of 550—650°C means that standard double reheat supercritical steam turbine technology (already deployed globally in coal, gas and nuclear facilities) can be used for generating electricity at the ZCA2020 proposed solar facilities. Higher temperatures also mean higher thermal efficiency of energy conversion to electricity.

FIGURE 2.20
Projection effect (Cosine losses). Diagram showing two solar extremes of DNI collection versus GHI collection.



Power tower (central receiver) and heliostat fields

IMAGE: ABENGOA

A heliostat field, comprising flat mirrors which track the sun, concentrates the solar radiation on a receiver located on the upper part of a tall tower. Heat is transferred to a fluid (water or molten salts) generating steam that drives a turbine.

- Heliostats track the sun in two axes, so suffer less projection effect and have improved winter-time solar collection.
- Receiver fluid can operate at 565, and potentially 650°C, the same temperature as conventional superheated steam turbines.
- Central receiver minimises area through which heat is lost from re-radiation.
- Molten salt thermal storage has been demonstrated with power towers.

Parabolic troughs

IMAGE: SCHOTT SOLAR CSP

Sunlight reflected from parabolic mirrors is concentrated onto a receiver tube, which runs parallel to the mirrors and contains a working fluid. A mature technology with over 20 years commercial history and more than 600 MWe in operation, more than 6 GWe in development. Parabolic troughs:

- Tracks the sun on one axis, aligned north-south in the horizontal plane, resulting in lower wintertime collection.
- Operate at around 400°C currently, aiming for 500°C.
- Line-focusing system means extensive piping in the field loses energy through re-radiation.
- Pipe plumbing requires specialised moving joints.
- Molten salt thermal storage already operational.
- Curved mirrors and specialised vacuum absorber tubes are relatively complex to manufacture.

Linear Fresnel reflectors

IMAGE: AREVA

Compact Linear Fresnel systems (CLFR) consist of multiple rows of flat mirrors track the sun, approximating the shape of a parabolic trough. Sunlight is concentrated a long receiver which runs parallel to the mirrors and contains a working fluid.

- Tracks the sun on one axis, aligned north-south in the horizontal plane.
- Operates at 290-500°C, and can require specialised low temperature turbines.
- Line-focusing system means re-radiative heat loss.
- Pipe plumbing is fixed, not moving with the mirrors.
- Uses relatively flat mirrors which are cheaper to manufacture than curved troughs.
- Requires less land area than parabolic troughs as mirrors are more closely spaced.
- Molten salt thermal storage not demonstrated commercially with CLFR.

Paraboloidal dishes

IMAGE: ANU STG

A parabolic mirror in the shape of a dish collects and concentrates the solar radiation onto a small area where a receiver is located. Heat is collected from the receivers on multiple dishes and then runs a steam turbine (with or without storage).

- Tracks the sun on two axes, with a higher optical efficiency than central receivers.
- Can operate at very high temperatures, greater than 650°C.
- Yet to be proven and commercialised in terms of installation cost and scale—challenges include wind loadings in large mirror systems and complexity of construction.
- Are available in a light-weight resource-efficient design, (from the Australian National University—ANU) which has the lowest resource requirements of the solar technologies.
- Energy storage is not yet demonstrated commercially, though it is compatible with molten salt storage, and others such as the ammonia thermochemical storage system at ANU.

Molten salts have the advantages of:

- Molten salt systems achieve higher temperatures than those using water or oil as a working fluid. High temperature steam is difficult to contain in its vapour state, and conventional synthetic oils used in trough fields deteriorate at temperatures above 400˚C. Molten salts, on the other hand, have a known high degree of thermal stability to 600˚C;
- Molten salt can be stored at temperatures in excess of 600˚C in insulated tanks. Storage remains viable for weeks, with losses averaging less than 1% of stored heat per day;
- Using molten salt as a working fluid as well as a storage medium also reduces heat exchange losses that are present in systems with multiple working fluids, as there is no heat exchanger and therefore no heat exchange loss;
- The technology is commercially available—the Solar Two molten salt power tower was developed and proven in the 1990s, and the Andasol solar power plants have been in full-scale commercial operation with 7.5 hours of molten salt storage in Spain since 2008[66]. As mentioned previously, many larger plants incorporating molten salt storage are now in construction in the USA and Spain;
- The molten salt system is recommended primarily for its low losses, low cost, material stability, raw material availability and material safety - currently in common use as agricultural fertiliser.

Cost Projections

The wholesale price of electricity from CST is projected to be as cheap as electricity from new conventional coal-fired power sources (around 5c per kilowatt hour) under the proposed ZCA2020 installation timelines by around 2015[67]. The electricity cost of CST with storage is undergoing a declining cost curve, and has been projected to drop to 3.5—5.5 cents (US$ in 2003) per kilowatt hour when the installed base of Solar Thermal Towers with Storage reaches 2,600—8,700 MWe[65]. This is 5-8c/kWh in today's Australian dollars. In 2008, the weighted average wholesale price of fossil electricity in Australia ranged from 4.4 – 10 c/kWh[68].

CST has the additional benefit of being virtually independent of the carbon price, thereby removing significant investment risk, a critical factor in capital-intensive projects such as those required to address climate change.

Solar thermal technologies have the ability to store energy, which is really rare for energy technologies. Really only hydro power has a similar capability. But because we are creating heat we can actually stick that heat in a big tank, much like a large thermos, and then we can pull that heat back later on and use it to create steam and make electricity.

CRAIG TURCHI, US DOE, NREL SCIENTIST[69]

2.5.3 Smaller-Scale Solar Technologies

Smaller scale solar technologies, i.e. solar panels on roofs, play a valuable role in reducing grid electricity demand, and are well-suited to applications such as negating air conditioner demand during hot weather. Electricity demand spikes during hot weather are a major source of high price events and brown/blackouts on Australian electricity grids. Solar hot water systems are well-suited to being combined with heat pump boosting systems. Solar hot water is able to be stored for later use, meaning that daily variations in radiation are not as much of an issue as for solar photovoltaics. The Plan recommends the use of small-scale solar for point-of-demand use to displace grid electricity requirements. The full costings of these will be included in the Buildings sector report.

Although solar PV currently only provides a small amount of the world's energy, it is the world's fastest growing energy source, increasing at around 48% pa since 2002, to a cumulative total of 15,200 MW in 2008[70].

FIGURE 2.21
Price of Photovoltaic (PV) modules and systems[72]

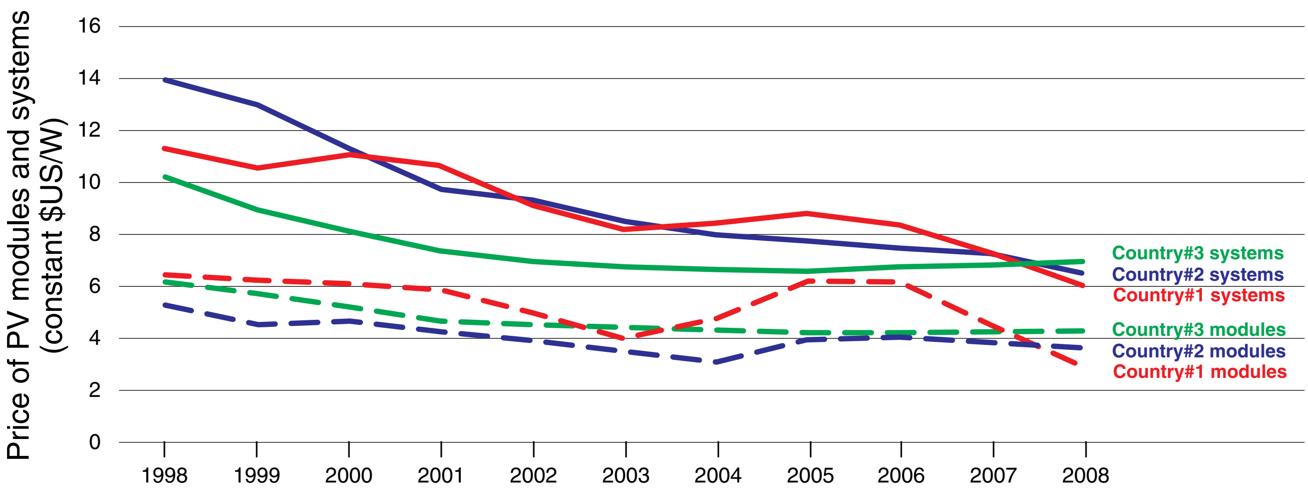
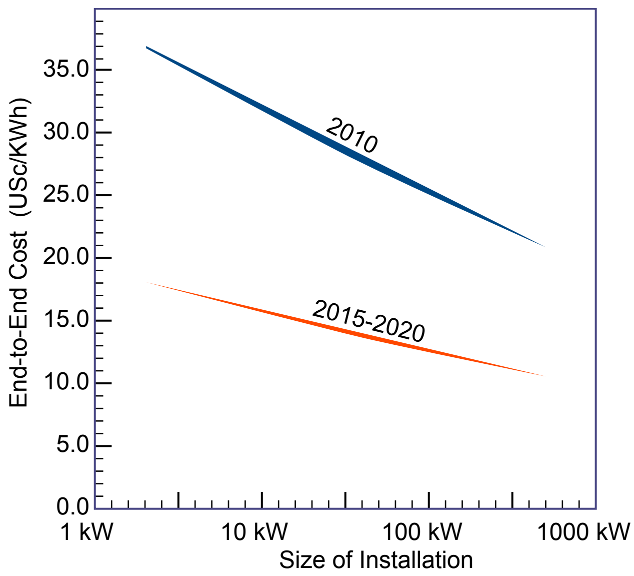


FIGURE 2.22
Cost of solar PV, kWh



Currently the cost of electricity from distributed solar PV is very high relative to the cost of centralised utility scale sources like CST with storage and wind, however it is worth noting that household PV competes with retail electricity prices currently (2010) around 20c/kWh in Victoria[71], which is much higher than wholesale electricity prices (3-4 c/kWh[68]). Also, in contrast to CST with storage, there are no large-scale commercial storage options for photovoltaics. Nonetheless the cost per installed peak watt of solar power has fallen rapidly, dropping 57% between 1998-2008 to US$6/(installed) Watt (peak). This has corresponded to a drop in cost of solar PV per kWh, and is projected to decrease further. It is also worth noting that the larger the installed PV system the lower the cost per kWh, as demonstrated in Figure 2.22 [73].

The IEA Photovoltaic Power Systems Program projects that solar PV could reach grid parity with current sources of generation (in certain parts of Australia) before 2017[74], thus Solar PV may reach parity with CST delivered to the consumer before 2017.

As it can compete with the consumer electricity price at point of demand, it is recommended that solar PV be developed on the demand side (at customer premises for instance) as a first dispatch with very low transmission costs, creating a negative demand for grid electricity. It is not recommended for use in central plants where the cost of transmission and storage need to be taken into consideration.

Because electricity produced from PV needs to be used as it is produced (during direct sunlight hours), this electricity could usefully displace the electricity being produced directly from solar thermal plants during daylight hours, allowing a higher percentage of thermal energy to be stored and dispatched when needed.

ZCA2020 System Flexibility

There may be a point where, for example, distributed PV is so prolific that there is close to zero demand for power from centralised power plants during direct sunlight hours. In these circumstances, the value of power from centralised PV without storage would be very low. Solar thermal power with storage, on the other hand, would offer a relatively high-value alternative, since it allows energy to be dispatched at any time during a 24 hour period, in line with demand.

The ZCA2020 system design is highly flexible and can be modified to accommodate different scenarios such as the situation just described.

In this example scenario, the ZCA2020 Plan system design would be adjusted by:

- using smart grid technology to schedule more nonessential demands during the day;
- reducing the number of wind turbines and/or solar thermal storage plants required;
- altering the design of planned solar thermal plants (with storage) by changing the ratio of mirror field to storage and turbine size appropriately; and
- adding 30% more heat storage to existing solar thermal plants by adding more storage infrastructure.

2.5.4 Wind Power

Australia has one of the highest commercially exploitable wind resources per capita in the world (see Figure 2.23)[75].

The wind resource in Australia is concentrated along the eastern and southern coasts, although there are also significant patches of inland resource. Wind speeds in Australia are conducive to the exploitation of the wind resource for power. The fact that many good wind sites are in areas that already have grid coverage is an added benefit.

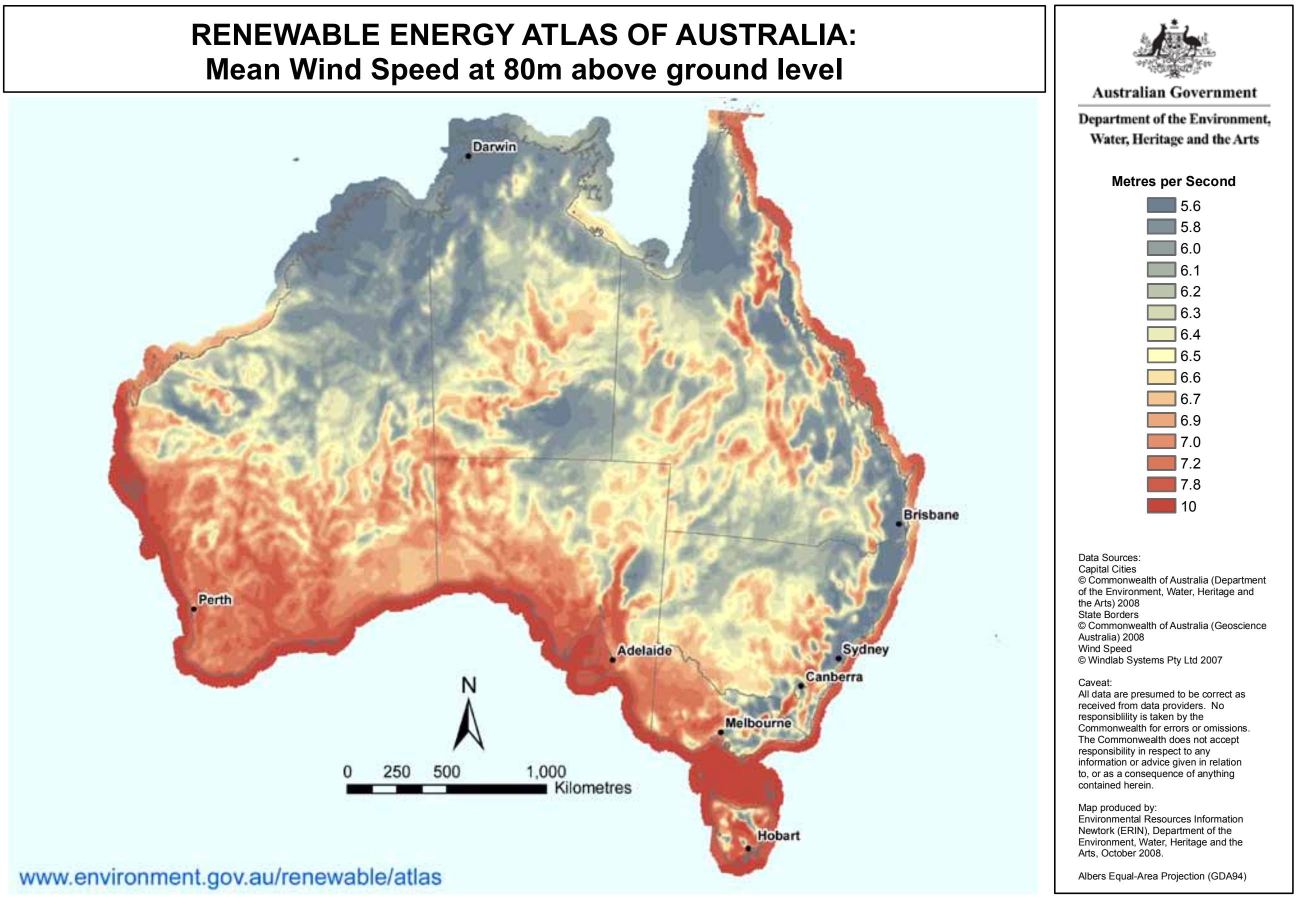
Wind power is the lowest cost renewable energy technology in Australia. The global boom in wind energy has already seen prices drop by 80% in the last two decades, from 30 cents per kilowatt hour in the 1980s to 5 cents per kilowatt hour today[77].

Projects such as the Chinese government's 20,000 MW 'Three Gorges of Wind' (already under construction) are expected to drop turbine costs to less than 75% of current prices in the short-term, judging by the cost of the project itself[78].

Ultimately wind's going to be the cheapest thing to do, so you'll dispatch that first

JON WELLINGHOFF, CHAIRMAN OF THE FEDERAL ENERGY REGULATION COMMISSION IN THE UNITED STATES[79]

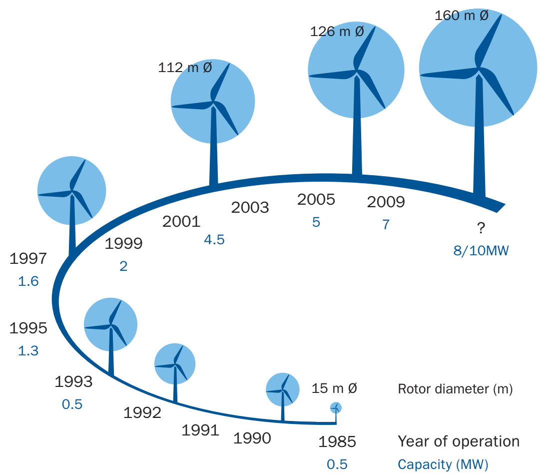
FIGURE 2.23
Mean wind speed at 80m above ground Source: [76]



Major technical advances in the last decade have greatly increased the power capacity of individual turbines, and the viability of large scale power generation from wind. These include:

- taller turbines—from 80-138m hub height (distance to blade centre), giving improved access to faster, more consistent wind speeds;
- increased turbine power capacity has generally led to lower costs;
- improved blade design has allowed the harvesting of very low and very high wind speeds and increasing the amount of power per swept area;
- power control electronics, together with electronic and hydraulic pump system gearboxes allow modern wind turbines to offer grid support and low voltage ride through; and
- storage options (such as integration with Molten Salt Storage CST) can be used to provide dispatchable power to integrate with wind's variability.

FIGURE 2.24
Growth in turbine size and capacity (1980—2009)[80]



Wind power is not only cheap and efficient, it is also widely utilised all over the world. In 2001, a total of 20 GW of capacity was installed globally, and in 2009 this has now exceeded 120 GW. Growth projections are very positive at around 20%—25% per annum" [81]. With less available wind resource than Australia, and 1/20th of the land area, Germany has in excess of 19,460 wind turbines and 23,000 MW of installed capacity[82]. Many of the turbines installed in Germany were installed at more than twice the price of modern turbines.

The ZCA2020 Plan proposes the highest percentage of wind power that can be reliably and economically integrated into the grid. Based on published studies, 40% is chosen.

This percentage may turn out to be conservatively low considering international research and precedents.

The Danish experience: The Danish Government has mandated that 30% of total Danish energy demand (including gross heat, transport and electricity) should be supplied from renewable energy. To reach this target the Danish government has mandated 50% annual electricity production from wind on the national grid by 2025. The Danish national grid operator, Energinet has created the EcoGrid project to model scenarios in which the 50% target would take place. Energinet published a paper called "Steps towards a Danish power system with 50% wind energy" which indicates that high penetrations of wind (up to 50%) can be achieved by using some form of 'balancing power' to manage wind variability [83]. This concept of 'balancing power' is an elegant idea that has aspects that depend on the various timescales of system events, and on various parts of the system (such as supply side, distribution, or demand side).

The Danish national grid operator, EnerginetDK, has explored several scenarios (Ecogrid) for increasing the penetration of wind and balancing increased penetration against existing grid infrastructure. The Ecogrid project reports that 50% wind penetration is feasible with the use of a small amount of wind output curtailment (shutting down wind generators at high wind speeds to avoid an oversupply of electrical energy into the grid) and a source of balancing power[83]. Importantly, sources of balancing power can be either interconnection with neighbouring grids and/or new domestic dispatchable power and storage systems[83]. Under the Danish system some of this balancing power is expected to come from neighbouring grids or from domestically sourced Advanced Adiabatic Compressed Air Energy Storage (AA-CAES)[83]. It should be noted however that Denmark has one fifth of the land area of the State of Victoria and therefore lacks the geographical diversity of the current Eastern seaboard electricity grid and the proposed ZCA2020 'national grid'.

While the Danish Modelling includes either grid interconnection or Advanced Adiabatic Compressed Air Energy Storage, in the Australian context, Australia benefits not only from geographical diversity, but also from the opportunity to use the balancing power of CST with storage.

In the ZCA2020 Plan, CST with storage provides the same service as the AA-CAES or neighbouring grid interconnection that is modelled in the Danish 50% annual wind contribution scenario.

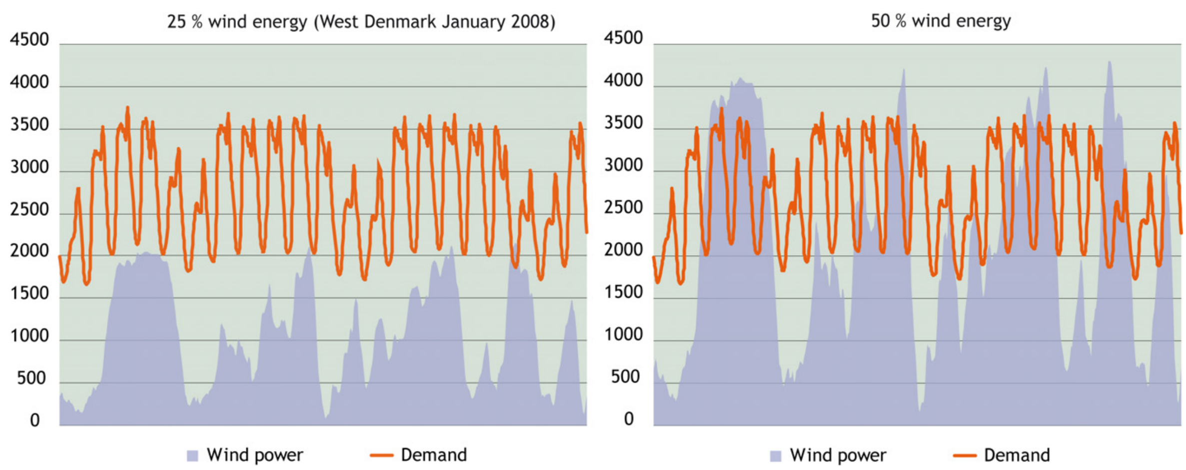
In the Australian context this balancing power can be achieved by adding grid interconnections to create greater geographical diversity, by active demand side management via a 'smart grid', and by the installation of CST with storage, which can effectively act as a giant distributed battery. Variability can be further managed by adjusting the demand curve through the supply side scheduling of space and water heat-pump loads in industry and homes and electric vehicle battery charging.

Research undertaken for the National Grid U.K. suggests that wind variability is not a significant barrier to wind penetration of up to and above 40% [84].

There are no significant barriers to the introduction of wind energy due to its variability, and contributions up to 40% or more of electricity consumption can be managed with quantifiable—and modest—variability costs'

DAVID MILBORROW,
GRID VARIABILITY EXPERT, UK

FIGURE 2.25
Danish wind energy contribution at 25% and 50% penetration[83]



These charts show Demand (orange) and Wind Contribution (Blue shaded) overlaid. In the 25% penetration example, wind power peaks provide 100% of demand in West Denmark and no wind power is discarded. When reaching higher penetration levels, such as 50% (right side of chart), on infrequent occasions wind output must be curtailed in order not to exceed the demand.

Variability of renewable sources is often deemed as a reason why renewables cannot provide 'baseload power'. However there are at least five ways in which variability can be mitigated, as follows:

1. To interconnect renewable energy sources. When numerous sources of power are combined over a large geographical region the effects of variability are reduced[85]. It has been found that by increasing the capacity of wind generation in a system, and increasing its geographical diversity, volatility could be reduced by up to 70% [86]. This was proven in a study completed by Archer and Jacobson in 2006. The study concluded that 19 wind farms guaranteed 312kW of power for 79% of the year, which was four times greater than the power generated from the same nominal capacity located on one farm. The more sites that were connected, the more the array resembled one single farm with steady winds[87];
2. Use appropriate forms of energy source that are able to respond reliably to demand. CST and wind are complementary technologies in that the thermal storage available with CST can be used to balance the variability of wind when required. Biomass and existing hydro technologies can also be used to accommodate the demand peaks.
3. Use smart meters, for example to provide electric power to vehicles when wind or solar sources are high;
4. Store electric power for later use; and
5. Forecast the weather to plan for energy supply. The weather forecast can be provided in minute-by-minute predictions up to 4 days in advance with good accuracy[88].

2.5.5 Biomass

Biomass, or plant matter, is renewable in the sense that plants grow and regrow in a matter of years, using energy from the sun and storing it as chemical energy. Biomass can be dried, stored, and later combusted. However, photosynthesis in most plants is only around 3% efficient at harvesting sunlight into usable energy. There is potential for algae to produce biomass at higher efficiencies, but this is not yet commercial technology. Sourcing biomass also raises issues such as biomass cropping competing with food production, and unsustainable forestry practices leading to ecosystem damage. Under the Plan, energy from biomass would only be sourced from wastes that would not otherwise be used (such as crop residue), and truly sustainably managed plantations.

Due to the relatively limited availability of biomass, sustainability issues and the fact that biomass combustion still causes localised particulate pollution effects, biomass is not a key primary supply of energy under the Plan. It will, however, play a valuable backup role by providing long-term energy storage, as dried biomass can be stored for many months. Pelletisation of agricultural waste can vastly improve transport and storage efficiency.

Biomass co-firing of the solar thermal plants is recommended as a contingency strategy for any extended periods of low wind output that coincide with full cloud cover at several CST plants. This co-firing would make use of existing steam turbine power block infrastructure within the CST plants, overcoming the need for additional turbines and power blocks, and requiring minimal additional costs. The ZCA2020 biomass backup system is based on the standard backup heater/boiler for CST plants, combined with a local distribution infrastructure (standard freight train hauling hopper freight cars and a biomass pelletising plant).

Solar Thermal plants will be built by bringing construction materials and labour force to the sites using rail infrastructure. This rail infrastructure will then be leveraged to distribute and amass pellets from pelletisation plants. Pelletisation plants would be distributed in locations near growers, before processed pellets are transferred to the rail network for distribution to the bunkers outside each of the solar plants. Local trains would then deliver the pellets from the bunker to the co-firing boilers at each of the solar thermal modules, allowing continuing electricity generation in the event that multiple sites are without solar radiation for extended periods (2-3 days).

Land use changes proposed in the ZCA2020 Land Use plan would free up some extra land for the production of biomass. However, electricity supply from biomass is limited by:

- land availability for growing feedstock without competing with food production;
- the risk of stripping vital nutrients from the land if too much crop residue is used; and
- the need for some biomass to also be used as liquid fuel to extend the range of electric vehicles—though initial ZCA2020 projections are that only ~50PJ/annum, or less than 5% of today's liquid transport fuel energy demand, would be met through liquid biofuels under the transport plan. It is used mainly for range-extension of plug-in hybrids in rural areas, and potentially for emergency services.

Biomass production could also be used to produce liquid fuels. For example, integrated wood processing of oil mallee produces bio-oil, agrichar and electricity[89], as well as reducing salinity in soils. Crops such as jatropha produce high yields of oil and can grow on marginal arid lands. While the energy density and ease of handling of liquid fuels (e.g. by using pipelines) would make them an attractive option for biomass backup, it must be remembered that there will also be some requirement for biofuels under the ZCA2020 transport plan. Therefore if liquid biofuels were chosen for CST backup, they would need to be priced at market prices for transport biofuel, and they would require more land dedicated to liquid fuel production, which currently yields lower calorific value per land area than other biomass harvesting options.

Processing our biomass into pellets is a cheap and easy storage option, so that processing can occur year round (or at the end of harvesting seasons). The biomass can be stockpiled in relatively cheap storage bunkers as used by wheat growers, and could be replenished or drawn down as required. A strategic reserve could allow for an additional buffer quantity over and above the predicted annual requirements under ZCA2020. This additional buffer could be amassed prior to achieving the 2020 target, to help create a more steady biomass industry.

Under ZCA2020, biomass is limited to less than 2% of the annual electricity production and is used to supply mid-winter electricity demand. This is a conservative figure and it is likely in practice that the grid will operate with less requirement for biomass backup than specified. In practice, biomass backup may not be required at all, and further modelling and optimisation could prove this scenario prior to implementation of the plan.

2.5.6 Hydroelectric Power—Meeting Peak Electricity Demand and Energy Storage

The Plan does not consider expanding Australia's current hydro capacity, but it is useful for its role in backup electricity supply and long term storage. Pumped hydro for long term storage has not been considered or costed in this version of the Stationary Energy Plan, but could play a part in a future energy mix.

Hydroelectric power is dispatchable electricity that can be used to help fill the winter shortfall from the CST component. However, changes in rainfall patterns are reducing the amount of hydroelectricity that can be relied upon in Australia. It is also likely that opposition to building more hydro power would be strong given the ecological effects of creating reservoirs in existing river systems. Hence, ZCA2020 does not propose adding to existing hydroelectricity infrastructure.

In those areas of Australia where rain continues to fall reliably, hydroelectricity can play a role in peak supply, dispatching power during peak demand times, when the solar and/or wind resource is less than adequate.

In areas where rainfall is declining or becoming erratic, hydroelectric facilities that are under-utilised, and possibly uneconomic, could also be used to provide pumped-hydro electricity storage rather than being decommissioned.

Pumped hydro is a method of energy storage as well as electricity generation. When there is a surplus of energy, it can be used to pump water from a lower dam to a higher one. When energy is needed, water is released to drive turbines and produce electricity. For existing hydroelectric plants, where turbine water races and turbines already exist, this option could offer some relatively cheap additional dispatchable firming power. This is not costed as part of the plan but is a viable additional measure that can be considered.

Given that there will certainly be times of excess energy production when high wind periods coincide with high solar incidence, and more energy is produced than can be held in thermal storage, **pumped hydro would be a useful secondary storage option.**

Pumped hydro storage using seawater in Okinawa

SOURCE: GOOGLE EARTH

One advantage of pumped hydro is that the same water supply is re-used with the only losses in water being evaporation from the dams. Australian topography and water scarcity limits the opportunities for this type of energy storage. However overseas examples of coastal pumped hydro plants using sea water may also be relevant in the Australian context.

Current proposals looking at the large scale addition of pumped hydro storage at existing hydro facilities require storage be built below (usually 200 metres or more below) the existing storage. Unfortunately, most areas where these facilities exist are of high ecological value and building these massive storages is considered inappropriate by the authors.

Round trip efficiency of pumped hydro is ~80%, this compares less favourably to storing sensible heat in molten salts and holding the heat back until dispatch is required, where losses are <1% per day.

2.5.7 Non-commercial Technologies

Only existing commercial solutions are specified, as deployment of the ZCA2020 Stationary Energy Plan needs to start right away. However, if other technologies become commercial during the roll-out at a competitive cost, they could also form part of the future energy mix.

There are other potentially promising renewable energy technologies on the horizon. However, as outlined in Part 1, a core parameter for the ZCA2020 Project is that we have specified existing technologies that are already a commercial reality, meaning that there are no technical barriers to their deployment. We already have the solutions that we need to address the urgent climate situation, so there is no need to wait for others to come along. This does not mean we should cease ongoing research and development of future technologies, but it needs to be recognised that further R&D is not a barrier to beginning deployment of existing solutions.

However, if other renewable technologies become available over the ten year transition period that are cost effective and could further improve the reliability and diversity of the overall energy mix, they could be included in later years. Technologies that it is anticipated may become commercially available during the 10 year transition period include:

- Arrays of Australian National Universities's 500 m^2 SG4 Concentrating Solar Thermal Big Dishes[90].
- Carnegie Corporation's CETO III Wave power technology, being demonstrated in Western Australia[91 92].
- Hot Dry Rocks geothermal (or Enhanced Geothermal), which currently is only going through first-phase demonstration and drilling. HDR geothermal, currently being tested in central Australia, is very different to the type of geothermal already commercially operating overseas in places like Iceland and New Zealand, and there are still technical issues to be overcome.
- Conventional geothermal, currently being commercialised in Victoria by GreenEarth[93], may be available before HDR, however at this stage only 140MW of potential has been identified.
- Beacon Power's large storage array flywheels [94 95].
- "Circulation control" aerodynamic technology which will increase wind turbine output at given wind speeds by up to 40%, allowing feasible commercial operation at sites with lower wind resources [96 97].
- Solar thermal Brayton combined cycle— such as that being trialled by CSIRO Newcastle[98].

2.5.8 Lifecycle Emissions of Energy Technologies

The first part of this section compares the emissions from building, running and supplying various "low-emission" sources relative to their energy output. The comparison shows that coal CCS still produces at least ten times the emissions of any other competitor. Nuclear, geothermal and solar PV fare better, but are still several times higher than the lower emission options. **The comparison clearly shows that solar CST and especially wind are best suited to achieving considerable emission reductions.**

The second part deals with the question of how long it takes from the time of the decision to build for a new plant to supply energy to the grid (as this is the time conventional sources need to be kept online and emitting) and how long it takes until the plant has produced more energy than it took to build and actually become a net producer. This comparison shows that nuclear power, due to its high technical and safety requirements, is by far the slowest to come online (on average 15 years), approximately ten years later than the low emission options. Coal CCS and hydroelectric fare better, but still take more than twice as long to come online than the other options. The remainder is similar in this regard, but **wind and solar CST dominate the field by their very fast energy input payback.**

Lifecycle Emissions (LCE)

It is important to know the timing and quantity of emissions produced by a given type of energy source. All sources require some form of construction and production. This involves concrete, steel and other materials as well as the transport and engineering to set up on site, followed by some form of ongoing maintenance. Fuel consuming sources require mining or drilling and pumping for the fuel, processing, transporting, energy extraction (e.g. by combustion) and possibly removal of waste. At the end of its lifetime the site will require some form of decommissioning. All of this results in at least some emissions. Summing all of this up and combining it with the site's lifetime and useful energy production allows us to calculate the emissions per kWh produced, usually quoted in g CO_2 equivalents/ kWh. There is obviously some variability, for example due to location (wind speeds, hours of sunshine), fuel quality (ore concentration), particular design (reactor type), etc., but by combining the data from different locations, plant sizes, fuel sources, etc., it is possible to get figures that allow a comparison of the lifecycle emissions between the various types of energy source.

Conclusions that can be drawn from Figure 2.26

Wind power has the lowest LCE followed by CST. Both are within or close to the range of less than 10 gCO_2e/kWh. PV, geothermal, hydroelectric, wave and tidal power are in the range of 10—60 gCO_2e/kWh. As the lower end estimates for nuclear LCE underestimate or omit emissions resulting from uranium mining and processing, the actual LCE figure is likely to be at the higher end of the 9—70 gCO_2e/kWh bracket. Despite the capturing and sequestration of a high proportion of CO_2 emissions resulting from coal combustion, Coal CCS power produces at least 5 to 25 times the LCE emissions of any of the other sources discussed.

TABLE 2.2
Lifecycle emissions of various energy technologies

Technology	Notes	LCE (gCO_2e/kWh)
Solar PV	Requires mining of the materials, production of the cells, transport and on site setup, and minimal maintenance.	19—59 [99 100]
Concentrated solar thermal (CST)	Requires materials, transport and construction and maintenance.	8.5—11.3 [101 102 103]
Wind	Requires materials, construction, transport and setup and minimal maintenance.	2.8 -7.4 [104 105 106 107 108]
Geothermal	Requires construction, setup and maintenance. Might result in emissions from the decomposition of groundwater carbonic acid to water and CO_2, but this can be avoided by using binary plants.	15.1—55 [99 109 110]
Hydroelectric	Emissions come largely from construction, but also from rotting biomass, dependent on location (e.g. higher in tropics). This can be lowered by clearing before flooding. Usually these plants have long lifetimes which lowers the LCE.	17—22 [99 111 112 113]
Wave	Requires materials, transport and construction; low maintenance.	21.7 [99 114]
Tidal	Requires materials and construction; low maintenance.	~14 [99 115]
Nuclear	Requires construction, mining, enrichment, processing, transport, waste handling, maintenance and plant decommissioning. Figures for LCE vary considerably in the literature, mostly due to different assessments of the emissions resulting from mining and processing of the fuel and who commissioned the study.	9—70 [99 116 117 118 119]
Coal CCS	Requires construction and mining and transport of the fuel. The majority of its emissions stem from the combustion of the fuel (dependent on fuel quality). CCS reduces direct emissions by 85-90%, but also requires more coal per kWh produced to run the CCS equipment. Quantifying CO_2 leakage over longer periods is hard to predict as it depends on the local geology and is hard to accurately measure. Injection at high pressures makes at least some leakage likely and rock erosion from the formation of carbonic acid from water and CO_2 is hard to predict. It is also as yet unknown how leaks over large areas would be dealt with. It is estimated that leakage will result in additional LCE of 2- 42 gCO_2e/kWh. [120]	255-442 [99 121 122 123] without CCS circa 800—1000)

FIGURE 2.26
Life cycle emissions

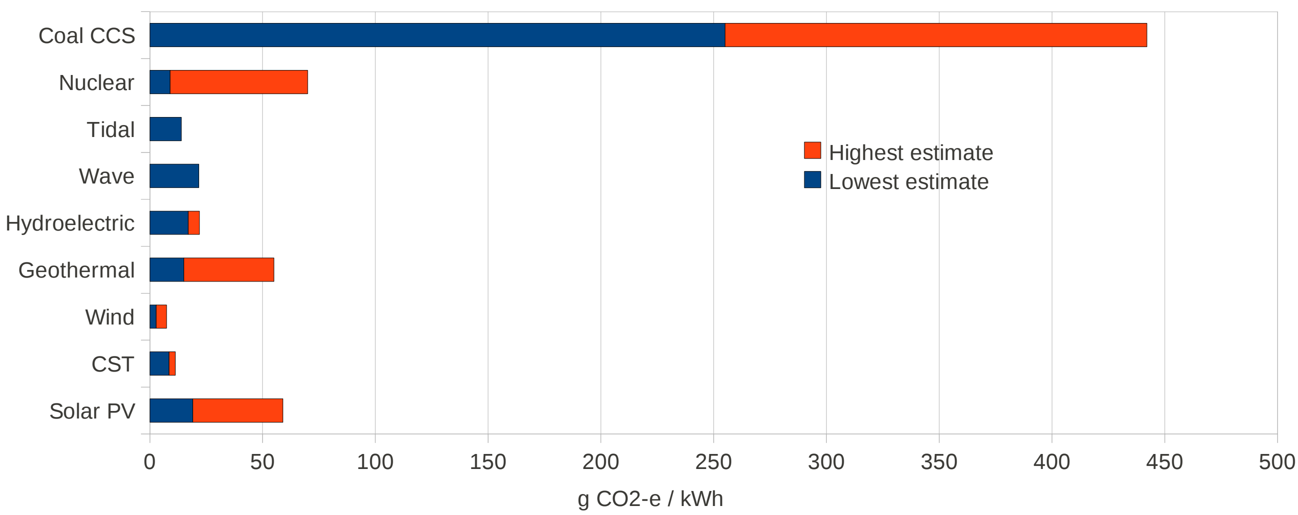
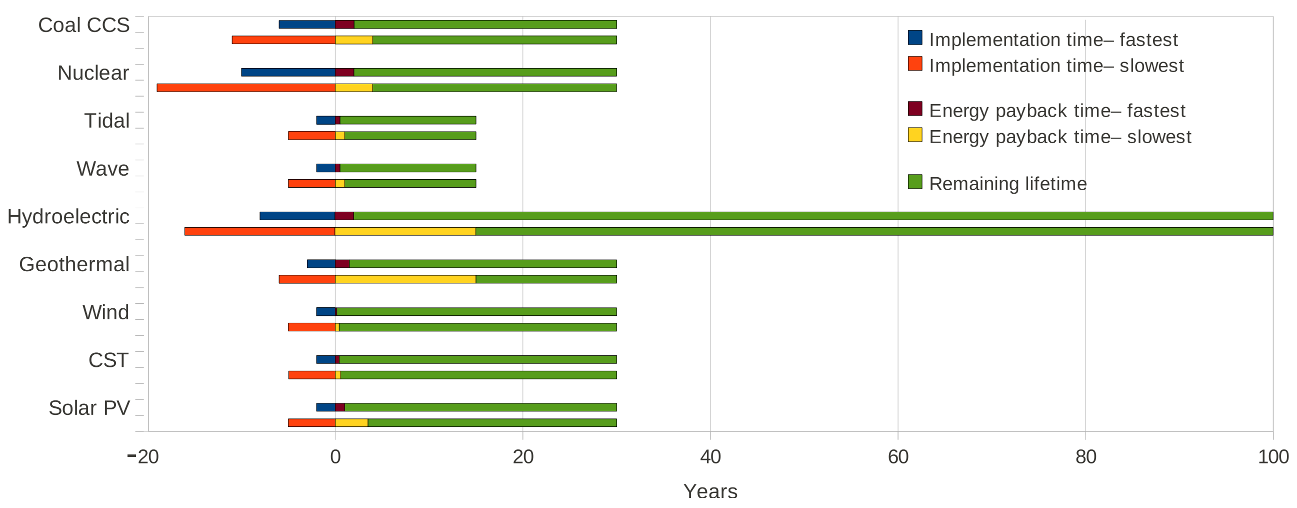


TABLE 2.3
Energy production timetable

Energy production timeline Technology	Notes	Implementation T ime
Nuclear	Due to the safety requirements and the complex design, this source has had very long ITs, varying slightly depending on the country. Easing bureaucratic hurdles and improving construction efficiency might improve this slightly. As it requires an ongoing energy input to mine and process the fuel, the EPBT depends strongly on the ore quality.	10—19 years. [124 125 126 127]
Wind	The typical planning period is 1—3 years and the construction period, depending on project size, 1—2 years. Similarly to CST the EPBT depends on the local wind speeds.	2—5 years [124 128]
Geothermal (conventional)	The construction time depends heavily on the location and its geology. The EPBT will depend on the local geology, which defines how much and how accessible the energy is. There is little data available on geothermal EPBT but is estimated that it will be between 5 and 50% of the plant lifetime.	3—6 years [124 129 130]
CST	This source is very similar to wind with regard to planning and construction aspects that affect ITs. The EPBT for concentrated solar power depends mostly on the location's hours and intensity of sunshine.	2—5 years [124 131]
PV	This source is very similar to wind with regard to planning and construction aspects that affect ITs. Solar PV has EPBTs depending mostly on which type of cells are used.	2—5 years. [124 132]
Wave and tidal power	These sources are very similar to wind with regard to planning and construction aspects that affect ITs. There is limited data on the EPBTs of these sources. Due to the harsher conditions these plants are exposed to, their overall lifetimes are slightly shorter than the other sources, so that despite the EPBT being nearly as short as (for example) wind and CST, it corresponds to a larger proportion of the overall lifetime.	2—5 years. [124]
Hydroelectric	Especially the construction time depends heavily on the size of the project. For the Aswan dam this was 13 years, the Hoover dam 4 years and the Three Gorges dam 15 years. The EPBT of these projects depends on the location and especially the scale.	8—16 years [124]
Coal CCS	Without CCS the typical IT of a coal plant is 5—8 years, with CCS it is estimated to be slightly longer. However, as no such plant has been built to date the actual figure is unknown. As these sources require an ongoing energy input to mine and process the fuel, the EPBTs depend strongly on the ore quality.	6—11 years [124 133]

FIGURE 2.27
Energy Payback Times for various technologies, where Year Zero is commencement of energy production



A long term consideration for LCE emissions is that recycling at the end of the plant's lifetime would lower the LCE even further, this is especially true for sources where construction materials such as steel and concrete are the main source of emissions. For example, this recycling could be for construction of the successor plant. Considering that plant lifetimes are in the order of several decades, a quantified prediction of the effect of recycling is not feasible, but qualitatively, the effect of lowering LCE is very likely. Energy inputs for successor plants (including those to power transport, materials acquisition etc) would be derived from the established zero emissions energy system. This would significantly reduce CO_2 emissions. If a low emissions replacement for Portland-cement was used, then emissions for a subsequent successor plant could conceivably be close to zero. For Portland cement, 50% of emissions are from a chemical reaction during the cement production (the other 50% is due to the high temperature kiln, which can be powered from a Renewable heat source such as solar thermal).

Energy Production Timeline

Lifecycle emissions are the total emissions from the planning and construction stage to the final decommissioning stage averaged out over this period. For emission reduction planning, it is important to know how long is required to implement and hence replace a higher emissions alternative. This is needed to calculate when the actual emissions savings will set in. Choosing a source with a long implementation time over a faster one results in conventional plants having to continue running for longer and therefore produces more emissions.

Implementation Times (ITs)

The implementation time is the sum of licensing, site acquisition, planning, construction and connection to the grid. This depends on guidelines and the application process of the responsible agencies, the specific design, the location and many more aspects of this process. As a future prediction of these is ambiguous at best, the umbers in Table 2.3 are estimates arising from previous and current construction.

Energy PayBack Time (EPBT)

The energy payback time is how long it takes for the facility to produce as much energy as its construction required, and therefore is the point in time when it has paid for itself energetically and begins to produce net energy.

Conclusions that can be drawn from Figure 2.27

Two different factors need to be considered in deciding the types of production sources to include in the stationary energy system. The first factor is the lifecycle emissions for that type of source. The second factor is the implementation time, because this affects the time for which existing higher emission sources need to continue to run. In principle, these continuing higher emissions during implementation should be added to the lifecycle emissions of the new sources for a valid comparison. For most of the sources discussed here, a source with longer implementation time also tends to have higher lifecycle emissions, and so it is mostly reasonable to focus on lifecycle emissions.

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Part 3

Australia's 100% renewable energy supply

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PS10 Solar Tower SOURCE: ABENGOA SOLAR[1]

Part 3 describes the Plan for each of the recommended technologies in detail:

- Part 3.1 describes the specifications of the proposed Concentrating Solar Thermal (CST) power plants with storage.
- Part 3.2 describes the installation of wind power and its complementary relationship with CST with storage.
- Part 3.3 describes modelling of the grid behaviour with renewable energy sources.
- Part 3.4 describes the use of other renewable energy technologies as backup, allowing for the event of several consecutive days of cloud cover.
- Part 3.5 provides extra detail on how the Industrial sector energy requirements can be compatible with 100% renewable electricity, together with case studies.

As outlined in 'Designing the system' of this report, Australia's projected on-grid electricity demand in 2020 is 325 TWh/yr.

40% of this electricity (130 TWh/yr) will be supplied from wind power, which the Plan proposes to provide through 48,000 MW of new wind turbine capacity, spread over 23 sites across the country. This requires 6,400 7.5 MW turbines. Due to the geographical diversity, it is projected that half of the electricity produced from wind will be 'firm' — always available with the same reliability as conventional 'baseload' generators.

The rest of the electricity will be supplied from Concentrating Solar Thermal (CST) with storage, providing reliable, 24-hour dispatchable power. 42,500 MW of CST capacity is proposed for twelve dispersed sites across Australia, and the plants have up to 17 hours of molten salt thermal storage capacity for provision of electricity overnight.

In the event of prolonged winter-time periods of low wind and high cloud cover, backup will be provided by existing hydropower capacity (5 GW on the mainland), and from biomass-fired heaters attached to some of the CST plants. These will only use waste biomass such as pelletised crop residue, and directly heat the molten salt tanks, to provide thermal energy to the existing CST generators. Modelling of the ZCA2020 Stationary Energy System shows that the wind and solar installations alone can meet 98% of the electricity demand, and biomass heater backup capacity is required to produce 15,000 MW (electrical equivalent) to ensure a 100% reliable supply of renewable electricity.

There is also an existing total of 4,810 MW of off-grid generation capacity in Australia, which includes remote mine and town sites. To replace this fossil fuel capacity with renewables, allowance has been made to supply the equivalent generating capacity from extra solar thermal plants, including their own biomass heater backup systems. After allowance is made for the parasitic energy losses in the existing plants, the renewable replacement capacity is sized at 4,475 MW.

The total investment capital requirements for the proposed system are summarised in Table 3.3. To build the 100% renewable grid will cost $AU353 Bn (2010 Australian dollars). The extra $AU17 Bn for off-grid installations takes the total investment requirements to $AU370 Bn.

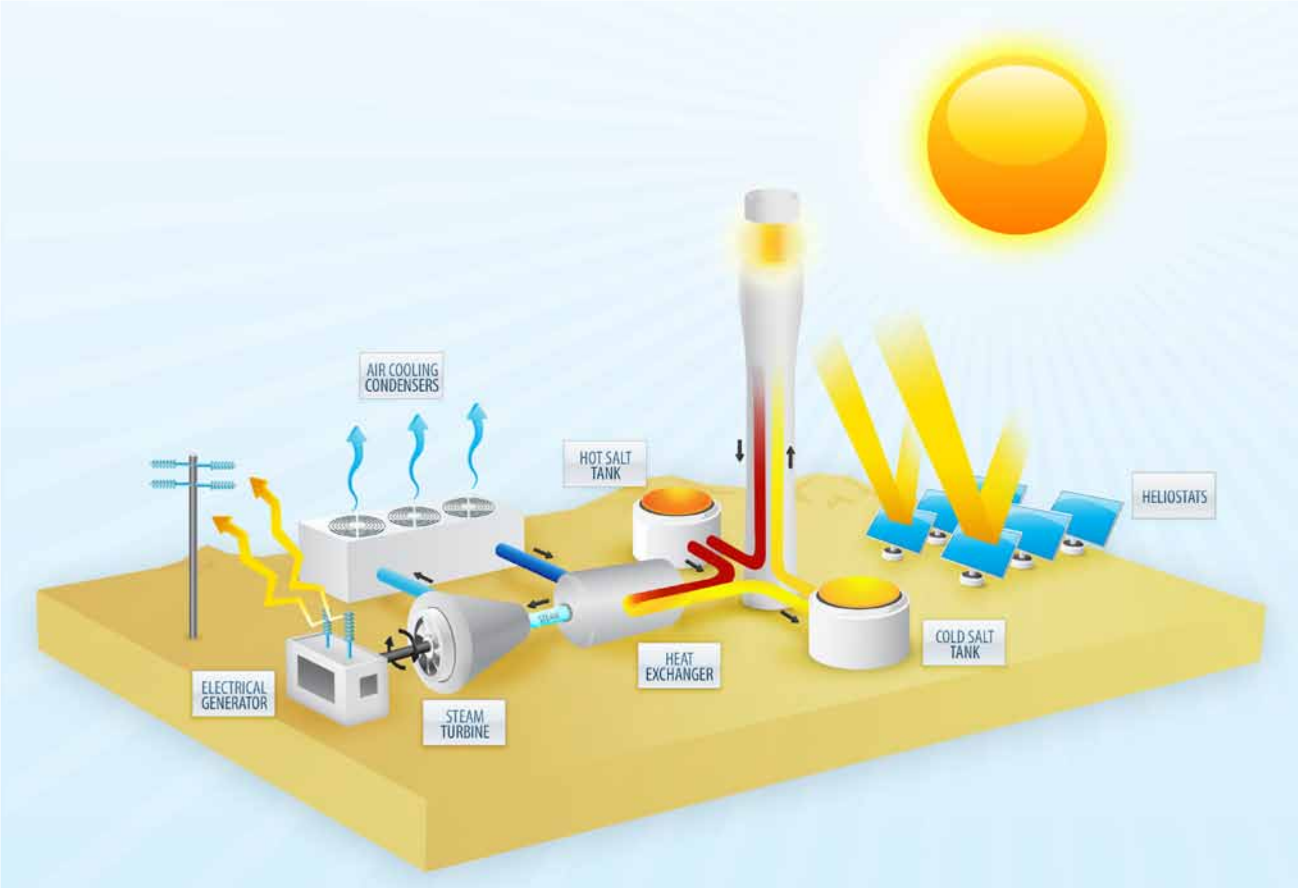
Detailed costings for the renewable energy generation infrastructure are explained in the rest of Part 3. The transmission upgrades and associated costings are detailed separately in 'Part 5 Grid and load management — creation of a national grid'.

TABLE 3.1
ZCA2020 Stationary Energy Plan total investment costs

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

FIGURE 3.1
Direct heating of molten salt in a power tower.

DRAWING: SHARON WONG



3.1 Concentrating Solar Power with Storage — 24 hour dispatchable power

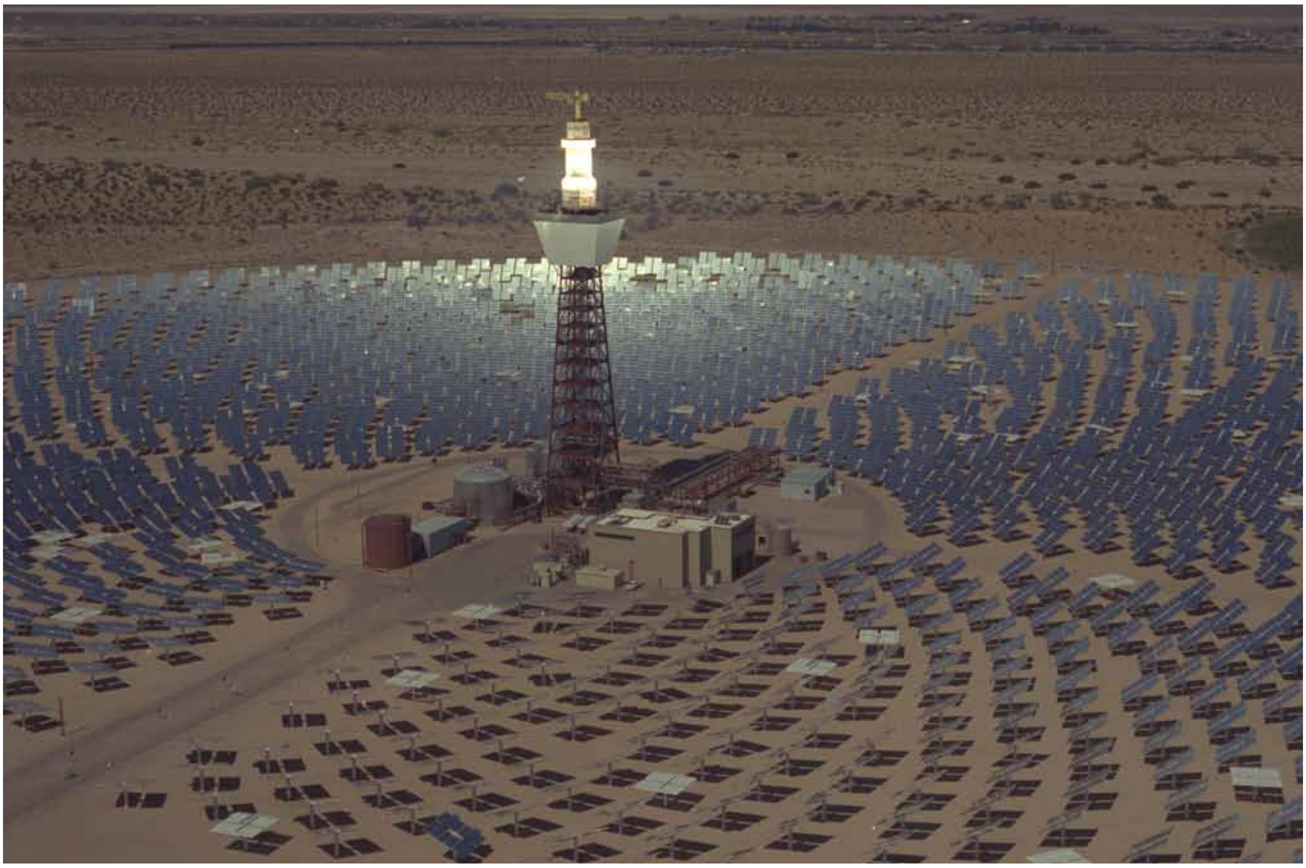
Under the ZCA 2020 plan, it is proposed that 60% of Australia's estimated 2020 electricity usage (195 TWh/yr) be generated by large-scale, dispatchable Concentrating Solar Thermal Power (CST) plants with storage. Solar Power Tower technology with molten salt storage is specified for all of the CST installations. As described in Part 2.5.2, power tower technology with molten salt as both working fluid and storage medium is the most suitable technology.

The general principle of operation of the chosen CST Power Tower technology to be used in the plan is shown in Figure 3.1. Note that for simplicity only six heliostats are depicted — in reality there are hundreds to thousands of heliostats for each tower.

The Sun's rays are reflected by several thousand heliostat tracking mirrors which follow the Sun's path and keep maximum energy focused onto the central receiver located on top of a central tower, which is up to 280 m high. The temperature generated in the receiver is 565-650°C, and the received heat is transferred directly to molten salt, which flows down the tower into the hot tank (shown in red). To meet electricity demand as required, hot molten salt is taken from the tank and passed through a heat exchanger to boil water and generate steam. This flows to the steam turbine where the energy is used to spin an electric generator and create the required amount of electricity. The heat energy extracted from the molten salt in the exchanger cools it down to 290°C, at which temperature it still remains molten, and returns to the cold tank (shown in yellow) where it awaits reheating again in the tower. The steam is re-condensed to water again by dry air-cooling fans so it can be reused.

The technical specifications and costings for the CST plants have been referenced from the U.S. Department of Energy's "SunLab" solar thermal program, a collaboration of Sandia National Laboratories and the National Renewable Energy Laboratories. These have been published in detail in the subcontract report "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts" carried out by Sargent & Lundy Consulting Group, LLC[7].

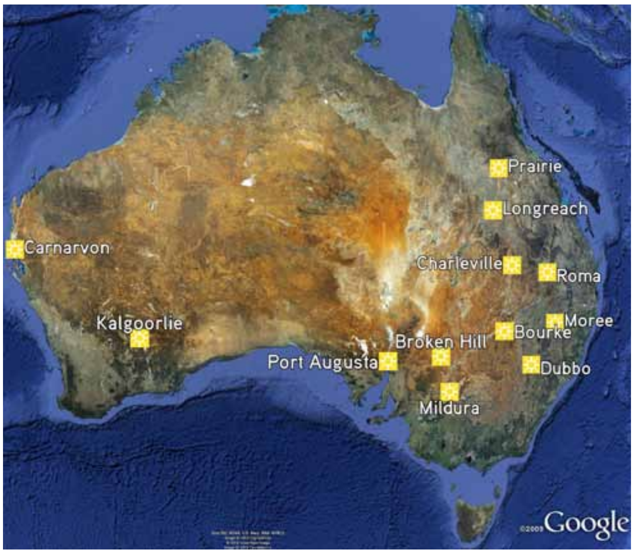
"... it is S&L's opinion that CSP [Concentrating Solar Power] technology is a proven technology for energy production, there is a potential market for CSP technology, and that significant cost reductions are achievable assuming reasonable deployment of CSP technologies occurs."



Solar Two in operation at Daggett, California, 1999[2]. Molten salt tanks are the silver pair at base of tower.

The 2003 Sargent & Lundy Report is one of the most detailed and thorough sources of data on solar thermal power publicly available, and is yet to be superseded.

FIGURE 3.2
Map of twelve proposed solar thermal sites



The Plan proposes 3,500 MW of CST capacity to be installed near each of the 12 towns shown in Figure 3.2. Each site is primarily made up of "Solar 220" generating units, which have a net output of 217 MW. Each unit consists of:

- A single central receiver power tower, a concrete tower 280 metres high, using molten salt as the working fluid (40% potassium nitrate, 60% sodium nitrate);
- 2.65 km^2 of mirror surface, consisting of 17,900 heliostats with an area of 148 m^2 each (just over 12x12 m);
- 13.9 km^2 of total land surface, in a circle with a 2.1 km radius. This is due to the spacing required between heliostats;
- A 245 MW (gross) supercritical reheat steam turbine, delivering 217 MW to the grid at full output, including an allowance for the air-cooling system;
- A two-tank molten salt storage system, able to store enough heat for 17 hours of full turbine output without sunlight; and
- Air-cooling system, using 15 fans of 9 m diameter each.

An allowance has been made for the first few power tower units at each site to be of smaller capacity, for example a progression of one 75 MW unit, two 100 MW units and three 150 MW units. This is explained in more detail in the following section. As a result, the exact specification for each site is for thirteen Solar 220 (217 MW) modules, and up to half a dozen smaller modules, for a total net output of just over 3,500 MW.

Torresol Gemasolar solar thermal power tower, Spain (Artist's impression) SOURCE: TORRESOL

3.1.1 Which CST power tower technologies?

Power towers with molten salt storage were proven during 3 years of commercial-scale operation of the Solar Two tower in the USA from 1996-1999[2]. Table 3.2 gives an overview of CST commercialisation history to date, including the latest project to be constructed — Torresol's 17 MW Gemasolar tower in Spain.

There are currently two companies offering commercial-scale concentrating solar power towers using directly heated molten salt for storage, namely:

- **Torresol Energy** — A joint venture between Spanish engineering firm SENER and the Abu Dhabi MASDAR corporation, Torresol is currently constructing the 17 MW Gemasolar Tower project with 15 hrs storage in Seville, Spain[5].
- **SolarReserve** — A US company, licensing Rocketdyne's molten salt tower technology, with active projects for 50 MW, 100 MW and 150 MW power towers.

TABLE 3.2
Molten Salt Power Tower History

Years	Project
1978-1985	Themis 2 MW prototype tower with molten salt storage operated in the Pyrenees, France (now being recommissioned)[3].
1996-1999	10 MW Solar Two tower operated with 3 hours of molten salt storage in California, backed by the US Department of Energy, Boeing, Bechtel and others.
2008-2010	Construction of Torresol's Gemasolar tower near Ecija, Spain — 17 MW with 15 hours of molten salt storage (~75% capacity factor)[5]
2010	Scheduled ground-breaking for SolarReserve's 50 MW power tower in Spain (~70% capacity factor)[4], and 100 MW plant in Nevada with 10 hours storage

In addition, there are several companies actively researching and developing capability in this storage technology, including:

- **Abengoa** — Spain's engineering and construction multinational (builder of the power towers PS10 and 20 in Seville, Spain).
- **Brightsource Energy** — an Israeli-American company with over 2,200 MW of tower projects announced in California. This includes six 200-220 MW towers. However they do not have storage and only operate during daylight hours[6].
- **eSolar** — backed by Google, eSolar has created innovative 1.14m^2 mirrors in close racking system, which are cheaper and quicker to construct and use less materials than conventional large heliostats.
- **Solar Millennium** — German technology provider for the Andasol 50 MW trough plants already in operation with 7.5 hours molten salt storage.

None of the latter four companies offers storage power tower products commercially as yet, however Torresol Energy and Solar Reserve do. These two companies are using the molten salt power tower technology developed by SunLab, a U.S. Department of Energy partnership between Sandia Laboratories (run by Lockheed Martin) and the National Renewable Energy Laboratories. The engineering designs and costings for 13.5, 50, 100, 200 and 220 MW power towers with molten salt storage developed by SunLab were reviewed and published by Sargent & Lundy, LLC, a power engineering consulting firm with over 100 years experience, in 2003[7]. This published data, along with information from **Torresol Energy** and **SolarReserve** projects in the construction and planning phases, has been used as the basis for designing ZCA2020's solar thermal energy system. The optimal plant capacity identified by SunLab of 220 MW with 17 hours storage forms the bulk of the installed CST capacity specified in the ZCA2020 Plan, once full industry scale-up has been achieved.

3.1.2 Technical specifications and description of CST plant design

TABLE 3.3
Basic CST plant components

	Component Technology
Mirrors	148 m2 Heliostats
Towers	Torresol / SolarReserve — concrete tower (similar to existing power station smokestacks)
Receivers	Torresol / SolarReserve — direct molten salt receiver, 550-650°C
Turbines	Supercritical Rankine steam cycle
Storage	Two-tank molten salt storage, 40% Potassium/60% Sodium Nitrate Salt
Working Fluid	40% Potassium/60% Sodium Nitrate Salt

Mirrors

A single Solar 220 unit will require just over 17,900 heliostat mirrors of 148 m^2 each.

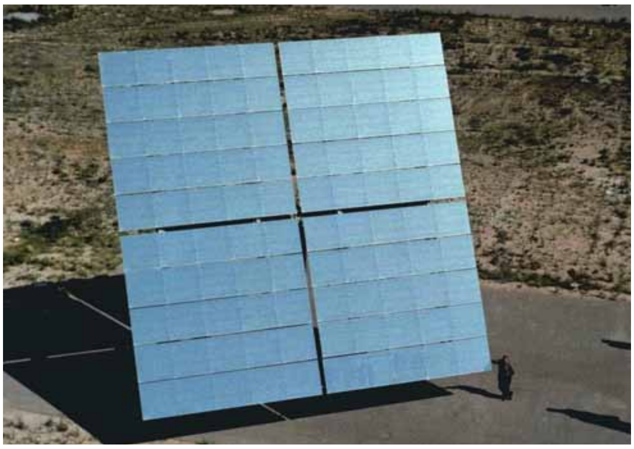
As mentioned in Section 2.5.2, the heliostat mirrors are slightly curved and track the sun through the course of the day, focusing solar radiation on the receiver. The conventional heliostat design includes large glass mirrors (50 - 150 m^2) with a supporting steel structure mounted on pedestals with concrete foundations in the ground. Larger heliostats of this design tend to be cheaper per unit area than smaller ones[9]. This is because there is a greater mirror surface area for each concrete foundation and pole — which require earth drilling and cranes for installation — along with the associated motors and tracking systems[10].

The 148m^2 Advanced Thermal Systems (ATS) heliostat, as shown in the photograph, is currently the largest heliostat specified by Sandia Laboratories[11]. Heliostats of similar size and design have been operated commercially in the Abengoa Solar PS-10 and PS-20 towers with a combined mirror field area of 200,000m^2 since 2006 and 2007 respectively. These heliostats were 121m^2 each. In addition, the ATS heliostat has been successfully operated at the US Department of Energy National Solar Thermal Test Facility in Albuquerque for over 20 years.

Over half the cost and most of the raw materials (concrete, steel, and glass) of a solar thermal power plant is in the heliostat field, therefore optimisation of this technology is important for improving efficiency and price. The heliostat field takes up the vast majority of land area in a solar thermal plant, and the size and spacing of heliostats are important factors in the land-use efficiency of the field.

eSolar option — While it has not been specified for the ZCA2020 plan, another innovative approach to heliostat fields is that invented by eSolar, a U.S. company backed by Google. The eSolar field uses very small mirrors — 1.14 m^2 in area. These are installed on a modular racking system which involves an interconnected steel frame mounted on concrete pedestals or ballasts which do not penetrate the ground. The modules are prevented from moving by the combined weight of the whole rack.

121 m^2 heliostat at Abengoa PS10 power tower, Spain[11]

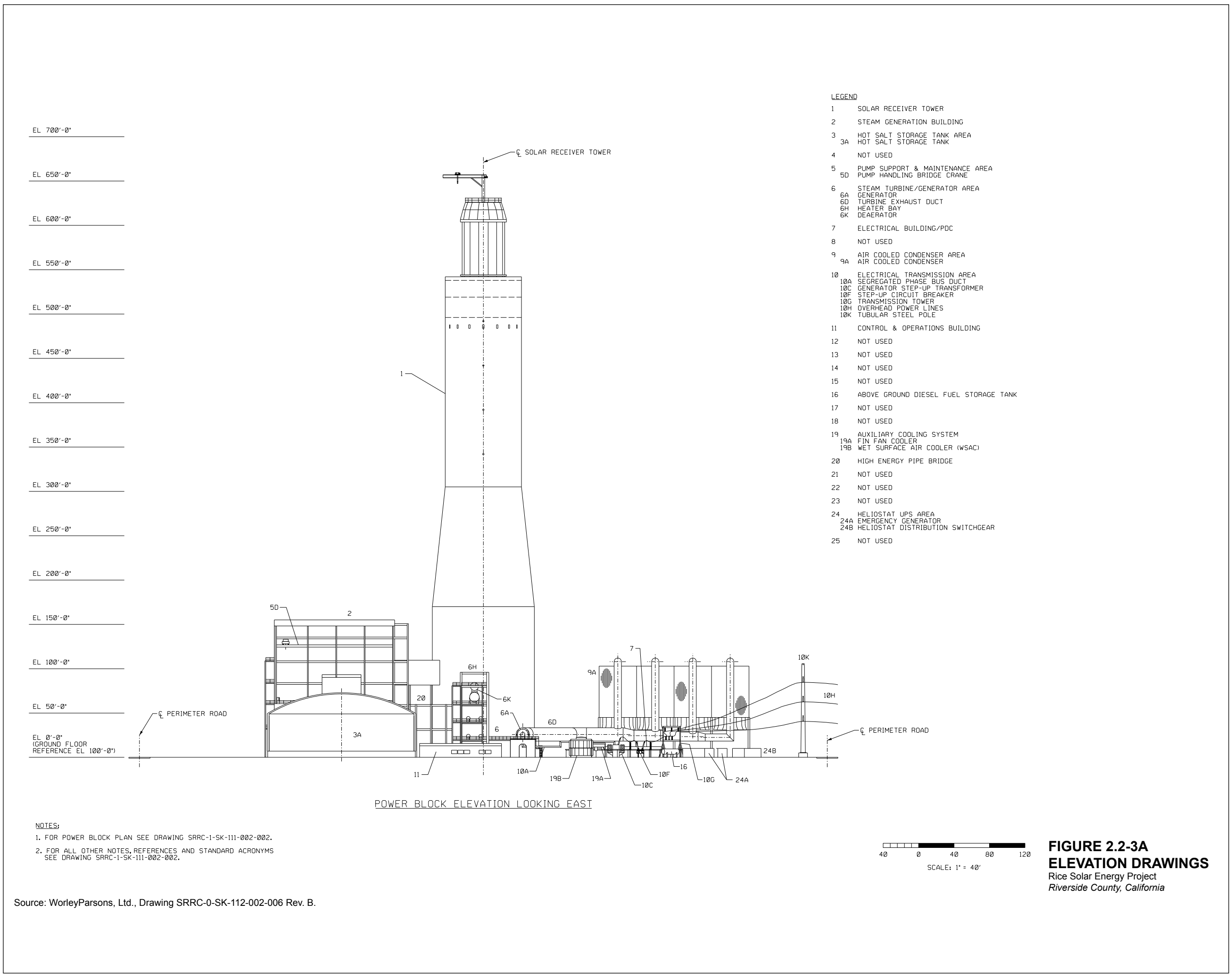


ATS148 Heliostat at Sandia Laboratories[12]

eSolar field in California[13]

Torresol Gemasolar construction site, June 2010, showing the hot and cold molten salt tanks, the tower, and the initial heliostats. Gemasolar is the third step in the scale-up to the Sandia/SunLab specified Solar 220 MW.

SOURCE: TORRESOL



Drawings of a SolarReserve Solar 150 MW tower to be installed in Rice County CA[8]

Workers at eSolar mirror field[13]

Molten salt storage tanks, Andasol 1, Spain

SOURCE: ACS COBRA

The result is advantageous for several reasons:

- less overshadowing by the smaller mirrors results in less land-use per unit area of mirror than larger heliostats
- small mirrors can be installed by hand by semi-skilled labourers, or electricians and other tradespeople on site, without the need for cranes and earth drills
- lower resource use (concrete, and steel) per m^2 of mirror
- lower overall cost
- very low wind loadings which leads to lower operational and ongoing costs due to less mirror damage and replacement, but also allows a lighter supporting structure for the mirror in the first instance[15].

Currently the eSolar technology is used without thermal storage for direct on-sun steam generation in small modules — 16 towers of 2.9 MW size each forming modules of 46 MW.

The benefits of eSolar technology were noted, and the authors considered the option of a hybrid incorporating eSolar (small form factor) mirror fields with Torresol/ SolarReserve towers and receivers (with molten salt as a working fluid). However, no work has yet been done looking at integrating these small form mirrors with the very large 2.1km radius fields required by a Solar 220 Power Tower. Therefore, consistent with a conservative approach, the Plan recommends the ATS heliostat technology.

"...when we were developing this design we looked at all the resources that go into making a solar plant and the cost of virtually all those commodities — steel, copper, aluminum — was going up. The only thing going down was the cost of processing power. So we consciously decided to trade a design that needed much more computational power in return for using less materials."

BILL GROSS CEO ESOLAR [15]

Storage tanks

The proven commercial storage currently available is the two-tank molten salt system used by the 50 MW Andasol 1 and 2 plants, and being constructed at the Torresol Gemasolar and SolarReserve projects. However, it is likely that single-tank systems, or Thermocline, will be proven commercially in the near future, as it has already been proven at demonstration scale by Sandia Laboratories. Torresol will have a commercial scale thermocline system setup at Valle I and II Solar plants in Spain that are currently under construction[18]. In a thermocline tank, the layering effect due to density differences keeps the hot salt floating on top of the cold salt — similar to how a home hot water system works. Cheap quartzite is used as a filler for thermal mass, displacing a significant amount of salt requirements with even more readily available materials. This system uses 32% of the salt of a regular two-tank molten salt system[19]. These fillers are very low cost, and reduce the requirements for more expensive processed nitrate solar salts.

For a standard salt requirement of 25 tonnes per MWh electrical[19], the tank for a Solar 220 module will need an operating capacity of 52 Megalitres (ML). This is comparable in size to tanks used for oil storage and petroleum refining. For example, the largest crude oil tank at Altona Refinery in Victoria, Australia, has an operational capacity of 80ML, with dimensions 24m high x 72m diameter[20].

Receivers

The receiver is positioned at the top of the concrete central receiver tower. It is a high-temperature heat exchanger, designed to absorb the reflected solar radiation and transfer it to the heat transfer fluid (in this case molten salt). In its simplest form, a receiver consists of many parallel tubes through which the molten salt flows while being heated by the focused solar radiation. This receiver technology was proven in the 1990s by the US Department of Energy's Solar Two program. It is recommended that the receivers be equivalent to those available and designed by Rocketdyne Laboratories, suppliers to SolarReserve or Spanish engineering firm SENER, supplier to Torresol Energy. They have the ability to operate at high temperatures whilst having low losses from re-radiation of heat. Use of direct heating of molten salt for both the working fluid and storage medium minimises losses compared to the extra piping and heat exchange mechanisms needed for using intermediate working fluids such as steam or oil for the receiver working fluid.

Other heat exchangers used in the power station (e.g. salt-to-steam) are simple shell and tube type designs that are standard for processing industries world-wide.

Working fluid and storage medium

As noted earlier in Section 2.5.2, systems using molten salt as a working fluid can achieve higher temperatures than those using water, or oil as a working fluid. For example, thermal oil as currently used in trough plants is limited to an operating temperature of approximately 400ºC[19]. The salt used is a mixture of 40% potassium nitrate and 60% sodium nitrate. When in its molten form, it is a clear liquid with a viscosity similar to water. Molten salt as a working fluid and storage medium has the benefits of low cost, material stability (it is not flammable), abundant raw material availability, material safety (it is already used as an agricultural fertiliser) and a product development roadmap[7]. This roadmap would include molten salt use in:

- the current two-tank system with a 565ºC hot tank.
- single tank thermocline systems with two-thirds quartzite filler and a temperature of 565ºC.
- two-tank systems with a 650ºC hot tank and oxygen blanket to prevent salt decomposition.
- single tank thermocline systems with two-thirds quartzite filler and a 650ºC temperature and oxygen blanket.

In addition, as the molten salt only has to travel up and down the tower, it experiences lower heat losses compared to the long pipes required to return the oil to the power block in a trough plant. As the molten salt serves as both the heat transfer fluid and storage medium, there is no need for a heat exchanger and thus, further losses before entering the storage tank are prevented.

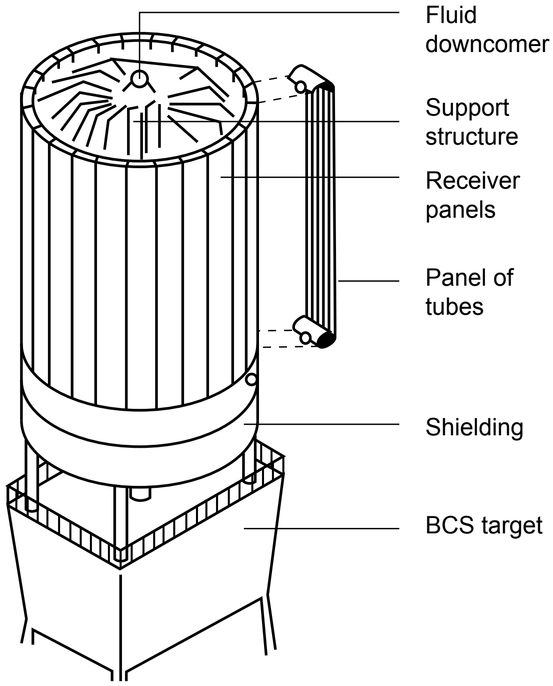
To generate steam, water is passed through a series of standard shell-and-tube heat exchangers to transfer heat from the salt to the steam. This heat exchange system is very flexible — changes in flowrate and energy transfer can be achieved in seconds to minutes, meaning that the power output can be ramped up and down quickly.

Turbines — High efficiency, Fast start

A standard supercritical double reheat Steam Turbine and Generator set is recommended, because these are currently being specified for the most efficient coal plants, are commercially available, and can achieve over 45% thermal to electrical efficiency[22] with temperatures above 565ºC. Both Siemens and General Electric have 10-15 years experience with supercritical steam turbines.

Solar thermal power plants have a fast response start-up time, and are well-suited to matching the variable output from wind power generation. Coal power plants have large boiler systems with high thermal inertia, complex coal-pulverising equipment on the front end and pollution control systems on the back, so they are unsuited to being ramped up and down. Siemens offers the SST-700 as part of their range of standard steam turbines, which is specifically adapted to use in solar thermal power plants. They are designed for rapid start-up and power cycling, making them more flexible than a standard coal turbine. There are already over 40 of these

Solar Two receiver[12]



A receiver showing the tubes through which the molten salt passes[16].

on order for solar thermal power stations around the world[23]. The SST-700 operates up to 585°C[24] which is the same temperatures as specified by the high-temperature molten salt power tower applications, and has separate reheat cycles for flexibility. It is optimised to maintain high efficiency across a range of power loadings[25]. If the turbine is shut down overnight, energy from the 290°C 'cold' salt is used to continue generating small amounts of steam, which is used to keep the turbine and seals warm, meaning that it is ready to start-up as soon as full steam generation recommences[26].

Cooling

Conventional air-cooling using fan banks is specified rather than water cooling, due to the limited supply of available water at many of the best solar sites, which are mostly located inland in low rainfall areas. Total plant water requirements are reduced to less than 12% of the requirements of a water-cooled plant[27]. This is inclusive of the small amount of water required for washing the heliostat mirrors and in the steam cycle makeup. The net annual performance loss due to slightly lowered efficiency and higher power use for the fans amounts to only 1.3% for power tower systems. Therefore the Solar 220 system, net rated at 220 MW, is de-rated to 217 MW. Air-cooling of thermal power cycles is a mature technology. The Kogan Creek black coal-fired 750 MW power station near Chinchilla, QLD uses air-cooling[28], with a bank of 48 fans each of 9 metres diameter. It is also specified in existing solar power tower projects, for example Brightsource's standard Luz Power Tower technology incorporates air-cooling[29], as do SolarReserve's projects at Tonopah, NV (Crescent Dune) and Rice, CA.

An even more attractive option may be the Heller system, pioneered in the 1950s, and the subject of recent studies from DLR and the Electric Power Research Institute. This is an 'indirect' dry cooling system, which could potentially be cheaper and have less parasitic energy losses than direct fan air-cooling[30].

Plant annual capacity factor

The solar thermal power towers specified in the Plan will be able to operate at 70-75% annual capacity factor, similar to conventional fossil fuel plants.

Storage of 17 hours provides enough energy to allow full power output 24 hours a day when fully charged. The annual capacity factor of a power plant is a measure of its power output over the course of a year. No power plant, whether renewable, fossil or nuclear, runs at full output 100% of the time, throughout an entire year. There is always downtime for maintenance and repair, and depending on the type of power plant, they may be throttled up and down at various times in response to changes in demand. Coal and nuclear plants are usually operated at constant or slowly varying load, though in low-demand periods may have to resort to the wasteful practice of blowing excess steam. Typically these plants can maintain a capacity factor of up to 80%, and 90% for plants of modern design. This means that, while a 1,000 MW power plant could produce 8,760,000 MWh/annum if operating at 100% output 24 hours a day 365 days a year, this is impossible, and in practice it actually produces, for example 80% of that figure — 7,008,000 MWh/annum. However it should be noted that in the Australian context, even so-called 'baseload' coal plants do not operate at such high capacity. In the state of New South Wales, there are 11,730 MW of coal-fired generation, which in 2008 generated 67,500 GWh net electricity[31]. This corresponds to a fleet capacity factor of around 66%, though some individual power stations are operating even lower, such as the 2,000 MW Liddell at 10,000GWh/yr, which is 57% capacity factor[32]. It can be seen therefore that individual power stations do not need to operate at full capacity 100% of the time to ensure reliable electricity supply. The NSW coal fleet is capable of operating at higher capacity if required, but the economics of importing cheap brown coal power from Victoria mean that they do not need to.

Gas plants are more flexible and many are designed as peaking plants that can adjust their output rapidly to meet grid demand at any given point in time or to respond to weather changes or emergencies. As such their capacity factor, which may be high technically, will often be much lower as their output is not called for long periods.

In the Australian context summer is currently the season of peak demand events and for this reason coal and gas generators do not schedule maintenance during this season. Conversely, a grid based on 100% renewable energy, with suitably managed end-use efficiency measures, will have its seasonal peak demand in winter. Therefore maintenance on solar thermal plants will be scheduled for the non-winter months.

The ability of solar thermal with storage to provide dispatchable power at high capacity factors is discussed and demonstrated below. For example, a "Solar 100" heliostat field and receiver as specified by the U.S. Department of Energy's Sandia Laboratories/Sargent & Lundy can collect enough energy to provide 2,066 MWh of electricity per day. If the plant did not have storage, then a 258 MW turbine could

TABLE 3.4
Mirror fields annual capacity

Mirror Field Size (m^2)	Total Electricity Per Day (MWh)	Storage Hours	Turbine Size (MW)	Hours of Operation Per Day	Annual Capacity Factor
1,366,100	2066	16	86	24	75-80%
1,366,100	2066	8	130	16	50-60%
1,366,100	2066	0	258	8	30%

be run for the average 8 hours a day that the sun is shining at full strength. However this electricity would not be available overnight, and the plant would have an average annual capacity factor of only around 30%. Alternatively, if the plant has storage, it can deliver the electricity over a longer time period throughout the day and into the night. The trade-off is a smaller turbine size, but the plant will still deliver the same total amount of electricity. This is summarised in Table 3.4.

The Solar 220 plants specified in the Plan have a "Solar Multiple" of 2.6 — this means that the mirror field and receiver at peak output produce 2.6 times more energy than is required by the turbine at full output. Therefore, during the day, for every unit of energy going to produce electricity directly at the turbine, 1.6 units of energy are sent into the storage tanks for use later at night.

3.1.3 Scaling up of CST

Solar 220 Power Tower plants will be able to produce electricity at a cost competitive with fossil fuels, after an initial period of industry scale-up from 2011-2015. This is dependent upon achieving a cumulative installed capacity of 8,700 MW by 2015.

As with most industrial technologies, larger installations of solar thermal plant become cheaper per MW due to the economies of scale of construction. For this reason, larger power plants generally deliver cheaper electricity than smaller ones. The Solar 220 described by SunLab/Sargent & Lundy is currently the maximum size specified for a single generating module. A 72% capacity factor Solar 220 with enough mirror area and salt storage for 17 hours has mirror field diameter of 4.2km. Beyond this distance, much of the light hitting the mirrors would not reach the central receiver, due to diffusion and reflection angles. Therefore, for larger installations than 220 MW, a number of modules are built side by side. This is common practice in existing power stations. For example, the Hazelwood brown coal fired power station in Victoria's Latrobe Valley has a total gross generating capacity of 1,680 MW, which is made up of eight 210 MW gross (193 MW net) turbines in parallel[33].

The 17 MW Gemasolar power tower being constructed in Spain is based on the Solar Tres design from Sandia Laboratories and will likely not be repeated at such a small scale. Existing projects in the pipeline from SolarReserve are of comparable size to a 75 MW plant if they ran at 75% capacity factor. Note that due to the different combinations of turbine sizes and storage with a given mirror field, the nameplate power rating (MW) is less useful for comparison than the annual power output (GWh/yr) or mirror field area. Indeed, in their initial applications to the Public Utilities Commission of Nevada, SolarReserve had not yet settled on a turbine size for their Crescent Dunes power tower in Tonopah, Nevada. Based on the size of mirror field and tower receiver they applied to build, SolarReserve could have used a turbine size ranging from 100-180 MW, depending on the final configuration and number of storage hours chosen. Since their original application they have settled on a 100 MW plant, meaning that it will have enough storage to run at a 50-55% annual capacity factor. It will have 10 hours storage[34], meaning it can run well into the evening peak with enough heat left over for fast start-up the next day, but will not dispatch electricity at times of lowest demand such as 3am in the morning. This ability to provide peak dispatchable power on-demand is of very high value to the electricity utility customer.

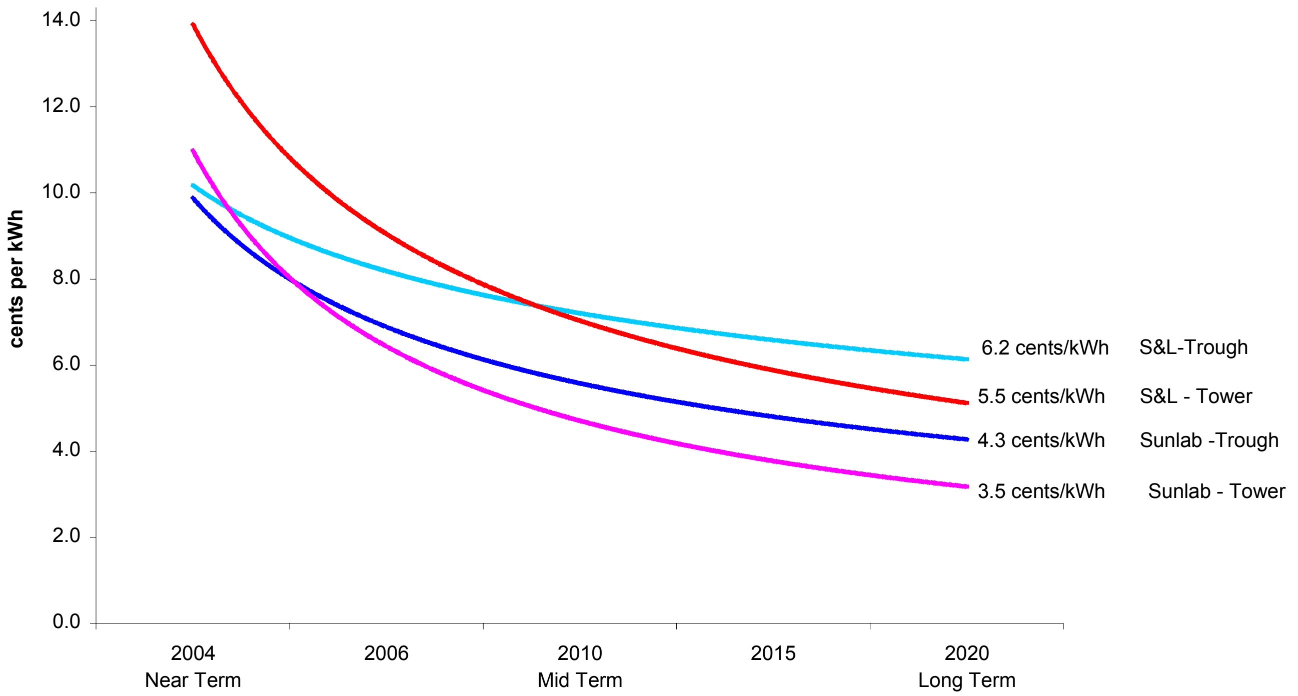
From the pipeline of actual projects seen in Table 3.5, it can be seen that the commercialisation is following the scale-up projected originally by Sargent & Lundy/SunLab, with Torresol's Gemasolar the equivalent of the Solar Tres, and SolarReserve's Alcazar equivalent to the scaled up Solar 50. If the Tonopah and Rice SolarReserve projects had 15 hours storage and 75% capacity factor, they could have a net output of 75 MW with their mirror field and thermal size – midway between Solar 50 and Solar 100. The approach of a solar thermal industry in Australia will be to progressively scale up the size of tower projects over time, until reaching the optimum size of 220 MW (with 2.1 km mirror field radius).

TABLE 3.5
Solar power plants annual power output. SOLARRESERVE ALCAZAR[35], SOLARRESERVE TONOPAH[36 37], SOLARRESERVE RICE[38]

Developer	Name	Net Power MWe	Storage hours	Capacity Factor	Mirror area m2	Annual power GWh /yr
SunLab	Solar Two	10	3	21%	80,000	18
SunLab	Solar Tres	13.65	16	78%	230,000	93
SunLab	Solar 50	50	16	75%	720,000	329
SunLab	Solar 100	100	13	73%	1,320,000	639
SunLab	Solar 200	200	13	74%	2,610,000	1,296
SunLab	Solar 220	220	17	72%	2,650,000	1,388
Actual Projects (— indicates details unknown at this time)						
Torresol	Gemasolar, Spain	17	15	67%	282,500	100
SolarReserve	Alcazar, Spain	50	—	70%	-	300
SolarReserve	Tonopah, NV	100	10	55%	1,100,000	480
SolarReserve	Rice, CA	150	—	34%	1,100,000	450

FIGURE 3.3

Cost Reduction Trajectory for Concentrating Solar Thermal[7]



	S&L High-Cost Bound	Cumulative Deployment 2002-2020	SunLab Low-Cost Bound	Cumulative Deployment 2002–2020
Troughs	6.2 cents/kWh	2.8 GWe	4.3 cents/kWh	4.9 GWe
Towers	5.5 cents/kWh	2.6 GWe	3.5 cents/kWh	8.7 GWe

As detailed by the Sargent & Lundy cost curve 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, 2003 dollars). This translates to about 5-6c/kWh in today's Australian dollars, which is competitive with the price of conventional coal power, in particular of recently built coal fired power stations which are still paying off their cost of capital. The weighted average wholesale electricity price in Australia ranged from 5.37-6.38 c/kWh from 2006-2008[39].

The red curve in Figure 3.3 represents the Sargent & Lundy cost projection for towers while the pink curve represents the SunLab projection. The 3.5-5.5 c/kWh is the Levelised Electricity Cost (LEC) — the wholesale price at which a power plant needs to sell its electricity to break even over the life of the plant. The main difference between the two projections is the cumulative installed capacity assumed by each. The key difference between these two figures was an estimated deployment of 2.6 GW in the case of Sargent and Lundy as compared to 8.7 GW in the case of Sunlab. In the original report, these were referenced to an installation timeline from 2004—2020, but the key factor in achieving the cost reductions was not the timeline but the total installed capacity. This projection of 8,700 MW is likely to be substantially exceeded. There is currently 14GW of planned CST projects in Spain[40] and 2,440 MW under advanced development and construction[41], 97 GW[42] of solar applications received by the U.S. Bureau of Land Management, and the ZCA2020 plan requires **47 GW** of CST deployment in Australia. Thus, the use of the lower levelised energy cost figure from Sunlab as the basis for costing the ZCA2020 Plan is conservative.

Sargent and Lundy noted the significant reductions in cost from the initial pilot projects of the 1990's to 2003 and foresaw continuing reductions based on:

- Industry learning from scaling up of plants to larger commercial size (49% of reductions)
- Economies of scale from large volume production of components (e.g. heliostats) due to high deployment rates (28%)
- Technological developments from R&D such as cheaper heliostat (mirror) modules and more efficient super-critical steam turbines (23%)

Since the Sargent and Lundy report in 2003 the development of the CST industry has been progressing, as has research and development. Companies, such as Torresol and SolarReserve, are commercialising industrial-scale power tower technology. Companies such as eSolar have commercialised cheap, high production volume, heliostat mirror designs — eSolar power tower stations are already in operation and producing electricity. An updated publication from Sargent and Lundy in 2005 confirmed that high-temperature super-critical steam turbines were now in operation.[43]

The first plants to be built will naturally be more expensive than those produced when more industry experience and manufacturing capability are able to drive costs of solar thermal down to AU5c/kWh, as projected by Sargent & Lundy. This has been taken into account when designing and costing the ZCA2020 CST system, with initial project costs referenced to the actual costs of SolarReserve's Tonopah Solar 100.

Therefore the first 8,700 MW of solar thermal capacity in the ZCA2020 plan will be made up of plants in the range of 50—150 MW and up to 200-220 MW. If distributed evenly across the 12 sites, this will result in 725 MW of initial capacity at each site. This could be made up, for example, of a single 75MW module, two 100 MW modules, and three 150 MW modules. After this point in time, it is proposed that all further CST installations be Solar 220. These later installations have been costed at the prices from SunLab/Sargent & Lundy.

Appendix 3 has more details of scaling up existing power towers to Solar 220 MW modules in Australia, including the overall costs of the first 8,700 MW of power towers based on existing project costs and SunLab mid-range cost estimates.

3.1.4 Choosing geographically diverse sites for CST

Geographical diversity is important in harnessing renewable energy resources, to take advantage of different weather conditions at different locations. CST is suited to large installations in areas of high solar incidence, and, as it can store energy, it is not affected as much by daily weather patterns to the same extent as other renewable energy sources.

As the locations with high solar incidence are typically inland, and a long 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, which has been taken into account in determining the number of solar sites and their locations. Large high-voltage direct-current transmission lines can deliver up to 4,000 MW, so the solar sites have been sized just below this. While the most ideal sites for solar would be around the centre of Australia, the transmission costs involved in connecting these to the main grid would be prohibitive. Therefore sites have been selected that are inland to take advantage of high insolation, but still in relative proximity to the main grids, in order to lower transmission costs.

Out of a number of potential high insolation sites, 12 have been chosen: Mildura (VIC), Moree (NSW), Bourke (NSW), Dubbo (NSW), Broken Hill (NSW) Port Augusta (SA), Carnarvon (WA), Kalgoorlie (WA), Longreach (QLD), Charleville (QLD), Roma (QLD) and Prairie (QLD). It is believed that these selections represent a good solution taking into consideration the factors discussed already. It is possible that with more in-depth multi-variable analysis of the trade-offs between solar resource, transmission costs, geographical diversity and other environmental factors, various different and potentially more optimised scenarios could be conceptualised, but the ZCA2020 team has made the best decision possible with available data and resources.

The proposed sites for the ZCA2020 CST plants were chosen based on three criteria:

- Relatively high solar incidence and daily sunlight hours to provide maximum 'charge up' time and solar intensity for the plants.
- Low winter to summer ratios i.e. avoiding areas which may enjoy excellent solar resource for one part of the year but which are dramatically less productive in another part of the year.
- Proximity to load centres. (See Part 5) The quality of a site in terms of the first two criteria needs to be reconciled with the need to connect the plants to existing population centres, which entails the construction of high voltage transmission infrastructure.

The economies of the townships adjacent to the sites chosen in accordance with the above criteria would benefit substantially from the project; first from the construction of the plants and then from ongoing operation and maintenance work.

3.1.5 Sizing Capacity for winter minimum

The impact of seasonal solar variations — such as lower solar incidence during winter in the southern part of the country, and lower solar incidence in northern Australia during summer monsoonal activity — can be mitigated by the choice of geographically diverse sites for CST plant locations. This reduces the need to oversize mirror fields and molten salt storage systems to accommodate these local regional variations. The annual average daily insolation collected across all of the 12 sites is 7.95 kWh/m^2/day, in terms of direct normal irradiation that is collected by the mirror fields. In the winter, the available aggregate energy drops by 24% below average across the twelve sites, while in the summer there is in fact more energy available than required.

Supplying a total of 325 TWh/yr of electricity to the Australian grid would require an average of 37 GW of installed turbine capacity, if demand were flat at all times. However, this does not take into account the extra turbine capacity required for peak output, during times of high demand such as winter evenings and summer afternoons. Extra CST capacity has been sized to meet peak demand.

As solar thermal draws its power from salt storage tanks independently of whether the sun is shining or not, it can produce power at full output at any time of the day. i.e., a Solar 220 can produce 217MW regardless of whether it has 15 hours of salt storage remaining, or only 2 hours. However, lower insolation in the winter lowers the total amount of energy that can be collected and stored per day.

Due to lower solar insolation and wind availability combined with space heating electricity requirements, winter will be the time when matching supply and demand is most crucial. Therefore, the solar thermal capacity has

FIGURE 3.4

Solar radiation collection at 12 proposed CST sites, kWh/m²/day (mirror field efficiency factored in). From JAC modelling (details in Part 4)

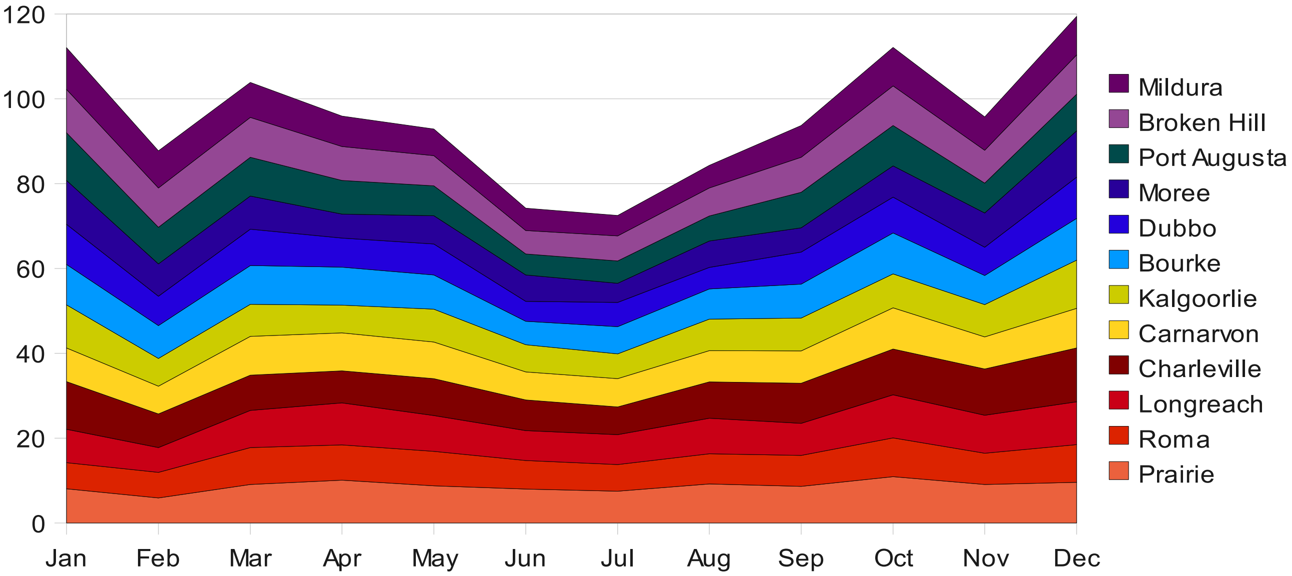


TABLE 3.6

Solar radiation collected by a solar thermal power tower, kWh/m²/day (mirror field efficiency factored in). From JAC modelling (details in Part 4)

Insolation collected by solar thermal power tower, kWh/m²/day															
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min	Min/ Avg
Carnarvon	7.9	6.5	9.1	9.0	8.7	6.6	6.6	7.4	7.6	9.7	7.6	9.4	9.7	6.5	82%
Charleville	11.2	7.9	8.4	7.5	8.7	7.2	6.5	8.5	9.4	10.8	10.9	12.7	12.7	6.5	82%
Roma	6.2	6.1	8.7	8.3	8.1	6.7	6.3	7.1	7.4	9.1	7.4	8.9	9.1	6.1	76%
Prairie	8.1	5.9	9.1	10.1	8.8	8.0	7.5	9.2	8.6	10.9	9.1	9.6	10.9	5.9	74%
Longreach	7.9	5.8	8.8	9.9	8.4	7.0	7.1	8.4	7.5	10.2	9.0	10.2	10.2	5.8	73%
Kalgoorlie	10.2	6.6	7.5	6.5	7.7	6.4	5.8	7.4	7.7	8.0	7.6	11.4	11.4	5.8	73%
Bourke	9.5	7.7	9.1	9.0	8.1	5.5	6.4	7.1	8.0	9.6	6.9	9.8	9.8	5.5	70%
Broken Hill	10.2	9.3	9.4	7.9	7.1	5.5	5.9	6.7	8.2	9.3	7.7	9.3	10.2	5.5	70%
Port Augusta	11.2	8.6	9.1	8.0	7.0	5.0	5.3	5.9	8.4	9.5	7.0	8.6	11.2	5.0	62%
Mildura	9.9	8.8	8.3	7.2	6.3	5.3	4.8	5.3	7.5	9.1	7.9	9.1	9.9	4.8	61%
Dubbo	9.5	6.9	8.6	6.9	7.4	4.7	5.7	5.1	7.6	8.5	6.7	9.7	9.7	4.7	59%
Moree	10.3	7.6	7.8	5.6	6.7	6.2	4.5	6.3	5.7	7.3	8.0	10.9	10.9	4.5	57%
Total	112	88	104	96	93	74	73	84	94	112	96	119	Overall annual average		
Average	9.3	7.3	8.7	8.0	7.7	6.2	6.0	7.0	7.8	9.3	8.0	9.9			
Overall winter minimum: 76% of average													7.95		

been sized to make sure that demand can be met in the middle of winter.

Through an iterative process of modeling output, 42.5 GW of solar thermal generating capacity has been sized for the ZCA2020 plan.

As outlined in Section 3.1.2 above, the first 8,700 MW of CST capacity will use plants with outputs in the range of 50-200 MW capacity. If divided equally between the 12 sites, this will result in 725 MW (gross) at each site, but this could be arranged differently depending on how the first stages of the roll-out proceeds. From then on, 13 Solar 220 modules will be rolled out per site, for a total generating capacity of 3,585 MW. When taking into account the average 1.3% parasitic energy for aircooling, this results in a net output of 3,535 MW per site.

The CST plants are designed for a 72% capacity factor with the equivalent additional mirror field to service this, but due to the extra installed capacity to meet peak demand periods, the plants combined will only have an effective annual average capacity factor of 52% to deliver the 195TWh/yr. They will still have a 90% availability factor. Thus, significant (73 TWh/yr) additional power generation would be available for at least eight months of the year. This cheaper energy would create opportunities for growth in innovative industries that can use seasonal energy surpluses.

This is similar to the situation in Australia today — there is a total 48.5 GW of (gross) power generation capacity on-grid, producing 227 TWh/yr (gross) which is an overall annual capacity factor of 55%[44]. Some baseload plants have higher capacity factors than this, but other peaking and intermediate plants operate at much lower capacity factors

Further optimisation to the system

All of the solar thermal power towers have been specified with 17 hours storage and solar multiple (oversized mirror field) of 2.6, for simplicity, and because these designs are already available from Sargent & Lundy. However, further optimisation could involve having some solar thermal plants with larger turbines and smaller storage, to act more like 'peaking' plants, which could reduce overall costs.

3.1.6 Installation timeline

Under the plan, the CST power stations are installed in two stages, to allow time to build up manufacturing capacity, establish sites and up-skill the workforce. It is proposed that the 2020 timeframe be achieved with a ramp-up of installation rates to 2015, then a constant rate of construction through to 2020.

Stage 1 (2010-2015): It is proposed that a target of 8,700 MW is set for installation by 2015, to be distributed across a number of the 12 sites depending on least cost opportunities for prioritising transmission infrastructure. An equal distribution across the 12 sites would end up with 725 MW at each one. This will involve fast tracking of site acquisition, and other planning measures in order to meet these tight timeframes. The plants will include 17 hours of storage — to provide 55 TWh/yr. The Torresol/SolarReserve towers and receivers would be built in module sizes such as 50, 75, 100, 150 and 200 MW. The first-of-a-kind plants will take 2.5 years to construct, as seen with SolarReserve's Rice and Tonopah projects[8].

Stage 2 (2015-2020): During stage 2, a constant rate of around 6,000 - 7,000MW/yr of construction will see the completion of the bulk of the required CST capacity, around 30 Solar 220 units per year, tailing off towards the end of the decade. It is expected that the construction time of a Solar 220 module will drop to 1.5 years, as the industry experience streamlines the rollout. The Andasol projects already completed in Spain took 1.5 years to construct[45].

3.1.7 Land Use for Solar Thermal Sites

One Solar 220 (217 MW net) module has a 280 metre high concrete tower surrounded by a field of mirrors covering a total land area of 13.9km^2. This is roughly in the shape of a circle with a diameter of 2.1km^2, with the tower offset towards the equator. This land is not completely covered by heliostats, there is a large allowance for spacing. There is in fact only 2.65km^2 of mirror surface for the Solar 220.

Each 3,500 MW site will require 230km^2 of land for the solar thermal fields, taking into account the effect of spacing between individual fields, each site could take up an area of land approximately **16km x 16km**. This would ideally be situated on areas of marginal farmland,

TABLE 3.7
Timeline of CST construction and electricity production

Year	Under Construction, gross (MW)	CST Operational net with Air Cooling (MW)	Capacity Factor	Annual Generation (TWh/yr)
2010		0	0	0
2011	1,000	0	72%	0
2012	3,500	0	72%	0
2013	5,750	0	72%	0
2014	8,060	1,974	72%	12
2015	9,680	4,935	72%	31
2016	10,120	11,410	72%	72
2017	10,120	18,141	72%	114
2018	9,240	24,655	72%	156
2019	8,580	33,992	65%	194
2020	2,640	37,032	60%	194
2021	0	42,461	52%	194

which already has low commercial or ecological value. The solar sites would not be located on good-quality farmland, National Parks or other areas of high value.

The total minimum land footprint of all twelve 3,500 MW sites will be approximately 2,760 km^2, equivalent to a block 53 km x 53 km — less than 5% of the area of Tasmania, or less than 0.04% of the area of Australia as a whole. All twelve sites would fit onto an area the size of Kangaroo Island and their total area would be considerably smaller than many of Australia's large cattle stations.

An approximate comparison of a proposed 3,500 MW site with existing coal fired power stations at Hazelwood in Victoria and Collie in Western Australia shows that the efficiency with which CST power stations utilise land to produce energy is well within an order of magnitude of both coal-fired cases. This comparison does not of course account for the fact that open cut coal mines will need to expand over time in order for their power stations to maintain constant energy output, whereas CST plants do not.

Figure 3.6 gives a relative comparison of the land area for the 19 solar modules at a 3,500 MW site. An initial site design was performed at Longreach to show a possible arrangement of the modules (shown in orange). The circles do not represent exclusive land use, just the region in which mirrors would be contained, with spacing in between. Alternative arrangements are also possible including greater distances between individual 220 MW plant modules to allow for other uses of the land. In Figure 3.7, the single 3,500 solar site is super-imposed over the land area used by Australia's largest cattle station in South Australia, known as Anna Creek, owned by S Kidman and Co. The total land area, shown in purple, of the three adjoining stations (Anna Creek, Peak, and Macumba) is 34,740 km^2. Also on the diagram is the total footprint of all 12 CST sites (green square) and the total footprint (tower base and foundation) of the 6,400 wind turbines (tiny blue square).

FIGURE 3.5
Heliostat field layout for Rice Solar Power Tower[26], showing increased spacing in outer field

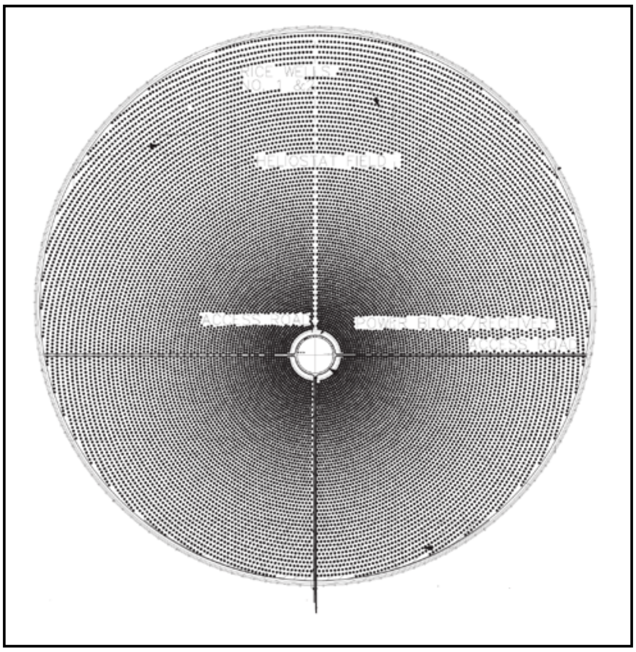


TABLE 3.8
Details of land requirements for ZCA2020 CST sites

Land Area Requirements	
Solar 220 land area	13.9 km^2
Diameter of circle	4.2 km
Net output	217 MWe
Land use efficiency	0.064 km^2/MWe
One 3,500 MW site	3,537 MWe
One x Solar 75	5.5km^2
Two x Solar 100	13.2km^2
Three x Solar 150	30.5km^2
Thirteen x Solar 220	180.7km^2
Total	230 km^2
Total Australia, 12 sites	2,760 km^2
Square analogy	53 km x 53 km
Circle analogy (if one large circle)	59 km diameter

TABLE 3.9
Land requirement comparison

Land Use Comparison	
Land use efficiency for a proposed CST site (22,700ha/3,500MW)	6.5 ha/MW
Land use efficiency for Hazelwood complex (3,554ha/1,540MWnet)[46]	2.3 ha/MW
Land use efficiency for Muja and Collie (~4,700ha/1,100MW)[47]	4.3 ha/MW
Area occupied by all twelve 3,500MW CST sites	2,760km^2
Total area of Kangaroo Island [48]	4,400km^2
Cattle station owned by Brunei, NT [49,50]	5,858km^2
Anna Creek and adjoining cattle stations, SA[51]	34,000km^2
Land at serious risk of being lost due to salinity in Australia (2000)[52]	57,000km^2
Area of Woomera Prohibited Area, SA[53]	127,000km^2
Total Australian Land Area[54]	7,688,503km^2

FIGURE 3.6
Possible layout of CST plant sitings near Longreach, Queensland.

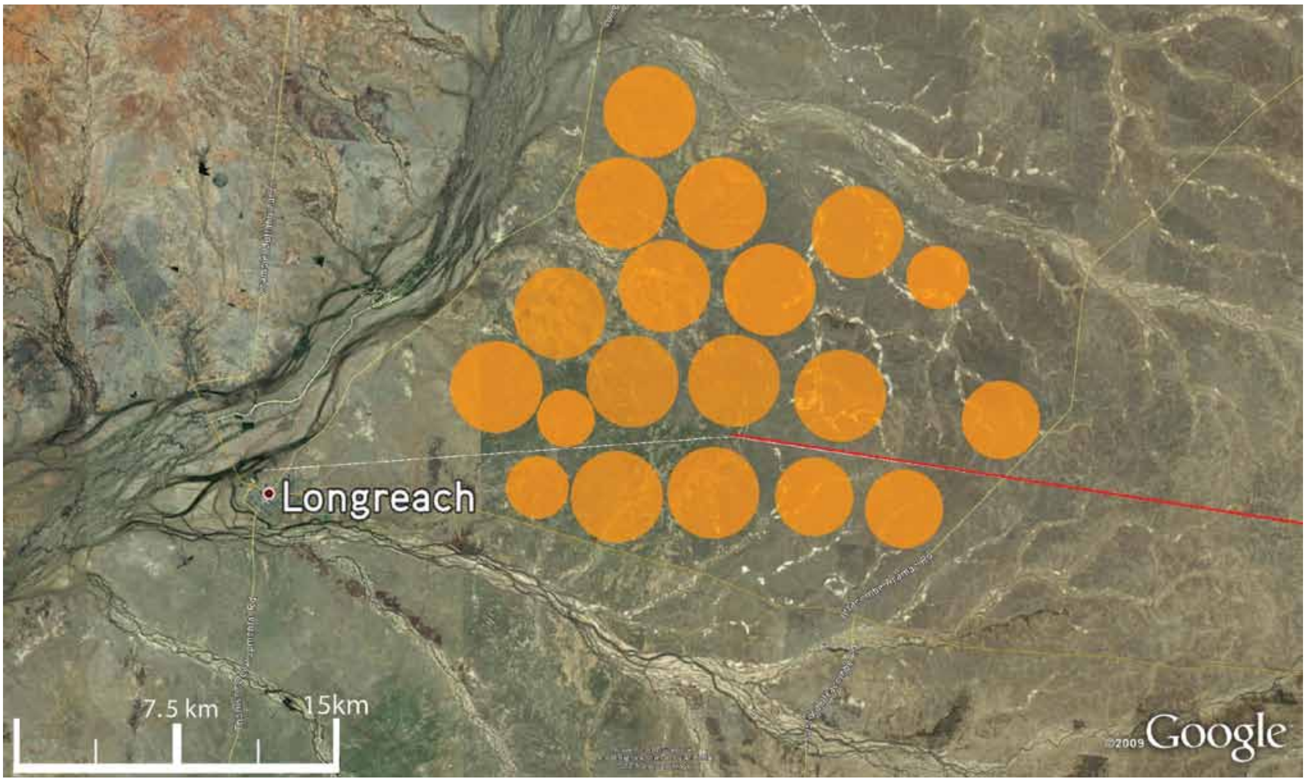
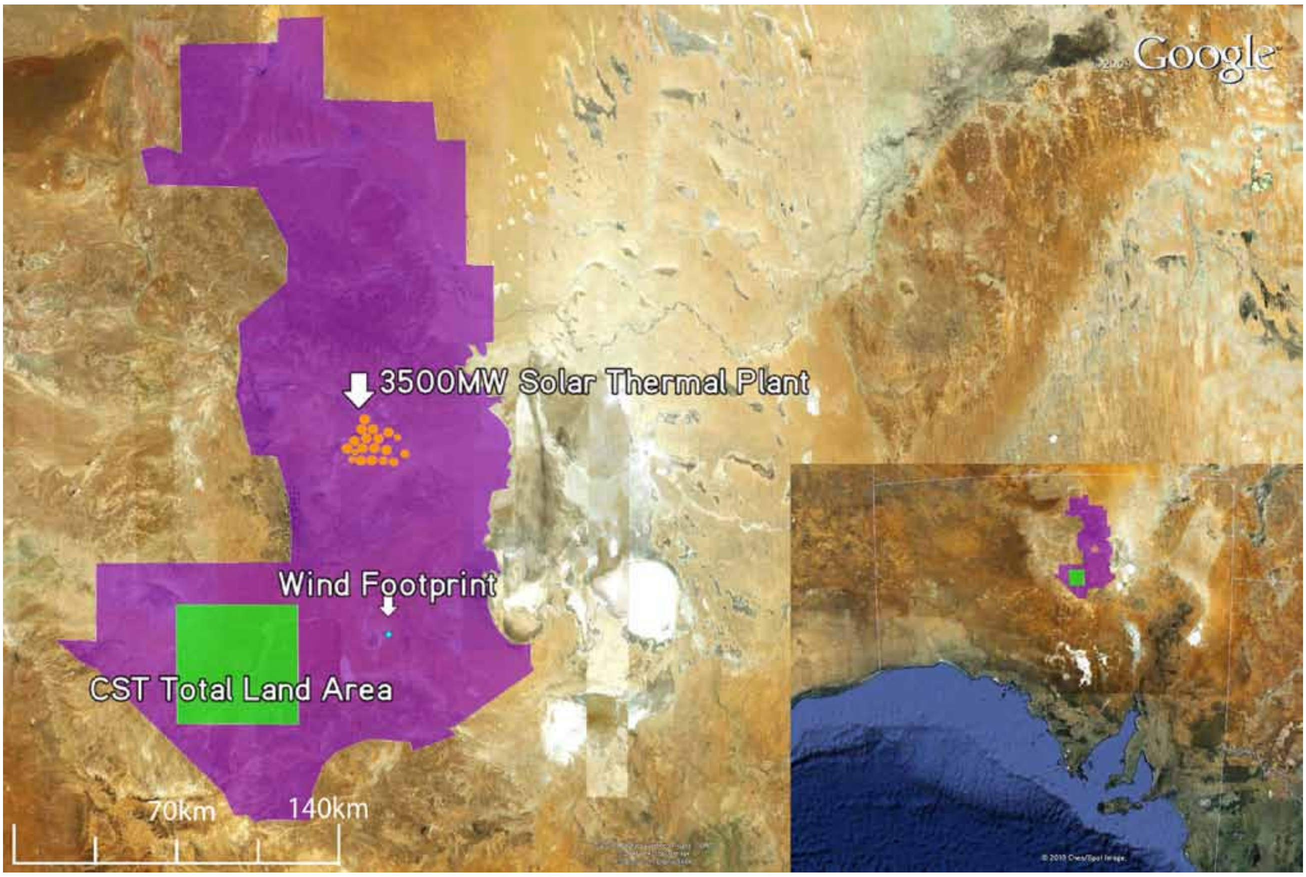


FIGURE 3.7
Comparison of ZCA2020 CST & Wind land area with Anna Creek Cattle Station, SA. Green box (CST Total Land Area) is the 2760 km² required for all 12 sites, which does not consider spacing in between the individual CST fields.



3.1.8 CST Water consumption

The solar thermal power plants proposed in the Plan will consume some water during their operation, although this will be kept to a minimal level through the use of air-cooling rather than water-cooling. Most of the water consumed will be for the occasional cleaning of the mirrors. The total water consumption of the 42,500MW grid of CST plants outlined in the Plan is 76 GL/yr. In contrast, the brown-coal generation of 7000 MW in the Latrobe Valley uses 106 GL/yr alone[55]. Clearly, Australia's total water consumption for power generation will reduce under the Plan.

Air-cooling to minimise water consumption

The steam Rankine cycle used by solar thermal power plants (as well as by coal and nuclear thermal power plants) requires cooling in order to function. Although many thermal power plants are water-cooled, technology is available to use air-cooling instead. For example, the 750 MW Kogan Creek coal-fired power station in Chinchilla, Queensland operates with air-cooling, using only 1,500 ML water/yr[56]. The solar thermal plants as outlined in the Plan will also use air-cooling, thereby reducing their potential water consumption significantly. Although a small amount of water is required for the occasional cleaning of the mirrors, this is carried out using efficient high-pressure jets and is still significantly less than the total water consumption of water-cooled coal-fired power plants.

As outlined in detailed studies from the U.S. Department of Energy on the consumption of water by solar thermal power plants, an air-cooled power tower uses 340 L/MWh, with only a 1.3% performance penalty on the power cycle[27]. In contrast the brown-coal power generation in Victoria's Latrobe Valley currently uses 2,100 L/MWh[57]. A single 217 MW solar thermal generating unit running at 60% capacity factor in 2020 will use 389 ML/yr, which, given the plant has an area of 13.9 km^2, corresponds to 0.28 ML/hectare/yr. In contrast, the national average irrigation rate is 4.2 ML/hectare/yr[58]. These figures are summarised in Table 3.10.

Water availability at each site

The water consumption of the CST plants outlined in the Plan only amounts to approximately 0.4% of Australia's total water consumption and only 5.7% of Australia's industrial water consumption (which includes the generation of electricity)[59]. Although this is not a significant amount, it is important to demonstrate the feasibility of each of the CST sites proposed in the Plan with regard to water availability (as they will each consume 6.3GL/yr) which is outlined in Table 3.11.

This investigation focuses on the availability and use of surface water. The average total surface water availability is the mean annual outflow of water. Not all surface water is available for use however, as some must be allocated to the environment. The sustainable yield of water is defined in the Australian Natural Resource Atlas as "the limit on potentially divertible water that will be allowed to be diverted from a resource after taking account of environmental values and making provision for environmental water needs"[60]. Although the "sustainable yield" of water is a more useful

TABLE 3.10
Water use for CST plants

Water Comparisons	
AIR-COOLED SOLAR THERMAL POWER TOWERS	
Water per power generated	341 Litres/MWh
Water requirements per land area	0.28 ML/hectare/yr
Water per ~3500MW CST site	6.3 GL/yr
Total Water All 12 Australian sites (~42,500MW)	**76 GL/yr**
LATROBE VALLEY BROWN COAL	
Water per power generated	2,100 Litres/MWh
Total water for Latrobe Valley Power (7,000MW)	**106 GL/yr**
FARMING IRRIGATION WATER USE	
National average irrigation application	4.2 ML/hectare
Total Irrigation usage (2004-05)	**10,085 GL/yr**

TABLE 3.11
Water use at Solar sites

Proposed Site	Surface Water Management Authority	Current Available Surface Water (GL/yr)	Current Water Usage (GL/yr)
Carnarvon	Gascoyne River	646[61]	<18[62]
Kalgoorlie	Salt Lake	No data	>11.4[63]
Port Augusta	Mambray Coast	38[64]	4[64]
Broken Hill	Darling River	2944[65]	299[66]
Mildura	Mid-Murray River	11,162[67]	4,045[67]
Bourke	Barwon-Darling Rivers	3,515[68]	230[68]
Dubbo	Macquarie-Castlereagh	1,567[69]	371[69]
Moree	Gwydir River	782[70]	321[70]
Roma	Condamine-Balonne	1,363[71]	722[71]
Charleville	Warrego River	423[72]	11[72]
Longreach	Cooper Creek	1,126[73]	6.9[73]
Prairie	Flinders River and Belyando/Suttor	6,718[74] [75]	86.3[74] [75]

figure, there is very little current data about sustainable yields in most of the proposed sites (see Appendix 4 for sustainable yields in some of the proposed sites). Hence, the average water use is also noted to indicate the potential availability of water. This figure must be considered cautiously however, as current water use is not necessarily at a sustainable level. These figures are summarised in Table 3.11.

3.1.9 CST cost

The total capital cost for the CST system described is $AU174 billion for on-grid CST (42,460 MW net) plus $AU15.1Bn for 4,475 MW of off-grid CST(see Appendices 2 and 3 for calculations).

This is divided into two phases. As described in Section 3.1.3 above, the first 8,700 MW to be built will be more expensive than end-of-cost-curve Solar 220 MW plants. As detailed in Appendix 3A:

- The first 1,000 MW is priced at similar price to SolarReserve's existing Crescent Dunes Tonopah project — $AU10.5 million per MW.
- The next 1,600 MW is priced slightly cheaper at $AU9.0 million per MW.
- The next 2,400 MW is priced at Sargent & Lundy' conservative mid-term estimate for the Solar 100 module which is $AU6.5 million per MW.
- The next 3,700 MW is priced at Sargent & Lundy Solar 200 module price of $AU5.3 million per MW

The total cost for the first 8,700 MW of CST with storage at 72% capacity factor is **$AU60 Billion**. Aircooling adjustment gives this a final net output of 8,587 MW. If installed across the 12 sites, this would be 725 MW (715 MW net aircooled)

Once 725 MW is installed at each site, the remaining capacity will be built as 220 (217 MW) modules — 13 modules per site. This will result in 3,585 MW of CST capacity per site, that is, **3,537 MW** minus aircooling.

Across all twelve sites, there will be a total of 43,020 MW CST, **42,460 MW** with aircooling.

The capital cost data for the Solar 220 plant (US$499.9Million) from the Sargent and Lundy report was used as the basis for costing the proposal. This figure was adjusted for inflation and converted to Australian dollars with an assumed foreign exchange rate of $AU1 = US$0.85. The extra capital cost of dry air-cooling has been calculated from data published by NREL separately. Dry air-cooling does cost slightly more in capital expenditure, and lowers the efficiency of the steam cycle, but delivers the benefit of requiring only 10-12% of the water of a conventionally wet-cooled plant.[78] The larger the air-cooling capacity, the better the efficiency of the steam cycle. Thus, there is a cost trade-off between the extra capital cost versus the returns made from higher efficiency. Kelly 2006[78] determined the optimum air-cooling size based on this trade-off, delivering the lowest Levelised Electricity Cost (LEC). The sizing of the air cooling was based on Kelly's model.

TABLE 3.12
CST installation cost table

Phase	Cost (2009 $AU)
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**

Based on these adjustments, the cost for one Solar 220 CST plant, (217 MW aircooled), is $AU739 Million. 156 Solar 220 (217 MW) modules, will cost **$AU115 Billion**.

4,475 MW of CST for off-grid installations have been costed at the same price as end-of-cost-curve Solar 220, $AU3.41 Million/MW **— $AU15.2Billion**.

Therefore the total cost to supply 60% of Australia's projected 2020 demand under the ZCA2020 plan would be **$AU190 Billion.**

See Appendices 2 and 3A for more details.

BrightSource Luz Solar Thermal Power Tower[77]

3.2 Wind: Cheap, Clean and Technologically Advanced

The ZCA2020 Plan proposes that 40% of Australia's total estimated electricity demand of 325 TWh per year be supplied by wind power. Therefore each year approximately 130 TWh will be generated by wind turbines. Assuming a 30% capacity factor this requires the construction of an additional 48,000 MW of wind turbines.

To supply this 130 TWh/yr the Plan proposes that approximately 6,400 7.5MW wind turbines be deployed at 23 geographically diverse sites across Australia at a total cost of $AU72 Billion.

Based on international studies, the Plan considers that 40% penetration from wind is achievable, with at least 15% of the aggregated rated capacity being considered 'firm' (guaranteed output available to the system at any time) and only 4% of power lost annually in avoiding an oversupply of power (curtailment) in high wind output conditions.

3.2.1 Wind Power Requirements

As presented in 'Designing the system', the Plan proposes that 40% of Australia's total estimated electricity demand of 325 TWh/yr be supplied by wind, which equates to 130 TWh/yr.

Due to the intermittent nature of wind resource, wind turbines do not operate at full capacity all of the time. The percentage of actual wind energy that is generated at a particular wind farm is called the capacity factor. This is measured by taking the actual annual energy generation and dividing it by the total amount of energy that would be generated if the turbine was always operating at full rated output.

In Australia capacity factors for operating wind farms are in the range of 30-35%, however higher capacity factors require sites with consistently high wind speeds and good topography, which is unlikely to be the norm for most future wind farm locations. In Victoria, the average capacity factor of currently operating wind farms is 30%.[79]

Given the large number of sites required for the Plan, an average capacity factor of 30% is expected.This means that a 7.5 MW wind turbine will produce an annual average output equivalent to running continuously at 2.25 MW all year round.

To supply 130 TWh/yr at 30% capacity factor, 50,000 MW of combined rated capacity is required. There is already an installed capacity of 1700 MW of wind turbines in Australia, with a further 300 MW of wind farm projects expected to be completed by the start of 2011 [80], so the Plan proposes to build an additional 48,000 MW of wind.

Which Wind Turbines?

The Plan proposes that high quality, technologically advanced 7.5 MW onshore wind turbines be utilised, as these are the largest commercially available turbines at present and their size enables the extraction of more energy from a given site by tapping into stronger and more consistent wind resource at greater heights. It is better to use fewer large turbines than many smaller turbines as there are less moving parts to maintain (and periodically replace)[82]. Smaller 2-3 MW turbines are currently used in Australia and in early years, this may continue. However as shown in Part 2.5.4, the global trend in wind has been towards larger turbines.

The Enercon E126 land-based wind turbine is currently the only commercial 7.5MW turbine, upgraded from 6MW previously[86]. However, given global growth trends, it is expected that 7.5 MW (and larger) turbines will be rolled out by all the major manufacturers. The Enercon E126 has a hub height of 138 metres, and a blade diameter of 127 metres.[83]

These turbines could be sourced from European manufacturers such as Enercon, Vestas, Nordic Wind, Repower, or Areva Multibrid, or their Chinese competitors. Another option is for a publicly owned company to produce proprietary technology under license and direction from one or more of these manufacturers. Incentives could be made available to locate these factories in coal communities.

Enercon E-126 turbines in Belgium. Source: Steenki[88]

Wind turbine blades transported by train[87]

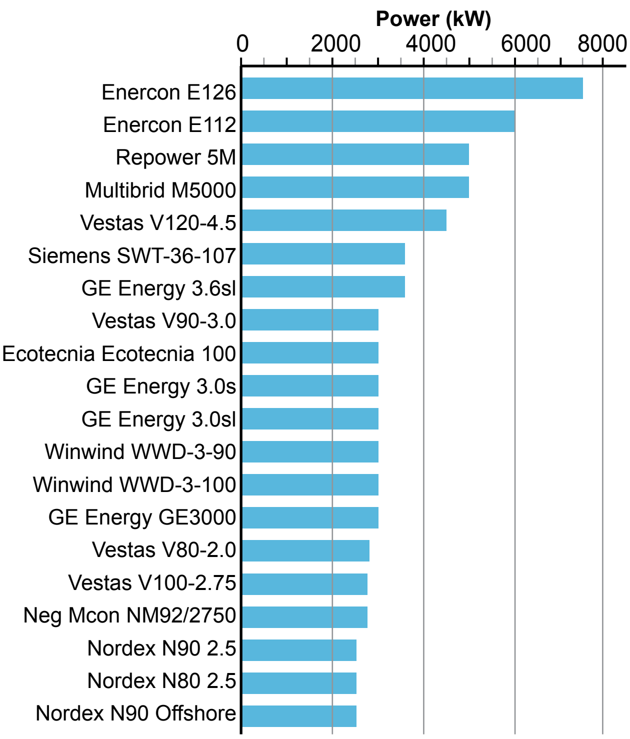
Larger turbines are currently being commercialised, for instance UK based Clipper Wind is developing a 10 MW offshore wind turbine[84].

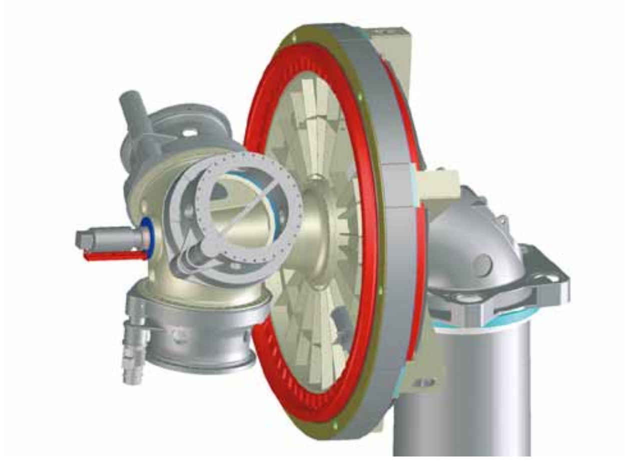
The Enercon E126 has other benefits including:

- Direct-drive turbines with gearless operation that require very little maintenance
- Improved blade design which enables more power generation per swept area, and the harvesting of a greater range of wind speeds

Transportation of the turbines represents a significant cost, which rises as the turbines become larger. In spite of its larger size, the Enercon E126 is easier to transport than its predecessor, the E112. This is due to the blades being manufactured in two sections, allowing for standard transportation, which could predominantly occur on existing rail networks.[87]

FIGURE 3.8
Wind turbine model capacity (kW)[85]





Direct Drive of Enercon Wind Turbine[90]

3.2.2 Siting for Geographical Diversity and Winter Peak Demand

The Plan proposes 23 sites for wind power — each consisting of either ~2,000 or ~3,000 MW of turbines. This is of comparable size to other large wind projects such as the Markbygden wind farm in Sweden, planned to have a capacity of 4,000MW and up to 1,100 turbines. Enercon is the supplier for this project.

Under The Plan the grid is strengthened (see 'Grid and load management — creation of a national grid') and the wind farms are located across the length and breadth of the country. 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.

Figure 3.9 shows the proposed wind farm locations selected for the Plan. It should be noted that the locations are indicative only and further site design, environmental studies, and community consultation would be required to determine the precise location of wind turbines. Moreover the turbines at each site do not need to be grouped in one single location. For example the 3,000 MW of wind capacity at Ceduna could be made up of ten 300 MW wind farms located in the general region of Ceduna, all linking back to the same single high-voltage AC transmission line hub.

Estimating reliable wind capacity. The Plan is based on a minimum reliable instantaneous output of 7,500 MW from the wind generators. This is 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.

A grid planning study by South Australian utility company ETSA, modelled output from sites without geographical diversity. The report found that the worst case reliable wind contribution for South Australia in isolation was

8% of aggregate turbine rated capacity for grid planning purposes.[91] Therefore the 15% estimate is twice that of the ETSA South Australian minimum. This figure is seen as a conservative estimate of reliable wind contribution, given the geographical and meteorological diversity of proposed wind farm locations under the Plan.

This estimate is consistent with a recently published study for the US National Renewable Energy Laboratory. This study modelled the amount of firm power that can be relied upon at any given time for different scenarios of wind farms located in the Eastern States of America, generating 20% of America's power. This estimated a minimum reliable instantaneous wind capacity for onshore wind generators of between 14 and 27%, depending on the transmission model used. For an upgraded and interconnected grid using high voltage DC and AC lines similar to those in the Plan, capacity values of up to 27% were achieved. However there are significant differences between the Australian and American electricity grid which limits the possibility of a direct comparison [92]. In the absence of a similarly detailed study for Australia, the authors believe, based on the NREL study and the level of diversity and grid interconnection proposed for the Plan, that a higher percentage could be 'firm'. However the conservative value of 15% is assumed.

If this instantaneous grid-wide minimum is assumed across the whole year, it can be considered a baseload equivalent of 7,500 MW, equating to 67.5 TWh. Given that each individual wind farm is projected to operate at 30% capacity factor, this means our baseload equivalent is approximately half the expected average annual ouput of the whole system.

If a period of system-wide low wind supply coincides with high total demand (such as the winter peak), then the system can draw upon the standby solar thermal energy, and on the very rare occasions when solar thermal storage is also low, the biomass boilers will be used to supplement dispatchable solar energy from the molten salt tanks.

Accommodating the winter peak. Under the Plan, the seasonal peak demand is expected to occur in winter due to the conversion from gas to renewable electricity for space and water heating in winter, and reduced air conditioning use in summer. As outlined in Section 3.1 Solar incidence in Australia is at a minimum in winter, and specifically in June.

Along the southern and western regions of Australia, the Roaring Forties westerly wind patterns generate the strongest wind speeds in Spring and the lowest wind speeds in Autumn [93, 94]. This differs from other wind patterns, which rely on land/ocean warming and cooling, where minimum wind speeds are in winter.

FIGURE 3.9
ZCA2020 Plan Wind Energy Sites

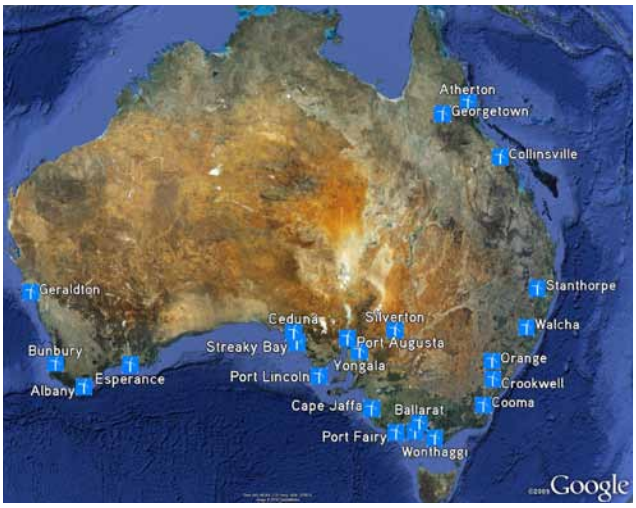


Figure 3.10 illustrates estimated power output from wind farms located in South Australia, New South Wales, and Victoria, using Bureau of Meteorology wind data and a Vestas V80 2MW Turbine power curve. This study was undertaken by the CSIRO in 2003. It shows the minimum wind output occurring in April/May.

To offset the reduced solar incidence in winter, some attempt was made to locate wind farms in southern regions and other areas with high average winter wind resource and low seasonal variation. Additionally sites were chosen to maximise geographical diversity, in order to minimise the effect of local wind patterns and weather events.

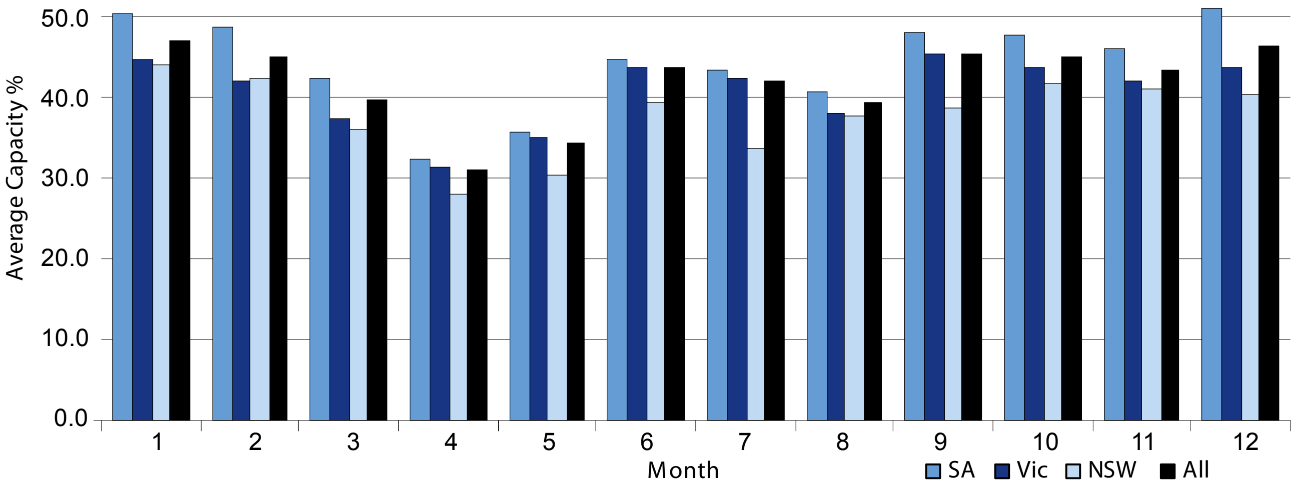
Sites with high wind resource have less variation at high wind speeds and reduce the intermittent nature of wind[97]. Therefore sites were chosen to have a minimum average annual wind speed of 7 m/s (at 80m hub height) from the Australian Renewable Energy Atlas.

The final location of sites will need to take into account site suitability, focusing on accessibility (for heavy machinery) in rural areas with non-critical farm land, away from forests

TABLE 3.13
Wind sites table

WA	Capacity (MW)	SA	Capacity (MW)	VIC	Capacity (MW)	NSW	Capacity (MW)	QLD	Capacity (MW)
Albany	2,000	Ceduna	3,000	Port Fairy	2,000	Crookwell	2,000	Stanthorpe	2,000
Esperance	2,000	Yongala	2,000	Ballarat	2,000	Orange	2,000	Atherton	2,000
Geraldton	2,000	Port Lincoln	2,000	Mt Gellibrand	2,000	Walcha	2,000	Collinsville	2,000
Bunbury	2,000	Cape Jaffa	2,000	Wonthaggi	2,000	Cooma	2,000	Georgetown	2,000
		Streaky Bay	3,000			Silverton	2,000		
		Port Augusta	2,000						

FIGURE 3.10
Estimated Annual Wind Power Variation Across South Eastern Australia[95]



and sensitive environments, and with reasonable proximity to urban areas. Once installed, wind turbines have a low impact on the land, allowing farmers to continue using the land for grazing and crops.

3.2.3 Installation timeline and resource requirements

The Plan proposes that 1,250 MW of wind turbine construction begins in 2011, and that the rate of turbine installation increases between 2011 and 2013 until the rate reaches 6,000 MW per year. From 2014 to 2020, 6,000 MW of wind capacity (800 x 7.5 MW turbines) should be installed per year for a total installed capacity of 48,000 MW by 2020.

This allows for an increase of domestic manufacturing capacity for turbines, and for establishing the sites. This approach is consistent with the experience internationally in Spain and Texas. In Spain, for instance, the rate of annual wind installation rose from 1,500 MW in one year (2006) to 3,000 MW (2007) [98]. In Texas, 1,618 MW was installed in 2007 and 2,671 MW in 2008 - an annual increase of 65 per cent [99, 100]. This was all achieved using smaller turbines and with less global experience in installing wind power than we have today.

The scheduled construction will occur in batches, with new installations beginning every 6 months. Each batch will be completed in approximately a year. For example in January 2011, 500 MW of wind power will begin installation, finishing by January 2012, and 750 MW of projects will begin in July 2011, finishing by July 2012.

It should be noted that there are currently just over 11 GW of wind farm projects in the pipeline for Australia [80]. We have not directly incorporated these projects into our timeline as most of the projects have not left the planning stage. If they do reach construction stage they will help to reduce the overall requirements of The Plan. However it is important that they are installed at a pace which meets the requirements of the projected timeline. This will require assistance and support to fast-track all the projects.

3.2.4 Managing wind variability by means of integration with CST with storage

Wind integrates more efficiently with a predominantly CST plus storage electricity system than it does with a coal-dominated system. This is because conventional coal plants have little or no large-scale energy storage. Instead they must cope with large, difficult-to-manage boilers. Therefore conventional coal power plants cannot efficiently dispatch energy at relatively short notice to fill in troughs in the wind energy delivery. Currently gas peaking plants would play this role in the absence of dispatchable stored CST electricity.

CST with storage, in combination with wind, creates an effective synergy. The dispatchable stored solar energy ensures energy security, by providing effective backup for the wind turbine fleet. At the same time, wind generated electricity that is supplied during the day displaces daytime electricity production, which would otherwise need to come from the solar thermal generators. Thus the wind energy allows a build-up of stored energy via the molten salt tanks.

On these occasions, instead of putting only 60% of the harvested solar resource into storage (as is specified in the average design provisions) a higher percentage (at times up to 100%) would go into storage. This would extend the reserves available for operation at night, and when there is no sun, beyond the plant's specified 60%.

During periods of no solar input (at night or during cloudy periods), wind-generated-electricity can be used in preference to accessing thermal energy stored in the molten salt tanks, thus maximising the available backup store of energy.

3.2.5 Wind surpluses at high penetration levels

Based on international studies the Plan expects that 40% penetration of wind is possible, with a maximum of 4% of wind power lost to oversupply.

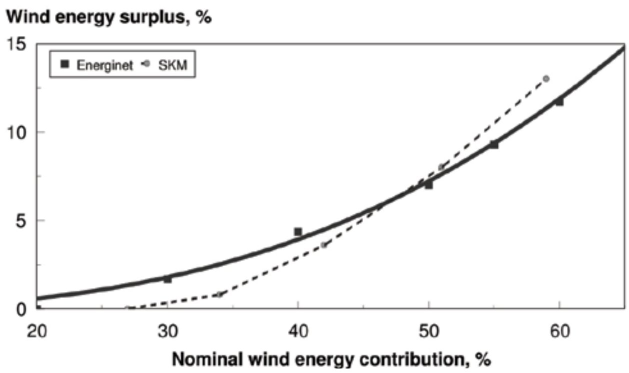
The issue of wind variability management is also discussed in 2.5.4 Wind Power, and the problem of curtailment is illustrated. For larger installed capacities of wind power, occasions are possible when high wind events push the combined output of the wind farms above what the electricity system can cope with. This is even more of a problem during low demand periods. At these times curtailment action is required to reduce the amount of power generated by each turbine. Curtailment is the technical term used to describe the process of remotely instructing the required number of wind turbines (at one or more windfarms) to reduce their output (by physically rotating them to face out of the wind). In these cases the wind turbines are stopped from producing as much power as technically possible, and power is un-utilised (or lost).

Work by British Energy Consultant David Milborrow[101] combines information from engineering consultancy Sinclair Knight Merz and the Danish grid operator Energinet DK in a report on managing wind variability. This study indicates that, at 40% annual production from wind, only 4% of wind power would be lost due to curtailment.

The percentage of wind power lost to curtailment increases with higher grid penetration. This is an important consideration when calculating the optimum level of grid penetration by wind for a given nation or region. The proposed Australian grid would have far greater geographical and meteorological diversity than, for instance, the Danish grid — which is one fifth the size of Victoria. Yet Denmark has a target of 50% annual electricity production from wind by 2025 [102]. This diversity in Australia ensures that the overall wind system will have a steadier output, meaning that Australia could potentially have a higher percentage of its power coming from wind than a country like Denmark, whilst at the same time requiring less curtailment. Some curtailment may occur where regional power lines are at capacity, but is expected to occur only rarely across the whole system.

If we plan for the conservative figure of 4% power loss due to curtailment, the absolute contribution from wind is factored to reduce by not more than ~5 TWh/annum. The CST system is over-specified to allow for this. This allowance is conservative, because curtailment is likely to occur mostly in the summer months, since this would be the period of highest supply (due to a relative abundance of spare capacity from the solar resource compared with the winter months) and of lowest demand (because cooling in summer uses less energy than electric 'heat pump' heating during the winter).

FIGURE 3.11
Estimates of surplus wind energy for contributions up to 60% [101] of total demand)



3.2.6 Cost of wind turbines

The total investment for the 48,000 MW of new wind capacity is estimated at $AU72 Billion. This takes into account cost reductions that would occur with a large ramp-up of the wind industry as proposed by the Plan.

Assessment of the forecast and real capital costs of seven large new and recently completed wind farms in Australia gives the current average Australian capital cost for wind farms as $AU2.5 Million/MW.

This cost is relatively high compared to other regions such as Europe and America. Australia has seen a much slower growth in wind power than other countries and as a consequence there are no turbine manufacturers in Australia, with most turbine components needing to be shipped from overseas. In addition, the current world price of wind turbines is higher than in previous years, despite the long term trend of price reductions with increases in turbine sizes and improvements in technology. This price increase was caused by a slower than expected expansion of the wind industry in 2001-2004, followed by a sharp increase in the global market for wind turbines (30-40% annually) until around mid 2008. This was combined with an increase in raw material prices and later the Global Financial Crisis[103].

The ZCA2020 Plan involves a large scale roll out of wind turbines, that will require a ramp up in production rate, which will help to reduce wind farm capital costs, and bring Australian costs into line with the world (European) markets.

A 2009 report by the European Wind Energy Association (EWEA) on the Economics of Wind Energy, included a long term projection of wind capital costs, taking into account the effect of current demand and supply on the costs of wind turbines[103]. Based on this study the 2010 forecast capital cost of onshore wind is approximately €1,200/kW (2006 prices) or $AU2,200/kW (current prices). By 2015 the European capital cost of onshore wind is estimated to be around €900/kW (2006 prices) (or $AU1,650 in current prices) and this is forecast to drop further to €826/kW (2006 prices) by 2020.

The European Wind Energy Association research however did not take into account the expected impact that China's wind turbines will have on the global market in the near future.

The Chinese government has recently announced plans to build seven wind power bases, each with a minimum capacity of 10,000 MW, by 2020. Laws in China require that new wind farms must have at least 70% of all wind power equipment manufactured in China. This is generating a massive boom in the Chinese wind turbine industry and some Chinese manufacturers are already selling their products internationally. Current industry estimates suggest that wind turbines manufactured in China cost 20-25% less than the Australian market price.

The first Chinese wind base, dubbed the "Three Gorges Wind" project, is the 20,000 MW wind farm to be constructed in Jiuquan city in the Gansu Province. Construction of this wind farm is now under way at an estimated capital cost of USD 17.6 Billion (120 Billion Yuan). This equates to roughly $AU 1 million/MW, less than half the current capital cost for wind farms in Australia [104].

Due to the planned nature of the ZCA2020 program, turbine suppliers would be given significant forward notice of orders for the Australian market. This significantly reduces the risk of capacity constraints, as the turbine suppliers are able to address their supply chain, and ensure that components and materials are available to meet the significant upswing in demand. Implementation of the plan would involve forward contracting for the supply of turbines in order to guarantee this.

Setting up a local wind turbine manufacturing industry would also assist in supplying some or all of the necessary components.

For the aforementioned reasons and the large scale of the Plan it is expected that Australian wind turbine costs in 2011 will reduce to the current European costs of $AU2.2 Million/MW.

For the first 5 years of the Plan, the capital costs of wind turbines are expected to transition from the current European costs to the forecast 2015 European amount — $AU1.65 Million/MW. This is because it will require some time before manufacturers can ramp up production and for orders to be fulfilled in Australia.

It is expected that the final 5 years of the plan will benefit from the influence of Chinese manufacturers on the market, either indirectly or directly (by purchasing from a Chinese wind manufacturer). Accounting for differing labour costs and adopting the 25% rule of thumb, capital costs are expected to drop to approximately $AU1.25 Million/MW in Australia.

The capital cost projections for the life of the project are summarised in Table 3.14. As explained in Section 3.2.3, installations begin on a six monthly time frame and take a year to complete. Note that the costs of transmission infrastructure is not included in these figures as it is presented in Part 5.

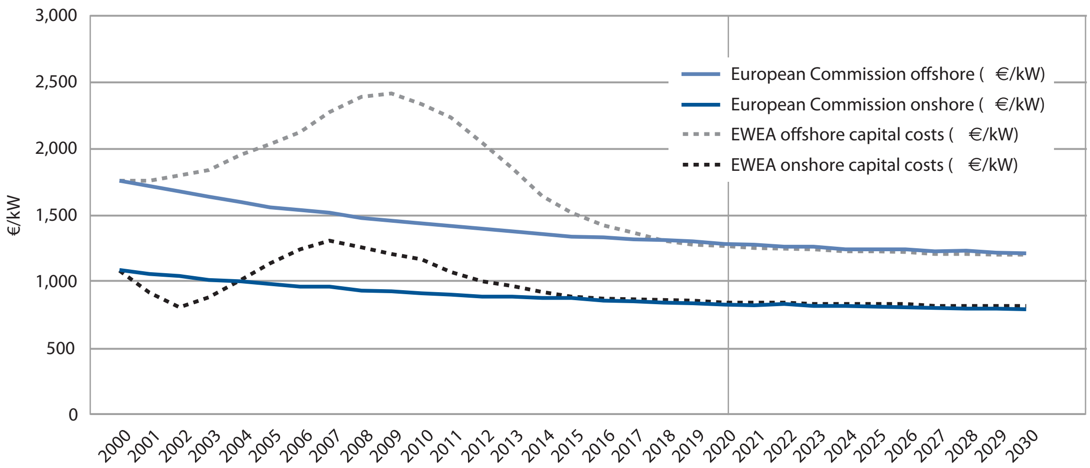
Thus, the **total cost** of 48,000 MW of wind power installed over 10 years to deliver 40% of Australia's electricity requirement in 2020 under the ZCA2020 plan is approximately **$AU72 Billion.**

See Appendix 3B for further details of wind power costs.

TABLE 3.14
ZCA2020 Projected Annual Capital Costs of Wind ($AU 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**

FIGURE 3.12
EWEA Onshore Costs Projection (€2006 prices)[103]



3.3 Modelling of the ZCA2020 Renewable Electricity Grid

Detailed modelling of electricity supply and demand on a half-hourly timescale shows that the specified 42.5 GW of CST and 50 GW of wind can meet 98% of electricity demand. This is outlined in further detail in Part 4. Initial sizing of the system was done based on monthly average energy availability data. At a later stage, more detailed modelling was used to test the system's performance. As expected, there are some short periods in which the wind and solar thermal with storage alone are unable to meet demand, so either backup is required, or extra solar or wind capacity would be needed. The tradeoff between backup sizing vs overdesign sizing has not been optimised, but the combination chosen has shown to be sufficient to meet 100% reliable demand.

Enercon Wind Turbine, Sweden[105]

3.4 Other renewable energy sources for energy security backup

Requirement for backup power. As described in previous sections, the geographic diversity and overcapacity of the proposed wind and CST installations will improve the system's ability to provide continuous baseload or dispatchable electricity. For example, there should be enough spare capacity in the grid to make up the 'slack', should one of the 3,500 MW CST sites receive several consecutive days of significant cloud cover, in which their molten salt reservoir becomes empty and unable to dispatch electricity.

There is the possibility of simultaneous cloud cover over several of the CST sites coinciding with a period of low wind and high demand. The kind of weather event which would cause this would be extended cloud cover over large areas of Australia, and this type of macro-scale weather front is easily forecast many days ahead of time. 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 is to incorporate a biomass 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.

Modelling of the proposed ZCA2020 Grid, detailed in Part 4 of this report, has shown that 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 sun. Under the modelling, 5.5 TWh/yr is delivered from biomass via the CST plant turbines, and 1.1TWh is delivered from hydro.

3.4.1 Hydroelectric power to address supply peaks and store energy

It is proposed that existing hydroelectricity infrastructure be used to provide dispatchable electricity that can also be used to help fill the winter shortfall from the CST component. Changes in rainfall patterns are reducing the amount of hydroelectricity that can be relied upon, and opposition to the building of hydro power is increasing. Hence, ZCA2020 does not propose adding to existing hydroelectricity infrastructure.

In those areas of Australia where rain continues to fall reliably, hydroelectricity can play a peak supply role. On the Australian mainland, there is currently 5,195 MW of hydro power generation capacity [106] (including pumped storage hydro). The Basslink HVDC interconnector allows up to 630 MW of electricity to be exported from Tasmania to the mainland[107]. Allowing for seasonal availability and some run-of-river installations that do not have significant storage, it is expected that 5 GW of hydro generation will be available under ZCA2020 for helping to meet peak supply and winter shortfall from wind and solar.

In the modelling outlined in Part 4, only 1-1.5 TWh is required from hydro to meet demand during the key low-sun, low-wind periods. In 2008, 4.65TWh was generated from hydro on mainland Australia[108], meaning that there is extra stored hydro energy available if necessary. However, increased drought conditions may reduce this excess hydro availability.

3.4.2 Biomass — Co-firing with CST plants

It is recommended that biomass be used to fire CST plants when the solar resource is inadequate for consecutive days over several solar sites. This co-firing method has the benefit of eliminating the need to install more turbines, as combusting biomass can heat the molten salt — which would otherwise be heated by the sun — to make steam to drive the solar plant turbines. The only extra capital cost incurred would be a biomass-fired burner, a simple and mature technology. It is also a more economical option to heat the salt, which operates near atmospheric pressure, than directly boiling steam in the biomass heater, which operates at much higher pressure and therefore requires more expensive materials. The winter shortfall in power delivered by CST could also be addressed by increasing the CST capacity under the plan. However, using other forms of renewable energy generation adds resilience to the system and reduces the overall cost.

It is proposed that enough biomass heater capacity be installed to supply 15 GWe of the CST plants with backup. In conjunction with forecasting, this would be fired up in advance of large weather fronts that threaten to lower solar energy availability, providing extra heat to the salt tanks prior to the peak demand/supply event. These would be distributed across all twelve solar sites, but the optimum capacity at each individual site has not been determined. It is likely that far southern sites such as Mildura, and far northern sites such as Prairie (affected by monsoon clouds) would have a larger amount of biomass capacity than more inland, sunnier sites such as Kalgoorlie and Longreach.

Taking into account steam cycle efficiencies (45%) and parasitic energy requirements, 1 MWe of electrical output requires 2.5 MWth of thermal energy delivered from the molten salt system. Therefore 15 GWe of backup corresponds to 37.5 GWth of heater capacity. In consultation with current industry pricings and taking into account minor cost reductions associated with replicating the same biomass module across the sites without re-engineering, the cost of the biomass backup is estimated at $AU0.5 million per MWe electrical backup required[109]. The 15 GWe of biomass backup for the grid system will therefore cost an extra $AU7.5 Billion.

As shown in the modellling in Part 4, this backup capacity is better suited to being spread out across many solar modules, providing partial backup instead of full backup. That is, instead of providing a few Solar 220 modules with full backup to supply the 542.5MWth needed for the 217MWe turbine, it is proposed that a larger number of modules are supplied with partial backup. In this way, pre-emptive firing of the heaters can 'top-up' the salt tanks, and the backup heat is supplied to a greater number of turbines, as ultimately it is the turbine capacity that is required to meet electricity demand.

The majority of the plants to be built with backup will be built in the latter half of the CST rollout plan, reducing the upfront expenditure.

Biomass backup is also specified for the entire 4,475 MW of off-grid CST, at a cost of $AU2.2 Billion. As off-grid CST has to be more of a standalone system, it makes sense to provide full backup.

The 15 GWe of grid biomass would provide up to 7 TWh/yr of electrical energy, requiring 75 PJ of primary biomass energy (i.e. 75 PJ from biomass combustion), taking into account thermal losses of the heater.

The off-grid CST installations running at 72% capacity factor will produce 28.2 TWh/yr. 36 TWh/yr is the current gross generation from off-grid capacity, or 33.5 TWh/yr net generation. Therefore 5.3 TWh/yr of electricity will be met by off-grid biomass backup, requiring 19 PJ of biomass primary energy. The total CST biomass backup will require around 93 PJ of combusted energy from biomass (results rounded).

To demonstrate the feasibility of supplying this amount of biomass energy, the example of wheat crop waste is used to illustrate one option for meeting the biomass energy demand of 93 PJ/annum.

Biomass from wheat crop waste — one option

Australia's average annual wheat crop is 19.5 million tonnes[110]. Given that there is on average 1.8 kg of crop residue (stubble, husk) per kg of wheat grain[111], there is up to 35.1 million tonnes of wheat crop residue each year in Australia. With a calorific value of 17.1 MJ/kg[112] , this means there is a potential 'primary' energy resource of 600PJ/yr from Australia's wheat crop residue. The total backup energy required for ZCA2020 is only 93 PJ/yr or **15.5% of Australia's wheat crop residue**. This would leave plenty of crop residue to be left on the fields to improve the soil, using 'no-till' cropping methods. The 75 PJ for just the ongrid backup is 12.5% of Australia's wheat crop.

Taking into account the thermal efficiencies, this 93PJ/yr for on and offgrid would generate 12.3TWh/yr of electricity. A study by the Clean Energy Council[113] has assessed that there is 47 TWhe of end-use electricity available to Australia in the long term (by 2050 under the CEC scenario) from crop residue alone, with an additional 10TWhe available from urban waste, wood waste and non-crop residue agricultural waste. Based on this benchmark, ZCA end-use electricity from biomass requirements are 26% of that which is available to Australia.

Transport of bulk biomass — biomass pellets for greater energy density

Biomass is usually of a lower energy density than fossil fuels, so is traditionally seen as better suited to a distributed energy system, with small-scale, local energy generation reducing the need to transport bulky biomass long distances. In recent times, a technology known as 'pelletisation' has become widespread in North America and Europe. Woody biomass (e.g. woodchips and/or crop waste) is pressed and extruded into pellets or briquettes, which have a higher energy density and a lower moisture content, making transport and storage more economical[114]. The product is commonly referred to as 'wood pellets', but crop wastes are regularly used to manufacture them as well as wood waste. Wood pellets are used for domestic, commercial and industrial purposes in North America and Europe. The 2005 global wood pellet market demand was estimated to be 30 million tonnes[115]. In contrast, the 92 PJ/annum CST backup only requires 5.3 million tonnes of biomass pellets. These would be transported by rail to the solar sites.

The transport of 5.3 Mt/annum of pellets by rail is a small task by comparison with exports of coal at the port of Newcastle, the world's largest coal export terminal, which is currently running at 92.8 Mt/annum, and is expected to expand to 133 Mt/annum by 2011[116].

Small scale pelletisation plants, which are commonly used in Europe and North America, can be set up in areas where there is significant crop waste resource. The pellets will be transported through the existing and upgraded rail system to the CST plants, where it can be stored in bunkers until required. 2,500 tonne trains, each consisting of 100 x 25 tonne wagons, would be used in the late summer / early autumn to transport pellets from the pelletisation plants to the bunkers at the CST plant sites. The trains would then be placed on standby locally at the CST plants over the critical winter period, where there may be a need for biomass co-firing in order to continue seamless operation of the electricity supply system. The electricity requirements for this transport will be small compared to the rest of transport activity in the economy, but it should also be noted that this haulage task will be taking place over the summer/autumn period where there will be excess energy availability from wind and solar.

The pelletisation of the 5.3 million tonnes of waste in 5 months over summer/autumn, would require 150 small scale pelletisation plants with a capacity of 10 tonnes/hr, operating 24 hours a day during the period. These would be set up in large agricultural areas, and could be either allocated to a single farm, or share the tonnage from several farms.

Cost. From industry sources, a 10 tonne/hr pelletisation plant would cost $AU8.3million[117].

The total cost for 150 crop waste pelletisation plants would be $AU1.25 billion

3.4.3 Biogas for industrial methane supply

Currently, gas use in industry is primarily for heating purposes, which can be replaced with electric heating, reactive processes and direct solar co-generation (as shown by various examples in this report). There are certain industrial processes where gas is used for its chemical carbon content, i.e. making synthetic chemicals. While this is a very small amount of total gas use, it is demonstrated that biogas could meet this demand as one alternative to conventional fossil fuel gas. This is not the only way that chemical carbon requirements could be met, it is just one example.

In the ZCA2020 plan, an allowance of 50 PJ/annum has been made to supply a small amount of methane from biogas. Methane is used as a feedstock for some chemical production (of methanol, for example).

Preliminary costing for supplying this small amount of bio energy is based on European bio energy projects. In Germany, a single biogas plant is being installed at a cost of 10 million Euro €, with a capacity of 228 TJ/yr biomethane production[118]. Scaling up this kind of facility to supply 50 PJ/yr of bioenergy for ZCA would require $AU3.5 Billion of investment (using AUD/EUR ForEx rate of 0.6). This final number could be investigated in more detail, taking into account economies of scale and different configurations for biogas production, but, as bioenergy is a minor part of the ZCA2020 proposal, it is simply assumed that $3.5 billion is a conservative allowance for this part of the plan.

3.5 Industrial Processes

While the full changes required in the Industrial Sector to reach zero emissions will be covered in full depth in the separate Industrial Processes report, this section shows some examples of how major industrial facilities can be integrated with renewable energy. Heating loads currently delivered by natural gas and other fossil fuels can be delivered by renewable electricity, while solar thermal co-generation can provide both electricity and direct heat, saving on costs significantly. It is even feasible to use more efficient modern Direct Iron Reduction combined with biomass gasification to produce steel, replacing metallurgical coking coal.

3.5.1 Electrification of heating loads

36% of all natural gas consumed in Australia is used by industry; this makes it the largest consumer. Natural gas is used in a multitude of processes, a large portion being heating applications and incineration [119].

Industrial heating processes can be divided into 3 classes: low-temperature (to about 400°C), medium temperature (between 400°C and 1150°C), and high temperature (beyond 1150°C). Low temperature applications can include baking and drying, medium temperature applications include annealing or heat-treating, and high temperature applications include steel making, welding and preparation of chemicals[120].

For each gas application there is an available electrical substitute. Electrical heating methods have advantages over other forms of chemical combustion in regards to: precise control over the temperature, rapid provision of heat energy, and ability to achieve temperatures not achievable through combustion. Electrical heating applications are also cleaner and quieter, with limited heat by-product when compared to combustion, and therefore can be installed anywhere in a plant. They do not produce flue gases, which lose 20-30% of heat in combustion processes. Methods of electric heating include electric resistance heating, induction heating, electric arc heating and dielectric heating.

Electric resistance heating

Electrical resistance heaters work by forcing a large current through a small wire. The resistance in the wire generates heat. The technology is advantageous as it is low cost, has a low temperature coefficient of resistance and uses readily available materials. The process is extremely efficient, approaching 100%, making it an attractive alternative for high temperature applications[121]. Electric resistance heating can be used to heat space, or in industrial furnaces using forced convection to heat to temperatures greater than 650°C. Alternatively electric resistant heating can be used in an immersion heater to heat water or generate steam for processes[122].

Electric arc heating

Electric arc heating is generally used in the melting of scrap steel, the production of phosphorous, aluminium and other metals. The technology generally uses three electrodes. An arc forms between the charge material and the electrodes. Heating of the material occurs through two methods; by the charge passing through the material and also the radiant energy created by the arc. The electrodes are automatically raised and lowered, regulating the system to maintain constant current and power whilst the charge is melting. Electric arc heating greatly reduces the specific energy per unit weight required to produce steel in comparison to combustion technology. It also has the ability to vary production, and rapidly stop and start, allowing the plant to respond to varying demand. This degree of control is not available with blast furnaces, and therefore a reduction in energy use is also seen here.

Induction heating

Induction heating is a non contact heating process. It works by sending an alternating current through the coil, to generate a magnetic field. When a work piece is placed in the coil the magnetic field induces eddy currents. This generates precise amounts of localised heat.

The technology has been used in industry since the early 1920s, and advances in solid state technology have made induction heating a remarkably uncomplicated, cost-effective heating method for applications which involve joining, treating, heating and materials testing[123].

Dielectric heating

Dielectric heating is also referred to as radio frequency or microwave heating. It is used to heat materials that are poor electrical conductors. The heat is generated from within the material. This heat can be created in asymmetrical and polar molecules. When a changing electric field is transmitted through the material the molecules will try to align themselves with the field, causing them to move and rotate, and therefore collide with neighbouring molecules, generating heat. Currently the technology is used in industry for welding plastic pipes, vulcanising rubber, and many other applications[124].

Supercritical water oxidation (SCWO)

The treatment of organic waste in industry is usually completed using an incineration process. The purpose of incineration is to remove organic materials and substances from industrial waste through a high temperature combustion mechanism that converts the waste into ash, flue gases and particulates. The flue gases need to be cleaned of pollutants before release into the atmosphere. In most applications in industry natural gas is used as the fuel for combustion, however alternative technology such as SCWO can be used as a cleaner technology.

SCWO operates at pressures and temperatures above the critical point for water[125]. In this state, there is no sharp boundary between gas and liquid phases. Water, oxygen, CO_2 and organic compounds act as a single phase therefore facilitating a complete reaction. Operating under these conditions the destruction and removal efficiency rate for most wastes is 99.99%[126]. SCWO has proven to be more reliable and more robust than traditional combustion techniques[127]. Currently the technology can be used to treat numerous contaminants, from wastewater to aromatic hydrocarbons and it has the ability to treat sludges, paints, synthetics, explosive, agricultural products and many more[128].

3.5.2 Case-study: Conversion of Industrial facility to solar thermal

The following case study provides an in-depth analysis of the feasibility of powering an alumina refinery directly from a nearby solar thermal facility, modified to provide both the heat and electricity requirements for the refinery as with conventional industrial cogeneration systems. The analysis proved successful; showing that 4 modified Solar 220 plants and 1 unmodified plant could provide the refinery with the required steam and electricity. The project has a 9 year payback period and a Return on Investment of 25.2% making it an environmental and economically beneficial option.

The world's largest producer of primary aluminium, United Company Rusal, recently published a public submission for the Australian Government's energy white paper. Specifically, the submission highlighted the company's vulnerability to an Emissions Trading Scheme (ETS), and the economic impact an ETS would have on the viability of the alumina refinery. As part of the submission, the energy types and requirements used and needed at the plant were outlined. These requirements were used in this case study and to formulate an economic case to modify the plant, using Solar 220 technology to run the plant, eliminating the economic effects and liabilities associated with an ETS. Like any thermal power system, solar thermal power can be run as co-generation to supply both heat (via steam) and electricity with adjustments to the steam power cycle system, independent of the solar field/molten salt part of the plant.

The plant currently utilises energy from three separate sources: coal, electricity (albeit via coal) and gas. Coal is the largest energy input and is required to meet the large steam requirement; high quality steam (5000kPa, 270°C[129]) is necessary to operate the bauxite digesters. The next greatest energy requirement is from the gas needed to fire the alumina calcination kilns, at temperatures in excess of 1100°C. The electrical requirement supplying auxiliary plant demand, although constituting the smallest component of the plant's energy use, is still significant. As outlined in the submission, these sources of energy will be affected by an ETS, which will ultimately affect the viability of the project. In this case study, modifications are proposed which

Queensland Alumina Refinery at Gladstone[129].

economically divorce the refinery from the liabilities of the ETS, and will allow the refinery to maintain a competitive advantage in a carbon-constrained economy.

In the proposed plant modification, the steam requirements are to be met by co-generation power plants, and the gas requirements replaced by electricity. Co-generation of steam and electrical power is a proven technology, and it is well established that large efficiency gains can be achieved by implementing such a system; energy efficiencies of up to 85% have been recorded[130]. The gas requirement in the kiln is to be replaced by electricity. In most cases, the choice between electric and gas-fired power is economic, since most processes can be carried out equally well with either of these power sources[131].

The modified energy requirements were calculated based on the current energy needs. An energy grade function of 0.913 for natural gas[130] could be used to determine the electrical energy requirement, for an electrically fired kiln. However, a value of 1 was used in the calculation, as this is a more conservative estimate. Similarly, a conservative estimate of the steam energy requirement was determined, by assuming a 90% conversion from the coal energy to steam energy[132]. The use of these conservative figures will over-estimate both the electrical and the steam requirements for the modified plant.

A back pressure turbine was determined to be the most suitable co-generation option[132]. A back pressure turbine discharges a portion of steam into a pressurised piping system that can be used for process heating, whilst the remaining steam is converted into mechanical energy and used to run a generator also providing electricity to the plant. An electrical efficiency of 25% and thermal efficiency of 60% are regularly recorded[132]. The steam requirements for the plant (i.e. steam at 5000kPa and 270°C) were used to determine the output conditions of the back pressure turbine. It was calculated that a back pressure turbine with a 15% electrical efficiency would be required to ensure that the output conditions were appropriate for the bauxite digesters. Based on this, the Solar 220 designs[133] were modified to include back pressure turbines (with the appropriate steam output conditions and electrical conversion efficiencies).

It was determined that four Solar 220 plants would be able to meet the total steam requirements, and 61% of the electrical requirements, of the entire processing facility. A single further unmodified Solar 220 (with no back pressure turbine) would be sufficient to meet the remaining electrical demand, and would even generate a small excess, which could be exported to the grid. This modification was therefore found to be technically feasible.

An evaluation of the modification was then performed to determine the economic viability and feasibility of the conversion. It was assumed that the modifications could be treated as a stand-alone project, whereby the revenue delivered by the project is realised by the offset of energy costs, delivered as a result of the modification. The revenue equivalent was determined by taking current treasury prices for the commodities used[134], and included the current wholesale (rather than retail) price of electricity. The capital expenditure for the project was taken from the Sargent and Lundy report[133], as were the operation and maintenance costs. It was assumed that the inclusion of back pressure turbines (as opposed to high efficiency turbines) would not affect the capital cost of the Solar 220 plants. In reality, the capital cost would be less, due to the use of smaller turbines with lower efficiency, however as a conservative measure, the unmodified Sargent and Lundy figures were used.

Utilising all the economic parameters, a cash flow analysis was performed and the internal rate of return, payback period, and net present value of the modifications were determined. A discount rate of 8% was deemed reasonable and the capital was assumed to depreciate in flat line manner over 10 years. The capital was assumed to be spent over the commissioning period of the plant, with the Solar 220 plant constructed over 2 years[133] and an economic life of 30 years[133] was also assumed. These figures indicate that the modifications have a Net Present Value of over $AU430 Million, and will provide a return on Investment of 25.2% and have a payback period of 9 years. The internal rate of return for such a project would be 10.5%. The project is therefore economically feasible in the current economic conditions. The introduction of a carbon price following this modification would have limited impact, and would in fact increase competitive advantage, over refineries which did not make such modifications.

With reference to Appendix 5 — Industrial Case Studies

3.5.3 Zero-emissions steel smelting

This section details the technical changes required to convert iron and steel production to a zero-emissions process, using the existing technologies of Direct Reduced Iron (DRI), and syngas produced from waste biomass. A detailed economic analysis has not been carried out as with the Alumina case study, however given that DRI processes are competitive overseas, it is expected that with appropriate policy measures, this zero-emissions process would be economically viable. The extra energy requirements for the process will be another 3.3TWh of electricity (1% of total ZCA2020 electricity demand), and 72PJ of gas, which could be provided through the gasification of 15% of Australia's wheat crop waste. This displaces 111 PJ of coal currently used for iron smelting.

Australia currently produces 7.86 million tonnes of steel per annum[135]. The method of steel making in Australia utilises the blast furnace[136], in which iron ore and coking coal are fed into a furnace to produce (liquid) pig iron (iron making). The pig iron is then fed to either a Basic Oxygen Furnace (BOF) or an Electric Arc Furnace (EAF), which reduces the carbon content, to produce steel (steel making). In Australia, the vast majority of steel making occurs in a Basic oxygen furnace. This is summarised in Table 3.15.

TABLE 3.15
Current Australian Steel Production by pathway and source (million tonnes per annum) [135,136]

	Recycled Steel	Virgin Iron	Total
Electric Arc Furnace pathway	1.4	0.35	1.75
Basic Oxygen Furnace pathway	1.22	4.89	6.11
Total	**5.24**	**2.62**	**7.86**

The blast furnace process relies on the iron oxides being reduced by the carbon, so unavoidably produces CO_2. Typically 500kg of coke is require to produce 1 ton of iron[137]. The Australian steel making industry's current total greenhouse gas emissions are almost 13 megatons of carbon dioxide equivalent[138] per annum, a significant emission to address.

The steel industry is an important part of the Australian economy, employing 78,000 people over Australia, with an annual turnover of $21 billion[139]. In order to transition to a zero carbon economy, the Australian Steel Industry must adapt to more appropriate low carbon process routes. Alternatives do exist, and have proven to be economic internationally.

The process with the greatest potential to completely eliminate the process's reliance on coal, and the emission of carbon dioxide equivalents, is Direct Reduced Iron (DRI), with 68 million tonnes of steel being produced via this process in 2008, the leading producer being India with 22 million tonnes[140]. This technique relies on the iron being directly reduced by process gas; coking coal is not required. The Midrex® and HYL® processes are commercially available technologies for DRI production, the predominant process routes for the total worldwide production of DRI. Typically, the process would involve natural gas or syngas (synthesis gas; a mixture of carbon monoxide and hydrogen)[141]. As such, DRI is usually produced in regions where the availability of gas ensures the iron production remains cost competitive with coal-based iron smelting[141]. The abundance of coal, (metallurgical grade coal required for steel making) in Australia has resulted in the industry being dominated by the blast furnace.

The DRI production route opens up the possibility of steel making via biomass; the direct reduction process can be carried out using syngas from biomass[142]. This allows a carbon neutral process route for steel making. A European program, Ultra Low CO_2 for Steel making (UCLOS), has performed a detailed analysis of this process route[142]. There is no technological or economical impediment to building a plant that incorporates both biogas to syngas, and syngas to DRI. The production of syngas from biomass is well documented, and the production of DRI from syngas is similarly proven technology; the plants could effectively be operated independently. UCLOS has indicated that DRI can be produced at a cost of $45-$90 per ton (30 - 50 €/t). Traditionally, DRI prices have been around the $150 per tonne mark, however recently input shortages have seen it at up to $435 per tonne[143].

The DRI can then be fed directly into either Electric Arc Furnace (EAF), or a Basic Oxygen Furnace (BOF) and refined to steel. The EAF is preferred over the BOF, as it can handle charges of almost 100% DRI[144]. The BOF is limited in that it may only be able to process as little as 20% DRI, (with the remainder being molten iron from a blast furnace)[136]. If the BOF is to be eliminated from the process route, then the EAF is essential.

In order to meet current production under a DRI process route, 8.19 million tonnes the the Direct Reduced Iron must be produced, (based on 94% iron content of the DRI[144]). That is, 8.19 million tonnes of new iron making capacity, via the DRI route must be installed to replace current blast furnace operation. Additionally, 6.11 million tonnes of new EAF furnace capacity must be installed, to supplement the current installed capacity, to allow the DRI to be processed to steel. Based on the modified installed capacity, 71.6 PJ of gas is required (at a rate of 8.74 GJ per tonne[142]), replacing the coke. This requires a total 5.33 million tonnes of biomass[142], which represents 15.2% of the Australian Wheat crop residue. The new EAF and new DRI installed required an additional 3.34 TWh (2.69 TWh for EAF[145], and 0.66 TWh for DRI[146]). A summary can be found in Table 3.2 outlining the current usage, the planned usage via a DRI path and also the usage via a DRI path but with the additional requirements needed to meet the steel demands under the ZCA2020 Plan.

A relatively small quantity of carbon is required in the EAF to control the reduction potential within the furnace. Coke can be used, however it is already common practice to utilise synthetic graphite[147]. Traditionally, synthetic graphite has been made through process routes involving coking coal, however, it has been shown to be possible through biomass routes[148]. This carbon requirement is essentially a control mechanism that is, in essence, wasted in the process. Its usage is in the 10s of thousands of tonnes per annum[147] (as opposed to the millions of tonnes used in the blast furnace).

TABLE 3.16
Comparison of current and projected iron and steel processing capacities (per annum)

	Current	Via DRI Path	DRI Path with ZCA 2020
Blast Furnace (MT iron)	7.7	0	0
DRI (MT Iron)	0	7.7	10.05
EAF (MT steel)	1.75	0	0
BOS (MT steel)	6.11	7.86	11.7
Additional Electricity (TWh)	—	3.34	4.6
Additional Gas (PJ)	—	71.6	93.4

In Australia, the steel making industry generally revolves around an integrated mill. That is, the blast furnace and basic oxygen furnace, which produce the raw steel, are incorporated with casting, rough rolling, product rolling facilities to produce rolled steel products. The proposed process modification does not render the remainder of the mill invalid. Retrofitting existing mills would utilise the existing capital, infrastructure and workforce availability. As mentioned above, the biomass and steel making facilities can be considered to be independent. As such, the biomass and syngas facilities could be produced either as part of the onsite process, or piped from an offsite process.

The Australian steel making industry could be transformed into a zero emissions process. It would require transformation away from the emissions-intensive blast furnace toward a process utilising biomass-based syngas in the production of Direct Reduced Iron, and use of electric arc furnaces. Current production can be met competitively, using only 15% of the wheat crop residue, as an energy feed stock, and an additional 3.34 TWh of electricity.

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Part 4

Modelling of ZCA2020 Renewable energy supply

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4.1 The ZCA2020 Grid Model

In order to assist with the Stationary Energy Plan, Jack Actuarial Consulting Pty Ltd (JAC) undertook to model, at fine time scales, the correlation of renewable resources (solar and wind) with demand.

To confirm that the proposed system can reliably meet the projected demand, modelling has been carried out on the proposed ZCA2020 generation mix on a half-hourly timescale, with data (insolation, wind and NEM demand) from 2008 and 2009.

The modelling results show that the 50 GW of wind and 42.5 GW of concentrating solar thermal (CST) alone can meet 98% of the projected electricity demand. The combination of existing hydro and biomass generation as backup at the CST sites can meet the remaining 2% of total demand, covering the few occasions where periods of low wind and extended low sun coincide. The model found that biomass backup equivalent of 10 GW(electrical) on the CST should be sufficient to ensure reliable energy supply in most realistic low wind and sun periods, however the ZCA2020 Plan has allowed for 15 GWe biomass backup for conservatism.

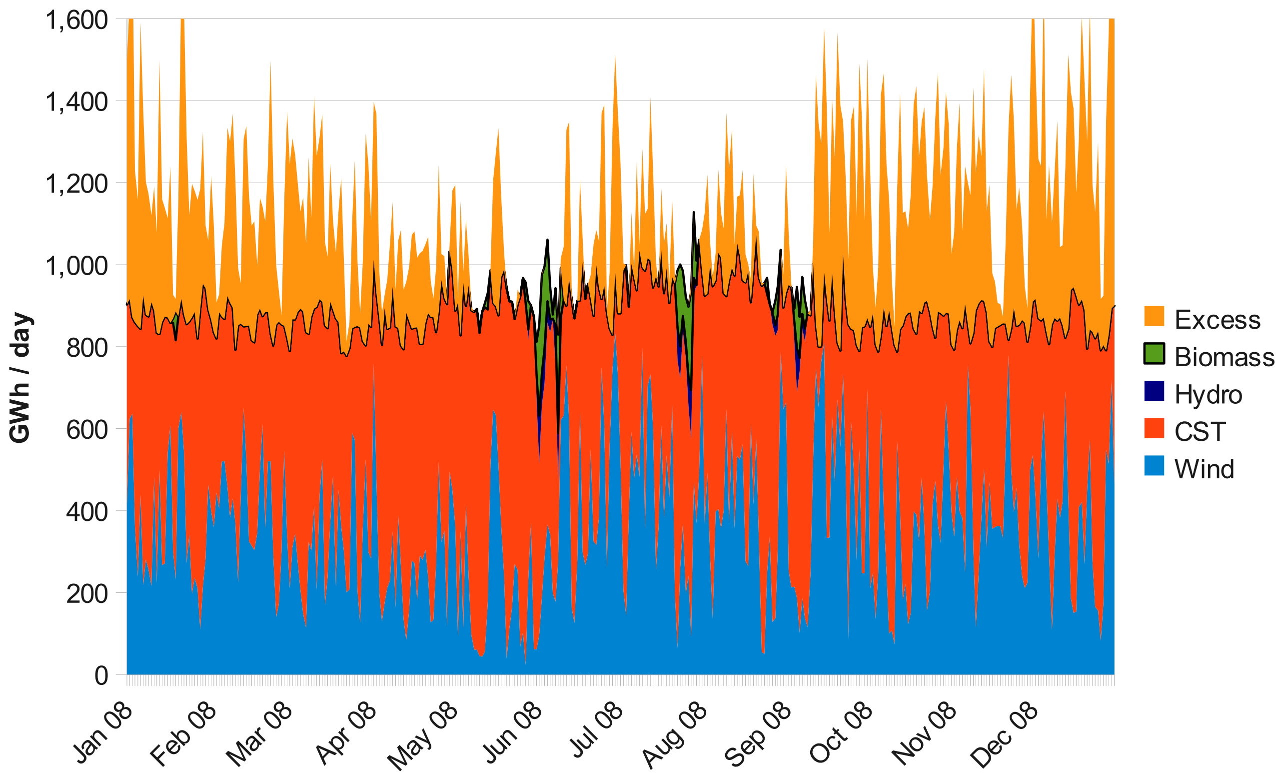
A further result of the modelling is that the ZCA2020 generation mix allows for elasticity of demand with more than 90 TWh per year of excess energy available from the specified renewable energy system.

Explanatory Notes for Figure 4.1 and Figure 4.2

Light Blue, [Wind] is electrical output from wind power. This is based on actual output from existing wind farms across southern Australia, published by the Australian Energy Market Operator, which has been scaled to represent the 50 GW of wind power specified in the Plan. Note that this model does not currently incorporate data from other regions, such as Western Australia and Queensland. As a result, the scaled wind output data has higher variability than would be expected under the proposed system and occasionally drops to a lower output value than would be expected from the total number of 23 wind sites proposed. If, as discussed in Part 3, the geographically diverse wind power can be relied upon for 15% of rated capacity at all times, total wind output would not drop below 7,500 MW, whereas in the model it actually does drop below this figure on occasions. Therefore this modelling is conservative, compared to what could be modelled if more region-specific data was available.

Dark Orange Shading, [CST] is the electricity dispatched from the CST plants. This is calculated from satellite derived solar data from each of the 12 ZCA2020 sites, sourced from the Australian Bureau of Meterology. The raw solar data has been used to estimate the electrical output from the solar thermal plants. This takes into account such values as the mirror field collection efficiency, steam cycle efficiency and other parameters. Underlying this data is the calculation

FIGURE 4.1
ZCA2020 Grid Model, 2008 (Results shown in daily averages, underlying model on half-hourly data)



of the amount of energy sent to the heat storage tanks each day for later dispatch.

Black Line, [Demand] projected electrical grid demand based on actual data from the National Electricity Market (NEM). This has been adjusted to take into account electrification of transport and industrial and space heating. The current baseline demand has also been reduced to allow for efficiency improvements. After these adjustments, the demand totals 325 TWh/year.

Light Orange Shading, [Excess] shows the excess electricity that would be available from the solar sites, but is not required by the demand.

Dark Blue Shading, [Hydro] shows electricity dispatched from the 5 GW of existing hydro capacity in periods of supply shortfall.

Green Shading, [Biomass] shows the electricity required from the biomass backup system in periods of low sun and wind availability. This is adjusted to reflect electrical output, though in reality the biomass system provides thermal energy to the heat storage tanks of the CST plants.

4.2 Detailed Overview of the ZCA2020 Grid Model

4.2.1 Introduction

This model enables assessment, at a high level, of whether or not the proposed generation mix is a plausible means of meeting the projected demand. It uses fine time scales to correlate renewable energy resources (solar and wind) with electricity demand.

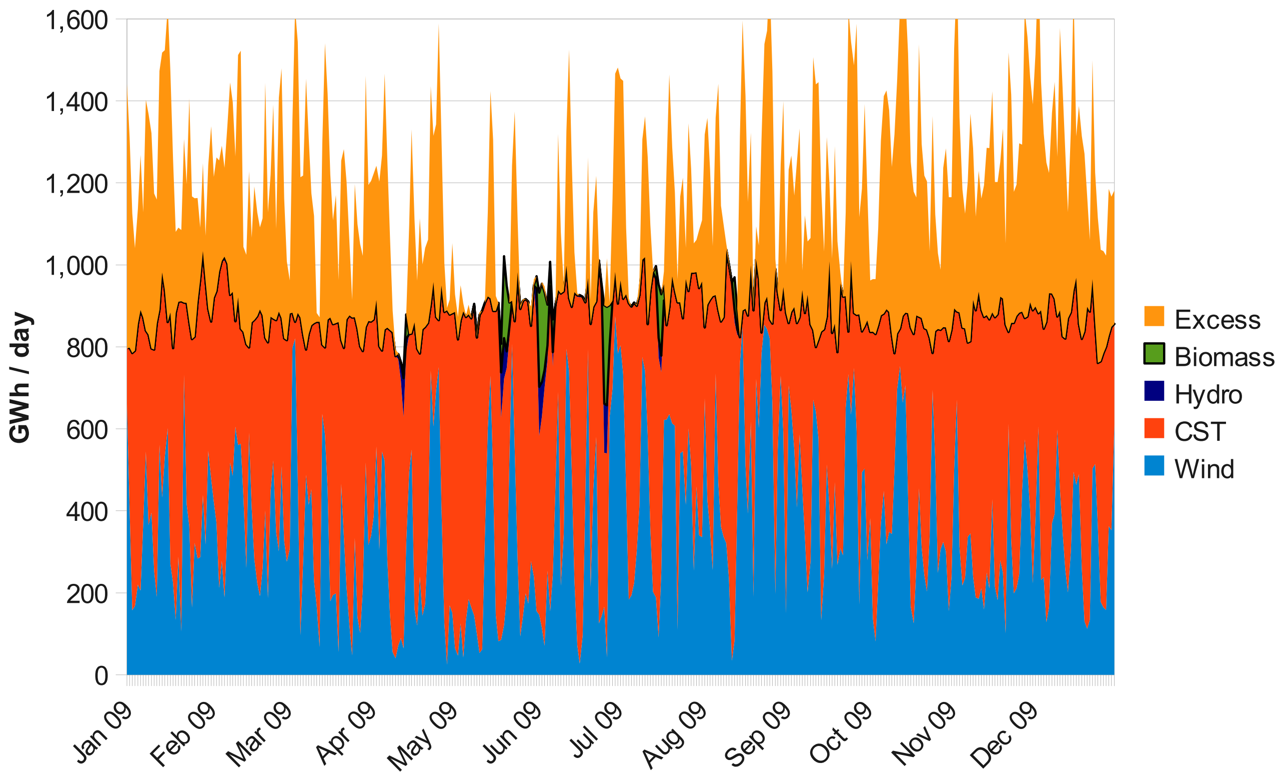
Although demand and supply have been modelled, no allowance has been made for transmission constraints or losses.

4.2.2 Proposed Generating Mix and Demand

The ZCA2020 Stationary Energy Plan proposes a stationary energy sector with the following components:

- 325 TWh projected annual demand for grid supplied electricity;
- 40% grid supply from 50 GW of wind generators installed at 23 sites;
- 60% grid supply from 42.5 GW of concentrating solar thermal (CST) power stations installed at 12 sites;
- 5 GW of hydro generation (the current mainland hydro capacity); and

FIGURE 4.2
ZCA2020 Grid Model, 2009 (Results shown in daily averages, underlying model on half-hourly data)



- Biomass fired boilers to supplement heating of the CST thermal reservoirs when required.

Critical aspects of the CST design are the solar multiple and thermal storage capacity. The standard CST design proposed by this Plan is a 217 MW (net) solar tower with a solar multiple of 2.6 and thermal storage of 17 hours.

The solar multiple is the ratio of the amount of power (electrical equivalent) that can be captured at peak insolation to the turbine capacity. Accordingly, a solar multiple of 2.6 in the context of a 217 MW plant, where 217 MW is the turbine rated peak output, could collect solar energy at peak insolation at a rate of 2.6 multiplied by 217 MW, giving 564 MW. A solar multiple greater than 1 allows thermal energy to be collected and stored for later use even if the turbine is operating at full capacity.

Thermal storage of 17 hours indicates that a thermal reservoir can store enough thermal energy to run the 217 MW turbine at full capacity for 17 hours. As a result, thermal storage for about 3.7 GWh(e) is modelled at each 217 MW CST plant.

The demand used here has a profile based on National Electricity Market (NEM) demand. The total demand has been increased to allow for electrification of transport and industrial and space heating, while the current grid demand has been reduced to allow for efficiency improvements, as explained in Part 2 of this report. Based on these adjustments the projected annual demand is 325 TWh.

4.2.3 Method and Characteristics of the Model

The model has the following characteristics:

- Daily global horizontal insolation (GHI) estimates derived from satellite images from the Bureau of Meteorology (BoM) are converted to estimated daily direct normal insolation (DNI) at each of the 12 ZCA CST sites.
- The daily DNI from the GHI is converted to an amount of energy available (for each CST site) either for dispatch or storage and spreads this through each day.
- A factor is applied for the mirror field as the heliostat field is not a perfect DNI receiver. This mirror field efficiency is based on the NREL Solar Advisor Model.
- NEM wind energy data is converted from 9 existing wind farms in South Eastern Australia to hourly capacity factors. Data from operating wind farms is publicly available for viewing and download.
- CST and wind sites are weighted with specified generating capacities of 50 GW for wind and 42.5 GW for CST (with associated solar multiples and storage)
- Potential output from solar and wind generators is compared to the projected demand.
- All available wind power and, if possible, sufficient CST power are dispatched to meet demand.
- Hydro, if necessary, is dispatched after wind and CST, to meet demand.
- Firing of the biomass boilers, to heat the CST thermal storage reservoirs, is triggered if these reservoirs, in total, fall below a specified level.
- All intermediate variables (eg demand, reservoir storage, wind generation, CST dispatch, unmet demand) are stored for later analysis.

For the purposes of this analysis the ZCA2020 generation mix has been used with data (insolation, wind and NEM demand) for calendar years 2008 and 2009.

Analysis of the resulting time series readily identifies whether or not the specified generation mix can meet the projected demand and, if not, the extent of the deficit and the 'reason' for the deficit. A subsidiary model fires biomass boilers which charge the CST thermal reservoirs. This backup thermal charging is done when total thermal stored energy drops below a specified level (e.g. 8 hours storage remaining). The biomass backup model is used to assess the boiler capacity and reservoir trigger required to meet the energy deficits identified in the main model. As the biomass will keep firing until the reservoir is back above the trigger level, this may result in short periods where biomass energy is firing even though hydro is not being dispatched.

4.2.4 Examples of Model Behaviour for Summer and Winter Periods

Summer — Curtailment due to excess supply

Figure 4.3 shows a selected period in February that demonstrates the 'normal operation' of the proposed generating mix. Insolation is high (typically in the range 50 GW to 100 GW) during the day. Wind is around 20 GW for much of the period, albeit with low periods during the middle of the day on both 13 and 14 February. With the high summer insolation, the reservoir is maintained at a high level, being charged during the daylight hours when insolation and wind added together significantly exceed demand and being drawn down overnight when there is no insolation and the wind does not meet demand. The reservoir energy varies in the period shown between about 580 GWh and 724 GWh. The upper limit, 724 GWh, is the storage capacity of the overall CST reservoir system. When this limit is reached, otherwise potentially harvestable energy is lost. This is evident in the flat section of the reservoir contents during the high insolation period on 12 February.

Winter — Insufficient wind, insolation and hydro, therefore biomass backup is used

The first few days of June 2009, shown in Figure 4.4, display a typical period of integration of wind, solar, hydro and biomass. First, with no allowance for biomass, there is unmet demand as wind and insolation are relatively low. The unmet demand, of some 25 GW on 2 and 3 June, is evident in the Figure 4.4 as the gap between the sum of the supply components (wind, CST and hydro) and the demand line. Note that the reservoir drops to zero on both 2 and 3 June.

FIGURE 4.3
Hourly dispatch with excess supply in February 2009

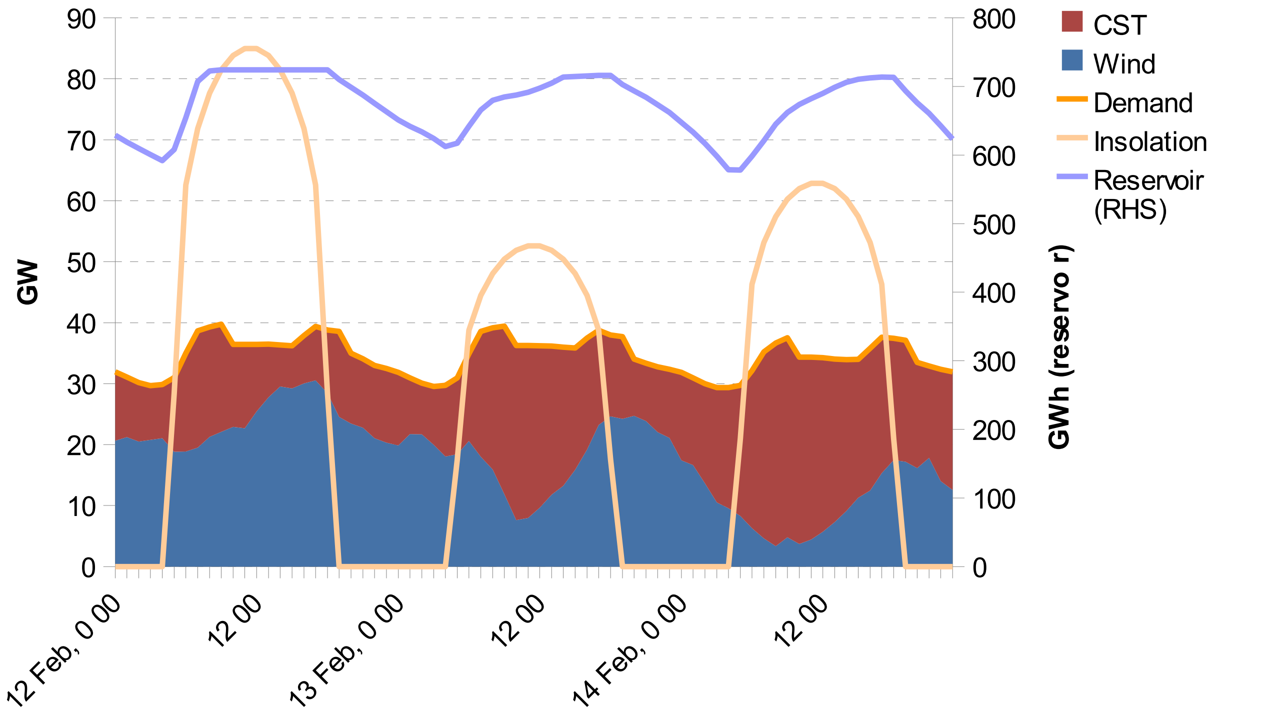


FIGURE 4.4
Hourly dispatch without biomass—June 2009

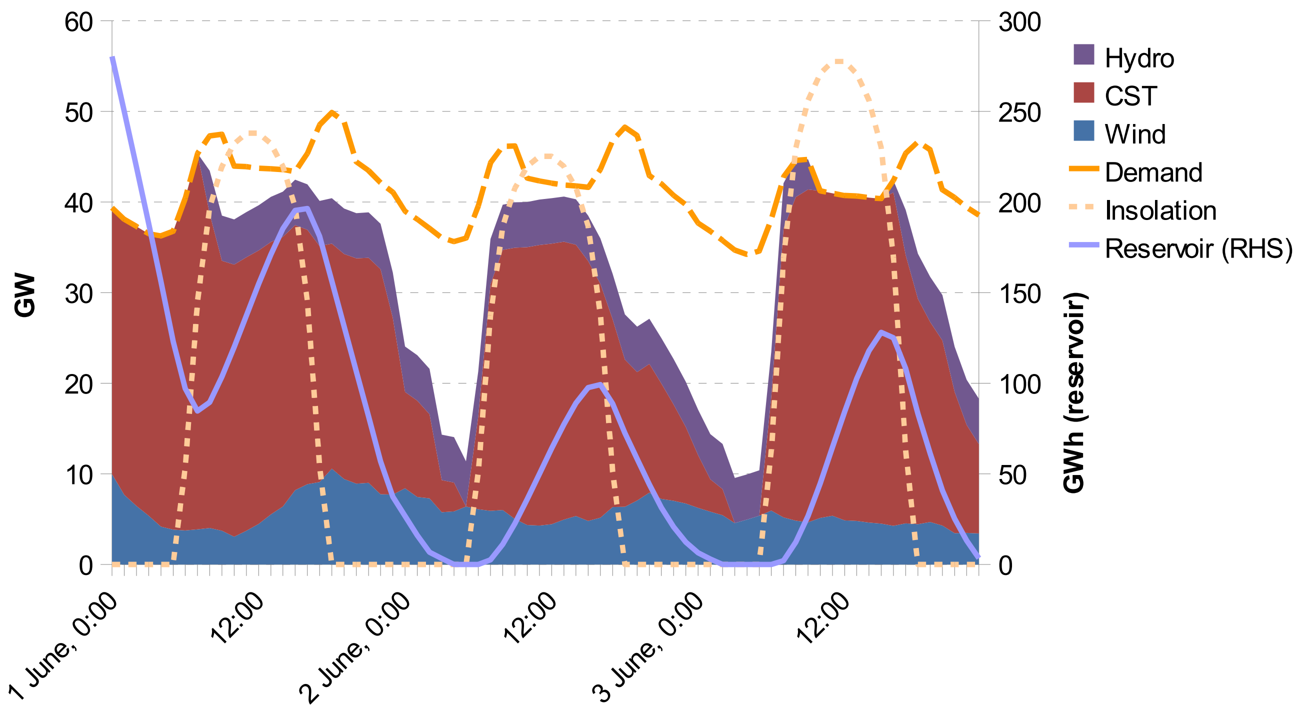
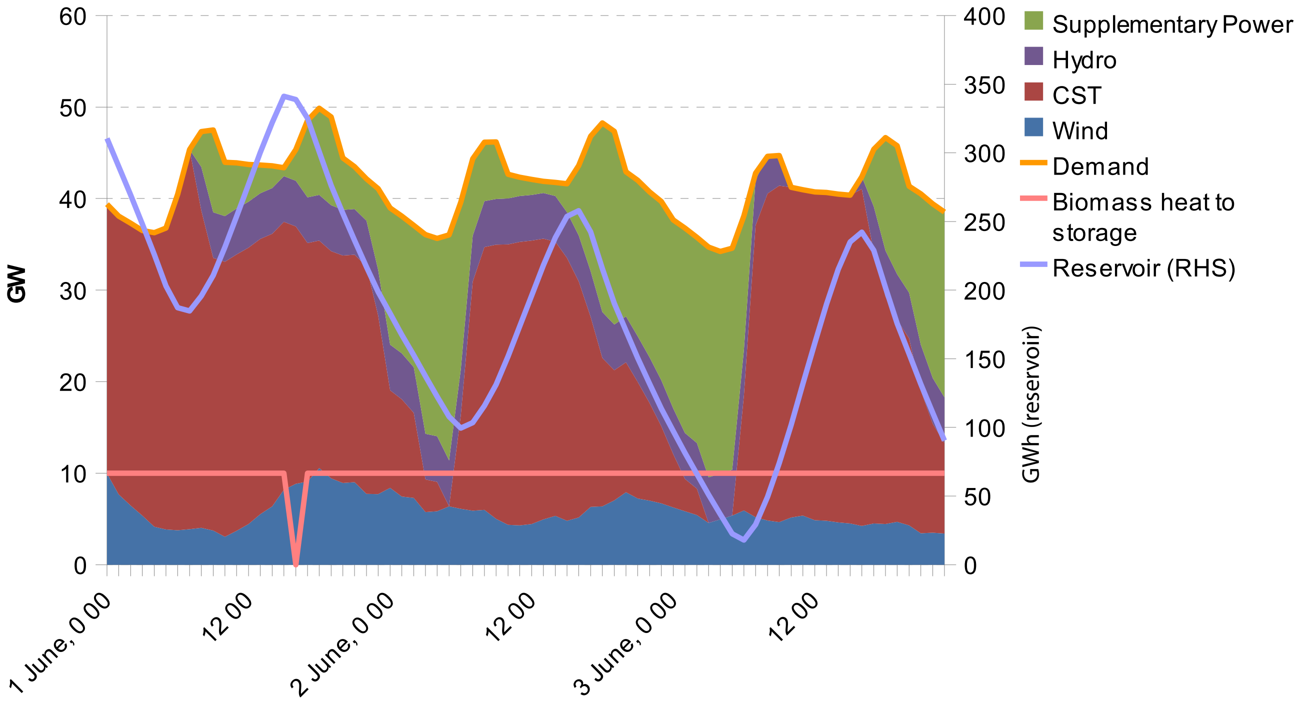


FIGURE 4.5
Hourly dispatch with biomass during June 2009



In this example the biomass is fired when the reservoir drops below 8 hours storage (about 340 GWh). Comparing Figure 4.5 to Figure 4.4 it is possible to see the additional supply possible from the CST plants due to charging the reservoir with biomass. During the times when the CST plants are using the reservoir to supply the supplementary power, the stored heat energy (RHS) can be seen to be decreasing. Biomass firing is a flat 10 GW(e) over the period apart from one hour on the morning of 1 June. It is clear that on the morning of 3 June the reservoir is nearly, though not in fact, exhausted. This situation would require the equivalent of 10 GWelectrical biomass heaters (25 GWthermal) distributed across around 25 GW(e) of the CST plants. The 25 GW(e) of turbines have partial biomass backup, not full backup.

Worst-case scenario

The period of lowest wind and sun over the modelled time period occurs on 27 June 2009 (early hours). This event arose after a single day of very low insolation (371 GWh on 26 June compared to next lowest for the month of 441 GWh and daily average for June of 690 GWh) and with very little wind overnight, dropping to almost no output. This low-wind situation would not be expected to actually eventuate in the proposed ZCA2020 grid, as geographical diversity suggests the system will have a realistic minimum wind output of 7,500 MW. (Refer to Section 3.2 for more information.) However, this example shows that using 15 GW of biomass backup is conservative: potentially only a smaller backup system would be required as the broader geographically diverse wind resource would reduce the variability of the wind output.

4.3 High Level Modelling Results

The outcomes of the high level modelling regarding the proposed generating mix (50 GW wind, 42.5 GW CST with 17 hours thermal storage) are as follows:

- The solar thermal and wind generating mix does meet about 98% of projected demand without biomass backup
- The generating mix can meet all of the otherwise unmet demand with hydro capacity of 5GW and biomass boiler capacity of 15 GW
- The generating mix sheds approximately 35% of total harvestable solar energy.

Monthly Supply Breakdown over 2008 and 2009

Figure 4.6 shows the monthly projections of supply breakdown if the generation model was used for data over the 2008 and 2009 calendar years. (Note that both the unmet and hydro components of this figure are too small to appear at this scale.)

There is a high level of consistency of the results between the two years, as shown in Table 4.1. Note that the CST values represent dispatched energy, not inclusive of excess energy that is discarded, mainly in the summer.

Curtailment is primarily the excess energy available from CST but also includes small components of biomass and wind. This arises from biomass being used to charge thermal reservoirs but then not being required or wind exceeding total demand. The values in Table 4.1 are for the case where there is 10 GW(e) of biomass capacity and this

FIGURE 4.6
Monthly supply breakdown over 2008 and 2009

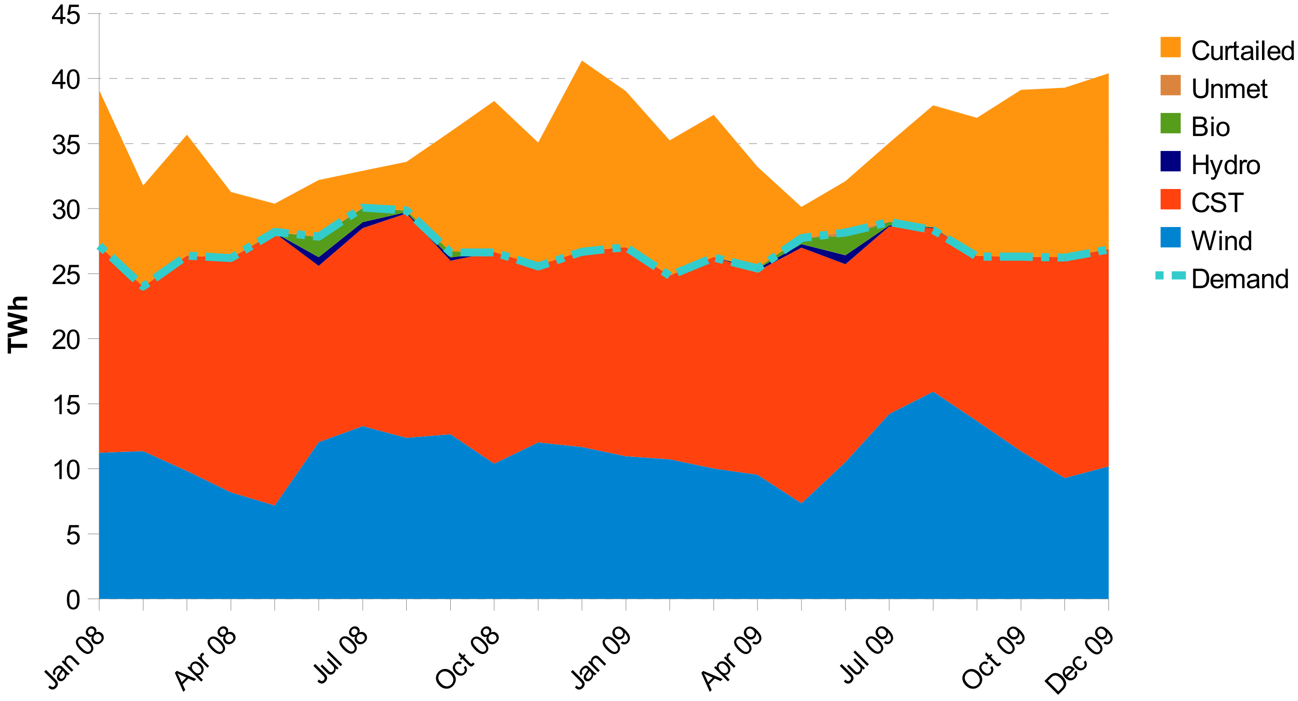


TABLE 4.1
Supply Breakdown Comparison between 2008 and 2009

Supply Component	2008 TWh	2009 TWh
Wind	132.2	133.8
CST	188.4	185.2
Hydro	1.5	1.3
Bio	3.4	2.7
Total	325.6	323.1
Demand	325.3	322.5
Unmet	0.0	0.0
Curtailed	95.7	116.6

is triggered when the reservoir, in total, is down to 5 hours of storage (5 multiplied by 42.5 GW, or 213 GWh).

With a biomass backup capacity of 15 GW and a firing trigger of 8 hours remaining storage, there is no unmet demand. Such early firing would be very likely if forecasting (particularly the poor wind) were allowed for. Various combinations of boiler capacity and boiler trigger were modelled. The results of this modelling, averaged over 2008 and 2009, are shown in Table 4.2 and Table 4.3.

The extra cost of using the earlier trigger for biomass firing (e.g. 8 hours of storage rather than 5 hours of storage) is high relative to the amount of energy supplied. Nevertheless it is, arguably, quite low in absolute terms. For example, considering the 10 GW(e) biomass capacity case, an additional 1.9 TWh(e) of biomass energy is used (5.7 TWh less 3.8 TWh from Table 4.3) for a decrease in unmet demand to 0.1 TWh from 0.2 TWh (from Table 4.2).

TABLE 4.2
Unmet demand (annual average) after use of hydro and biomass backup (TWh)

	Boiler Capacity			
Boiler Trigger (hrs of storage)	5 GW(e)	10 GW(e)	15 GW(e)	20 GW(e)
2 hours	1.8	0.9	0.4	0.2
3 hours	1.6	0.6	0.2	0.1
5 hours	1.2	0.2	0.0	0.0
8 hours	0.9	0.1	0.0	0.0

TABLE 4.3
Biomass energy (electrical equivalent) (annual average) (TWh)

	Boiler Capacity			
Boiler Trigger (hrs of storage)	5 GW(e)	10 GW(e)	15 GW(e)	20 GW(e)
2 hours	1.4	2.4	3.0	3.3
3 hours	1.7	2.9	3.5	3.7
5 hours	2.5	3.8	4.3	4.5
8 hours	3.8	5.7	6.4	6.8

4.4 Conclusions

The proposed generating mix would have been adequate to meet the modelled demand using 2008 and 2009 data. The demand modelled incorporates current demand, efficiency improvements and electrification of transport, industrial and space heating.

It appears that 17 hours of thermal storage is sufficient to allow for the absence of insolation overnight and for most cloud events that occurred during the period under analysis. To meet other deficiencies, 15 GW biomass backup is sufficient when combined with 5 GW hydro. With improved forecasting and demand management, a lower biomass capacity would likely be sufficient.

The seasonal correlation of supply and demand means there is excess energy in summer periods. Although the CST plants could run at around 75% capacity in the absence of supply constraints (meaning, if all that could be produced could be dispatched to meet demand), the overall capacity factor derived from the model is around 50%. So approximately one third of the total solar energy available is lost through curtailment, and this occurs mostly over the summer period.

4.4.1 Limitations and Future Work

The modelling has been done at a very high level and with several limitations. Many of these have the effect of making the model more conservative vs what would actually occur. Although the high level conclusions are deemed broadly valid, further research is necessary in order to develop a more sophisticated model and thereby further confirm the adequacy of the proposed stationary energy plan. Some of the limitations of the model include the following:

Transmission

The ZCA2020 Grid Model provides for substantial investment in transmission infrastructure. The present work has not allowed for the transmission capacity proposed by the ZCA2020 Project, rather it has assumed that there are effectively no transmission constraints. As the proposed demand of 325 TWh has been based on the output in the NEM, there is, accordingly and effectively, some allowance for transmission losses at similar levels to those in the NEM.

Insolation model

Satellite image derived daily global horizontal insolation (GHI) has been converted to half hourly direct normal insolation (DNI) using a correlation reported in the literature for the GHI to DNI conversion and a heuristic diurnal shape for the half hour allocation within each day. Given the large storage capacity assumed, the latter is unlikely to introduce errors or bias. The GHI to DNI conversion is thought to be quite reasonable on average however, further work is required to assess the appropriateness of its use in the context of the modelling reported here. It is possible that the daily pattern of DNI used may be sufficiently different from reality to introduce some errors.

Wind data

The wind data used is only from from existing wind farms, publicly reported generators within the NEM, only in South Eastern Australia. This Plan proposes a wider geographic spread than that covered by the NEM. Accordingly, it is likely that the current model overstates the variability (i.e. understates the benefits of geographic diversity) of power available from the wind component of the proposed generation mix.

Thermal losses

There is no allowance for thermal losses from the CST reservoirs. In fact, the CST modelling is very simplistic. However as the thermal storage is 99% efficient (there is 1% loss of stored thermal energy per day), the effect of this is considered negligible.

Demand management/smart grid

Other than that embodied in the NEM demand pattern, no demand management has been allowed for. Particularly with electrification of transport and space heating, there is a high capacity for short term demand management in the Plan. Accordingly, it is probable that the proposed wind and solar capacities are greater than required for a reliable and secure grid using active demand management.

Demand

Allowances for heating, ventilation, cooling, industrial and transport demands are high-level averages. Although the total energy demand modelled matches the demand proposed by this Plan, the pattern may be somewhat different.

Extended data timeframe

The two years modelled data offer a good insight as to the capability of the system as designed. Modelling over more years of data would improve the reliability of the results. This has been limited by the wind data only being available in recent years.

Part 5

Grid and Load Management—Creation of a National Grid

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The ZCA2020 Stationary Energy Plan proposes a comprehensive upgrade to Australia's electricity grid to allow full utilisation of the distributed renewable energy network.

The centrepiece of this upgrade is the interconnection of the three main grids across Australia that supply electricity to consumers, to form one single "National Grid". This is achieved with High Voltage Direct Current (HVDC) and High Voltage Alternating Current (HVAC) transmission lines.

The upgrade also requires the reinforcement of interstate connections within the National Electricity Market (NEM) grid, to overcome existing capacity constraints.

Transmission lines are also specified to connect the new renewable energy sources to this grid.

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

Whilst peak demand will be reduced by the electrification of heating and cooling, demand and supply will be managed across the network via a Smart Grid system.

The Engineering firm Sinclair Knight Mertz has reviewed the connection to the transmission network of the generation scenario proposed in the ZCA2020 Stationary Energy plan.

The review found *"that 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."*

"The transmission concept is to use the existing network wherever possible and to develop major HVDC hubs in South Australia, Victoria and New South Wales (at Port Augusta, Mildura and Mt Piper respectively). The HVDC transmission will provide full access to the Solar Thermal generation located across a number of time zones. HVDC at voltage levels in excess of +/-500kV is used extensively throughout the world and is considered a 'mature' technology."

The location of the hubs has not been optimised but they are viable locations, given the "sources of generation (Solar and Wind) and the underlying transmission network. "

"Where HVDC is not practical ... 500kV HVAC transmission has been used (e.g. for wind farms across South Australia). 500kV HVAC is currently employed in both Victoria and New South Wales and is being proposed for Queensland."

"In addition, AEMO (Australian Energy Market Operator) has recently published reports entitled 'Network Extensions to Remote Areas: Parts 1 and 2'. In these reports, the concepts of major enhancements to the 500kV grid are examined, as well as using long-distance HVDC to connect remote renewable generation and upgrading interstate transmission capability. To some extent, these reports validate the transmission concepts proposed for the various renewable energy sources."

IMAGE: SPACEMAN[1]

"The costing of the proposed transmission connections has been carried out using figures derived from past projects but no formal evaluation has been made in this regard. It is recognised that the costs presented are very high—but not unrealistic if the development timeframe is considered. The costs could amount to $10B/year over a 10 year development horizon with much of the cost 'back-ended'."

— SINCLAIR KNIGHT MERZ, 2010

5.1 Upgrading the Grid

The ZCA2020 Plan calls for a nationally connected electricity distribution grid.

The creation of a national grid is an essential public infrastructure project that will make the supply of 100% renewable energy more economical and help ensure Australia's energy security into the future. The proposed interconnections and transmission upgrades allow full utilisation of the distributed renewable energy resources.

Currently three main grids supply electricity to Australian consumers[1]. The Plan calls for these three grids to be combined into one National Grid. The existing three grids are shown in the map in Figure 5.1.

- The National Electricity Market (NEM), which supplies the majority of the population, covering Queensland, New South Wales, Victoria, South Australia and Tasmania.
- The South West Interconnected System (SWIS), which supplies Perth and southern Western Australia.
- The North West interconnected system (NWIS), which covers the north of Western Australia and accounts for the added load from mining activities in that area.

In addition, there are some separate small grids to supply Darwin, Alice Springs and some intensive mining areas in Western Australia and west Queensland. The Plan does not, at this stage, propose linking these into the National Grid. Nonetheless we have included in the total system costs estimates for solar thermal plants and biomass systems to supply these isolated grids and "off grid" areas, but have not done the detailed modelling of where they would be located. This will be dealt with in a future report. More detail on the costings can be found in Part 7.

Creation of the new National Grid requires four main upgrades to the existing grid:

1. Extend the existing grids to enable transmission of power from solar and wind energy plants proposed in the Plan.
2. Interconnect the three main existing grids—NEM, SWIS and NWIS.
3. Upgrade connections within the existing grids to provide resilience and reinforcement
4. Introduce more centralised grid management including active load management via a Smart Grid.

The new high-voltage transmission links have been designed to connect into the key high-voltage distribution nodes of the existing grid. This means that the proposed upgrades

FIGURE 5.1
Australia's existing electricity grid

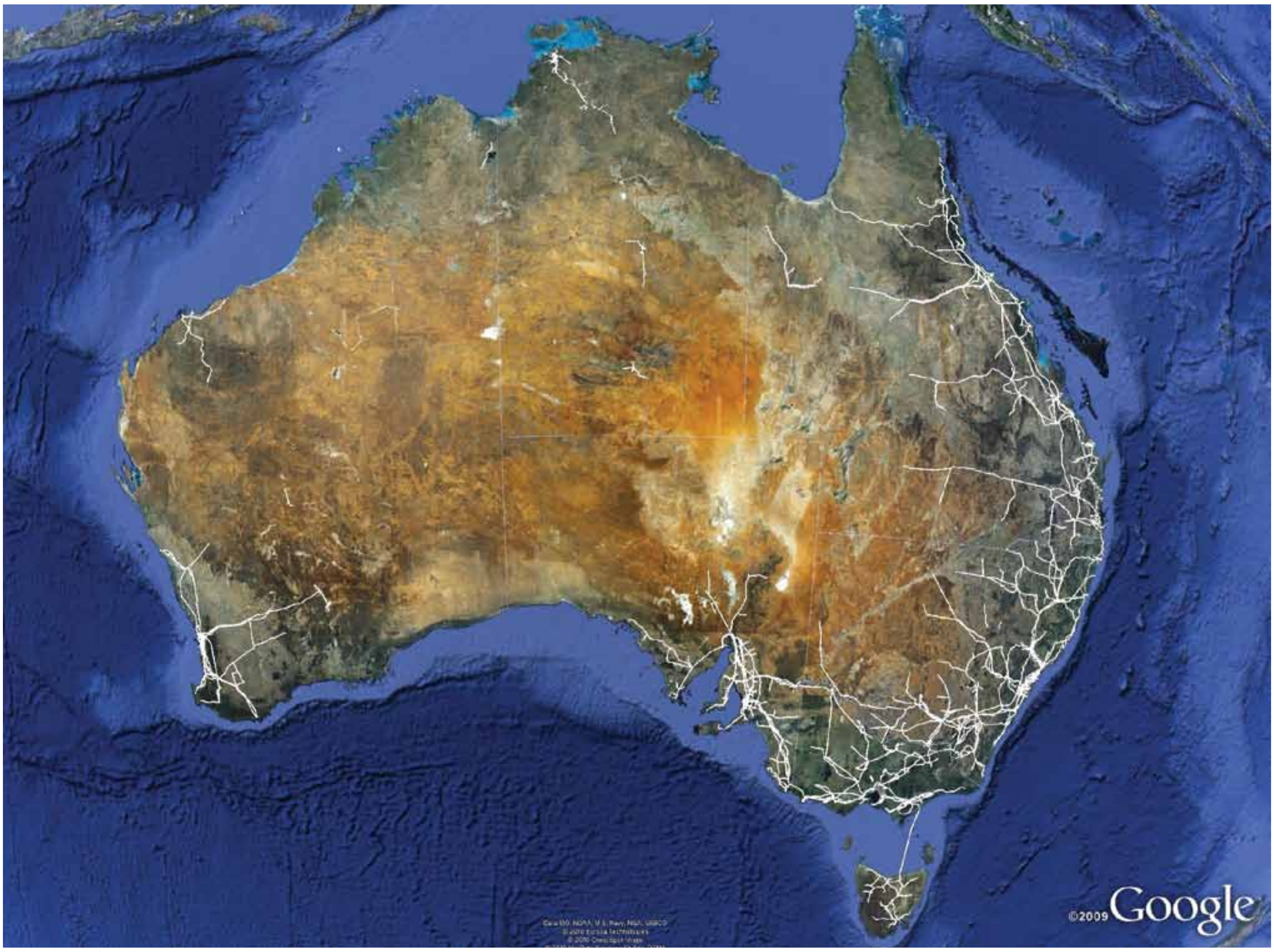
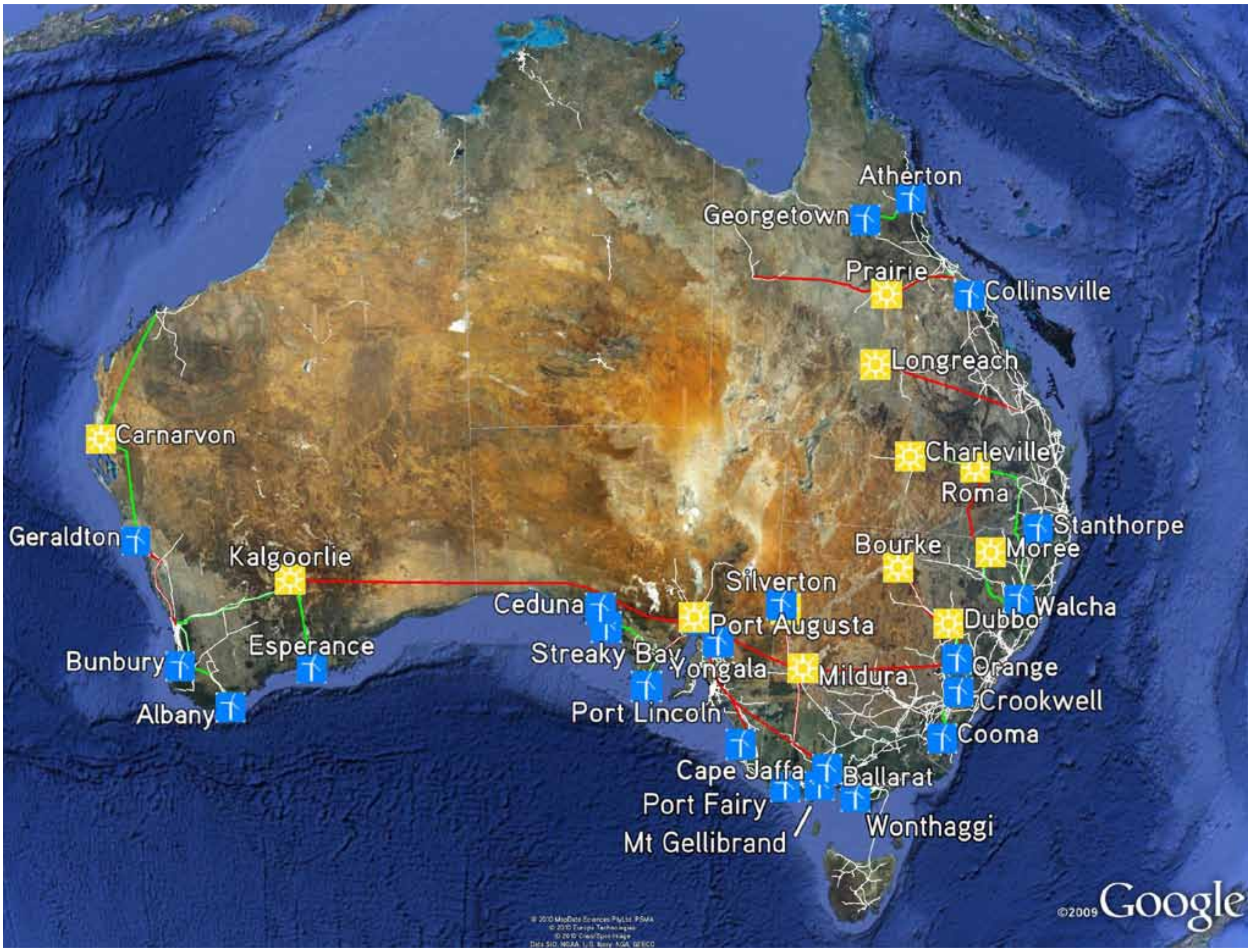


FIGURE 5.2
Proposed ZCA2020 National Grid
Solar sites are shown as yellow icons. Wind sites are shown as blue icons.
HVAC links are shown as green lines. HVDC links are shown as red lines



will easily merge with the present grid infrastructure and enhance the secure distribution of electricity around the country.

These new transmission links are shown in Figure 5.2 and Table 5.1, and discussed further in the sections below.

Table 5.1 shows all the proposed new transmission links, separated into categories of:

1. "Solar Plug-ins" and "Wind Plug-ins"—links required to connect the new renewable energy generator sites into the grid
2. "Grid Upgrades"—new links to improve the resilience and power flow through the existing NEM grid
3. "Inter-Grid"—links to interconnect the three main existing grids

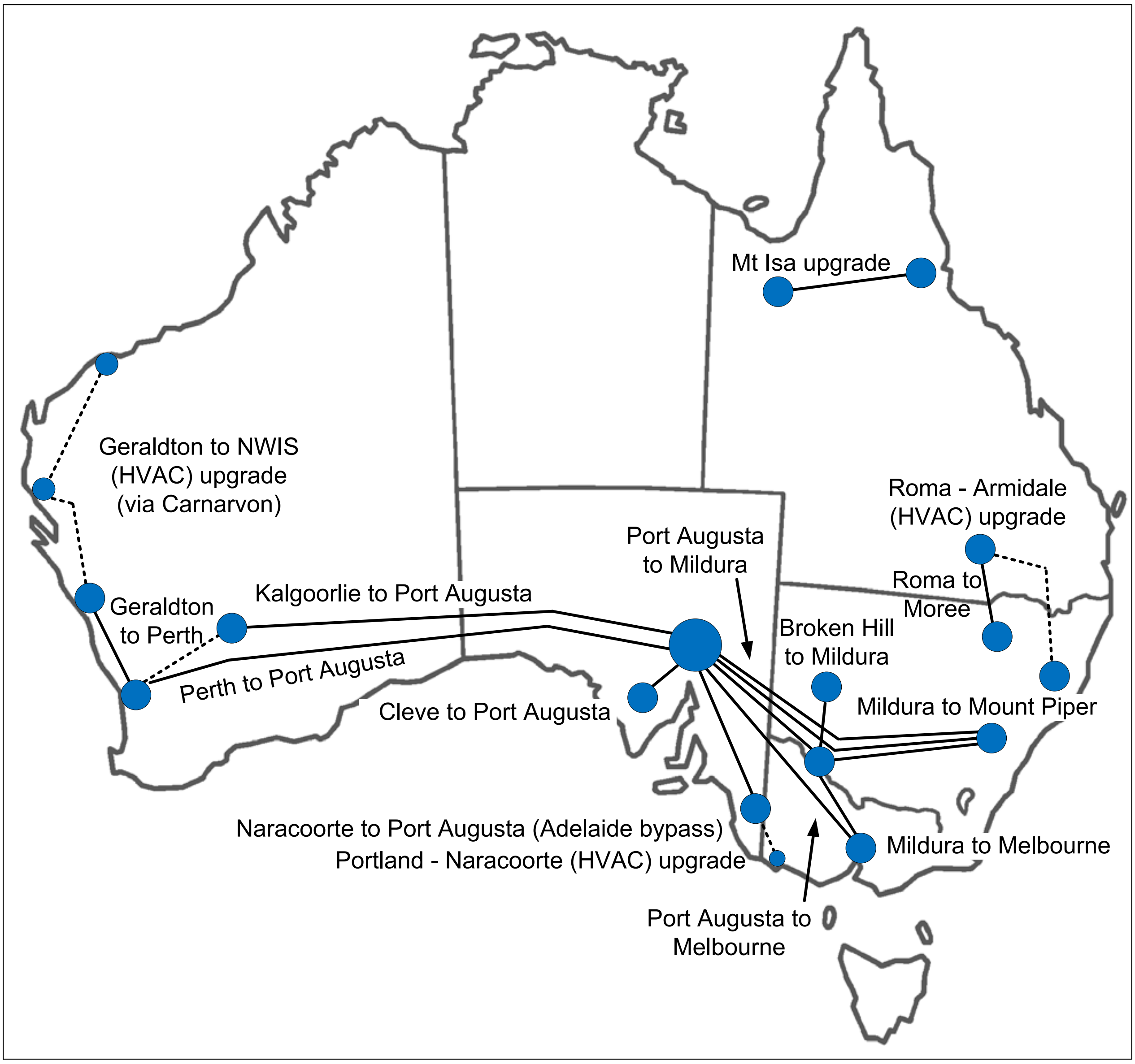
Role of High-Voltage Direct Current Transmission in ZCA2020 Grid

High-Voltage Direct Current (HVDC) is the most economical technology for long-distance bulk power transmission links. There are two parts to the cost of a link: cabling, and AC-DC converter stations (for inter-connections to the rest of the AC grid). HVDC links have relatively low cabling cost (approximately AU$1.2 million per kilometre [3]), and relatively high converter cost. Because of this, HVDC is more economical for long links, and HVAC for short links. However HVAC lines are also sometimes preferred for longer links, if multiple connections to the existing AC grid are needed along their length—this is because of the high cost of multiple converter stations.

The map of Figure 5.3 shows the proposed HVDC connections and long distance HVAC lines This shows how the HVDC lines are used for connection to remote solar generation sites and for grid interconnections.

The Plan requires the roll-out of some 23,300km of high-voltage transmission. These are summarised in Table 5.1 and explained below. Note that some corridors contain two parallel transmission lines, so the distances specified in Table 5.1 add up to less than 23,300km.

FIGURE 5.3
ZCA2020 proposed high voltage grid upgrades



5.1.1 Grid extension—connecting renewable energy plants into the grid

As outlined in Part 3, the ZCA2020 Plan proposes that solar and wind generators be located at sites chosen for optimal solar or wind resource, together with their proximity to major load centres and consideration of environmental and social factors. These sites need to be connected to the existing grid to deliver power to consumers. Table 5.1 shows the required grid extensions to connect the new renewable energy sources. The proposed capacity for each CST site is just less than 4,000 MW, so the transmission links connecting these sites to the grid are designed to carry 4,000 MW. The proposed capacity for wind sites is 2,000-3,000 MW, so the transmission links are designed to match.

The wind and solar sites at Port Augusta and the solar site at Mildura have not been specified with dedicated plug-in transmission links. This is because their final location would need to be worked out. However they are in close proximity to major transmission hubs, which are sized to meet the load from these generators.

5.1.2 Connecting NEM, SWIS and NWIS to form a National Grid

The creation of the National Grid (by interconnecting the NEM, SWIS and NWIS grids) will improve its resilience, by harnessing the geographical and energy supply diversity of the generators, and add redundancy (duplication providing alternate transmission paths in case of failure). A national integrated grid will smooth peak electricity demands across the geographical expanse of three time zones, whilst providing increased security of supply to consumers.

The two essential transmission projects to interconnect the NEM, SWIS and NWIS grids are:

1. The Western Australia-South Australia SWIS-NEM Connection - 2,146 km of 4,000 MW capacity HVDC. Despite the considerable length of this link, the estimated losses in worst case transmission scenarios would be six per cent. Another link via Kalgoorlie also serves as a connection point for the Kalgoorlie solar thermal power plant—1,586 km of 4,000 MW HVDC from Kalgoorlie to Pt Augusta, and 560 km of 6,000 MW HVAC from Kalgoorlie to Perth.
2. The SWIS-NWIS Connection - 561 km of 4,000 MW HVAC. This also connects the Solar Thermal plant at Carnarvon to the SWIS and NWIS grids. This has been specified as HVAC to allow plug-ins along the way, however the option of making this HVDC could be further investigated.

TABLE 5.1
Detail of ZCA2020 Transmission Lines

	Line name	Type	Length km	Power MW	Total Cost AUD$M
Solar Plug-ins	Carnarvon to Geraldton	HVAC	499	6000	$3,610
	Kalgoorlie to Perth	HVAC	560	6000	$3,895
	Broken Hill to Mildura	HVDC	262	4000	$1,936
	Bourke to Mount Piper	HVDC	567	4000	$2,293
	Dubbo to Mt Piper Direct	HVAC	249	3000	$1,220
	Moree to Armidale	HVAC	364	6000	$2,980
	Prairie Plug-in	HVAC	296	6000	$2,660
	Longreach Plug-in (direct)	HVDC	654	4000	$2,395
	Charleville to Roma	HVDC	311	4000	$1,993
Wind Plug-ins	Albany Plug-in	HVAC	430	3000	$1,643
	Esperance Plug-in	HVAC	363	3000	$1,487
	Geraldton to Perth	HVDC	440	4000	$2,144
	Bunbury Plug-in	HVAC	10	3000	$662
	Cleve to Port Augusta	HVDC	201	8000	$3,729
	Ceduna Plug-in	HVAC	327	3000	$1,403
	Yongala Plug-in	HVAC	125	3000	$930
	Port Lincoln Plug-in	HVAC	121	3000	$921
	Cape Jaffa Plug-in	HVAC	54	3000	$765
	Streaky Bay Plug-in	HVAC	269	3000	$1,267
	Port Fairy Plug-in	HVAC	61	3000	$780
	Ballarat Plug-in	HVAC	79	3000	$823
	Mt Gellibrand Plug-in	HVAC	56	3000	$769
	Wonthaggi Plug-in	HVAC	96	3000	$862
	Crookwell Plug-in	HVAC	86	3000	$839
	Dubbo-Orange-Mt Piper	HVAC	93	3000	$854
	Walcha Plug-in	HVAC	35	3000	$719
	Cooma Plug-in	HVAC	122	3000	$923
	Silverton to Mildura	HVAC	287	3000	$1,310
	Stanthorpe Plug-in	HVAC	98	3000	$867
	Atherton Plug-in	HVAC	62	3000	$783
	Collinsville Plug-in	HVAC	18	3000	$680
	Georgetown Plug-in	HVAC	272	3000	$1,274
				Subtotal, plug-ins	$49,416
Grid Upgrades	Roma to Moree	HVDC	417	4000	$2,117
	Port Augusta to Mount Piper	HVDC	1169	8000	$5,994
	Mildura to Mount Piper	HVDC	708	4000	$2,458
	Mildura to Melbourne	HVDC	544	8000	$4,533
	Port Augusta to Mildura	HVDC	461	4000	$2,169
	Port Augusta to Melbourne	HVDC	886	4000	$2,666
	Port Augusta to Naracoorte	HVDC	560	4000	$2,285
	Naracoorte to Portland	HVAC	216	6000	$2,286
	Roma to Armidale	HVAC	662	6000	$4,372
				Subtotal, grid strengthening & upgrades	$28,879
InterGrid	Mt Isa upgrade	HVDC	847	4000	$2,620
	Perth to Port Augusta	HVDC	2146	4000	$4,140
	Kalgoorlie to Port Augusta	HVDC	1586	4000	$3,485
	SWIS-NWIS Connection	HVAC	561	6000	$3,900
				Subtotal, national grid interconnections	$14,145
				TOTAL for ZCA2020 Grid	$92,440

Geographical Diversity

The increased geographical diversity of the new National Grid will have several major benefits for energy security:

- **Weather diversity:** For CST sites, the geographical diversity reduces the likelihood of extended cloud cover over several sites at the same time, and for wind sites it significantly increases the minimum reliable instantaneous power output available from the combined system.
- **Seasonal variability:** A mix of northern and southern latitude CST sites offsets the seasonal lows in solar radiation. The summer monsoon in northern latitudes is offset by high solar incidence in more southerly latitudes, and conversely, lower winter incidence in southern latitudes is offset by higher incidence in the northern latitudes during the dry season. Similarly, the seasonal variability between wind patterns along the southern coast and northern regions is minimised by the integration of all wind farms into one single grid.
- **Time differences:** The linking of CST plants in different time zones helps to extend the overall generation capacity of solar thermal. For example, Western Australian solar power can help to meet the early evening peak demand in the eastern states.

5.1.3 Increasing reinforcement and resilience within the existing grid

Network resilience is the ability of the network to continue providing service in the face of faults or unusual levels of demand. Network reinforcement is a term for additions to an existing network to improve its capacity or reliability.

Within the existing NEM eastern seaboard grid, there are significant capacity constraints on the interconnecting transmission lines, particularly between states.

The ZCA2020 Plan proposes upgrades to address these exisiting constraints. The upgrades are also designed to improve the flexibility and security of the network, by allowing capacity to ship significant power from one area to another. To maintain security of supply under the Plan, it is necessary to be able to readily send power from one region to another. This can help lower electricity costs by eliminating the need for localised peak generation units, such as gas power plants, as power can flow from a region of high reserve capacity to regions of low capacity and high demand. Under the Plan, due to the large wind and solar resource, and the gain from diversity, power generally is sent eastward. This contrasts with today's NEM grid where a net surplus of power is typically sent west to South Australia.

- **Portland to Port Augusta upgrade**: It is recommended that the existing 500kV transmission line from Melbourne, which terminates at the Portland Aluminium Smelter, be upgraded with an extension to Naracoorte in South Australia and then a HVDC line to Port Augusta. This will be achieved with a 560km 4,000 MW HVDC line between Port Augusta and Naracoorte, and continued with a 216km 6,000 MW HVAC line between Naracoorte and Portland.

- **Port Augusta to Hunter Valley (Mt Piper) link**: It is recommended that 1,169km of 8,000 MW capacity (2 x 4,000 MW) HVDC transmission line be built to allow wind and solar power generated in the west to be shifted east to supply the major demand centre in Australia (Wollongong—Sydney—Newcastle). The transmission line will run from Port Augusta via Mildura across South Western NSW to the existing generation hub in the Hunter Valley.
- **QLD-NSW import/export upgrade**: Currently the connection between the Queensland and New South Wales grids has a capacity of only about 1,150 MW. This is provided by the QNI and Terranora interstate connections [4]. However there is significant export potential southwards from Queensland (16,000 MWe of solar thermal and 13,000 MW of wind power). To allow greater flow of electricity between these two states, the Plan recommends a 417 km link of 4,000 MW HVDC from Roma-Moree and a 662 km link of 6,000 MW HVAC from Roma-Armidale.

5.2 Control of Supply and Demand

The creation of a national grid and the integration of country-wide renewable energy generators will require some management and control mechanisms for forward organisation of supply and demand correlation.

Under the current electricity system, baseload generators provide power for most periods of the day, however peakload power is needed for a few short periods when power demand increases significantly. A typical cause of these peaks is when air-conditioners are switched on simultaneously in mid afternoon in summer.

The ZCA2020 Plan combats this variation in demand both through system design and active load management, using Smart Grid technologies. The Plan also requires the active monitoring of country-wide weather events to choose the proportions of power supply source (wind, CST, biomass, hydro) utilised to maintain energy supply.

The Plan involves the retrofit and redesign of commercial and domestic buildings to minimise the need for heating and cooling, while also converting from gas heating to electric heat pumps. This will help to reduce peak energy demand and also allow for control over the timing of heating and cooling during non peak periods.

SmartGrid[5] is an umbrella term for a set of modern grid management technologies which can be combined to coordinate the control of demand and supply across a national grid. It is an information and control system, which can send information and commands from generation to load and vice versa. The term was developed to highlight the shortcomings of conventional grids, which provide very little real-time information to controllers and consumers, and hence are insufficient to deal with the emerging complexity of modern electricity networks.

5.2.1 Minimising Peak Demand

The ZCA2020 Plan involves a system design in which the overall extra generating capacity needed to meet peak demand is reduced relative to the current requirements. A major cost in the existing electricity system is the installed capacity needed to meet peak demand. Figure 5.4 shows the large difference between current average demand and the total installed capacity to meet the peak demand.

The ZCA2020 Plan makes these changes to the energy demand pattern:

- Reduction in total stationary energy demand, through building efficiency programs which reduce the overall need for heating and cooling.
- Conversion of gas heating to more efficient heat pumps, which reduces overall energy demand, while increasing total electricity demand. However, given that a large part of total current gas use is for industrial applications, which is a relatively stable demand, this reduces the variability (ratio of peak to average) of electricity demand.

In addition the electrification of heating, in conjunction with an active load management system, enables the deferral of heating and cooling load to smooth out peaks in demand. This significantly reduces the overall installed capacity required to meet peak demand, as the load is distributed across a longer time frame, flattening the instantaneous peaks generated when consumers turn on air-conditioners or heaters simultaneously. Deferral of electric vehicle charging also provides a form of load management.This is discussed in section 5.2.4.

A simplified presentation of the components of energy supply and demand is shown in Figure 5.4.

Here the total current annual energy demand (213 net TWh/y) is converted to an average power figure (24 net GW). The current installed capacity to meet maximum demand is 45 GW. The difference (21 net GW) is then considered power for meeting the demand for intermediate and peak loads only.

This is compared with the components that make up the demand under the ZCA2020 Plan. These components are:

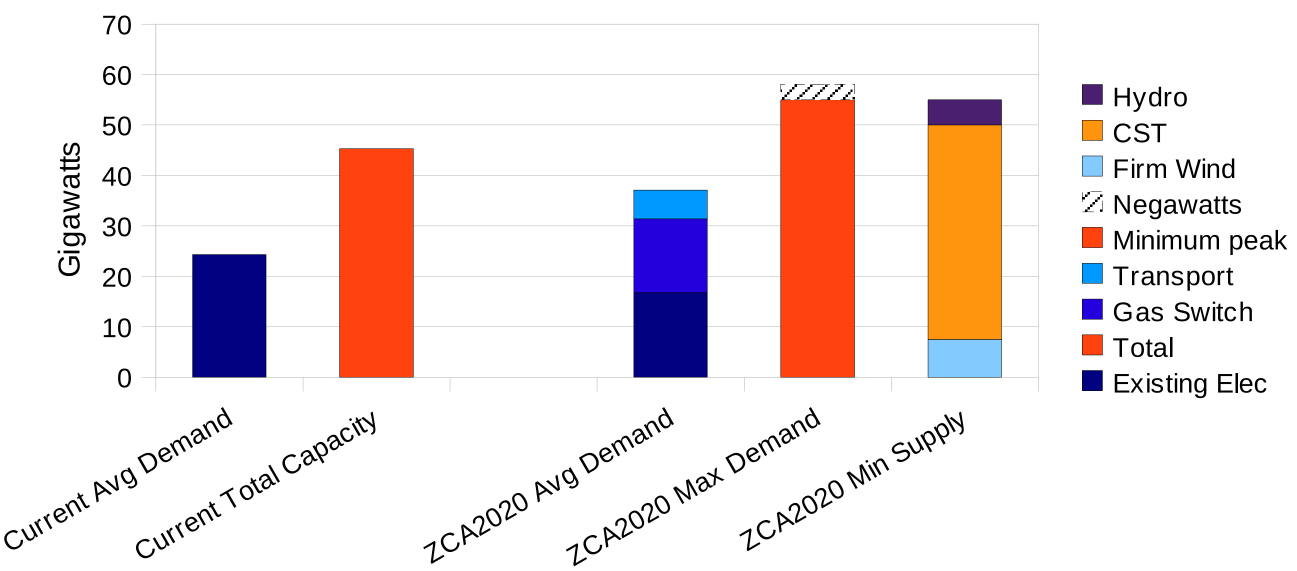
- The present average electrical energy demand, reduced by 30%, which is the projected contribution from energy efficiency programs and distributed solar PV generation. The annual average of this demand is shown as 'Existing elec' in Figure 5.4.
- The expected increase in average electricity demand due to the conversion of industrial gas applications to electricity (shown as 'Gas Switch').
- The extra average amount of electrical power needed to charge electric vehicles and for increased public transport (shown as 'Transport').
- The additional provision for meeting peak loads is initially assumed to be equal to that for the current demand pattern (21 GW on top of the average of 37 GW), but this is reduced by a 3 GW allowance for 'Negawatt' reductions in peak demand, to give an overall maximum demand of 55 GW.

With a normal wind output, there is a comfortable excess of installed generation capacity to meet peak demand. In the worst case scenario of low wind and low sun, there is a minimum of 55 GW reliable capacity. It is projected that 15%, or 7.5 GW, of wind power will always be available. The 42.5 GW of solar thermal turbine capacity can be called upon at any time, with up to 15 GW of this turbine capacity backed up by biomass heaters. The 5 GW of existing hydro capacity is also available on-demand.

Negawatts can be conceptually understood as real decreases in necessary installed generating capacity, due to real reductions in overall peak energy demand [6]. In the ZCA2020 Plan, Negawatts are achieved through energy efficiency programs which have the effect of lowering both overall energy demand and peak electricity demand, and the time shifting of loads due to active load management. Normally wind energy will operate somewhere between the minimum firm amount and the maximum peak output amount, so the reliance on Negawatts will only arise on a few occasions during the year. The economic incentive for these Negawatts is that they cost less than the extra installed generating capacity that would otherwise be required for only a few short periods in the year [7].

It should be stressed that this is only a simplified representation of the real peak and non-peak demand requirements of the system. Future work needs to be conducted to determine the actual peak demand expected in the proposed renewables grid, and the amount of reduction in peak demand that can actually be achieved. The latter will be dealt with in the Buildings and Industrial Processes Reports. However, the demand values assumed here are considered to be conservative.

FIGURE 5.4
Illustration of peak and average generation capacity for current and projected demand



5.2.2 Supply Side Management

The variable nature of the wind and solar resource will require active monitoring of Australia-wide weather events to plan the proportion of power supplied from the different energy sources in the grid.

For example a weather pattern providing good consistent wind resource at a number of wind farm sites would allow the CST plants to keep more heat in storage. On the other hand a large storm front hitting the south eastern states could cause a sharp loss of power, as wind turbines are shut down at high wind speeds to avoid any damage. In this circumstance wind turbines would go from producing at maximum output to producing nothing in the space of minutes. Such an event would need to be planned for in advance, with CST plants ready to dispatch power to ensure supply continuity. If this event coincided with a forecast period of low solar incidence, the biomass boilers would need to be switched on a few hours in advance so that they are operating at sufficient capacity to heat the molten salt storage tanks to meet the loss in supply. Hydro-electric power can also be rapidly dispatched in situations of unexpected change in weather conditions, to provide an additional back-up.

In most cases the system will operate with a reserve capacity, either stored energy in the molten salt storage tanks, or via curtailed wind turbines to avoid power oversupply. This reserve power can be rapidly deployed to increase the total energy supply, during peak periods. For example, during periods of high wind resource, curtailed wind turbines can act as a form of 'spinning reserve' [8] (reserve turbine capacity in terms of today's baseload plants), because wind turbines temporarily turned out of the wind can be rapidly returned to full power generation.

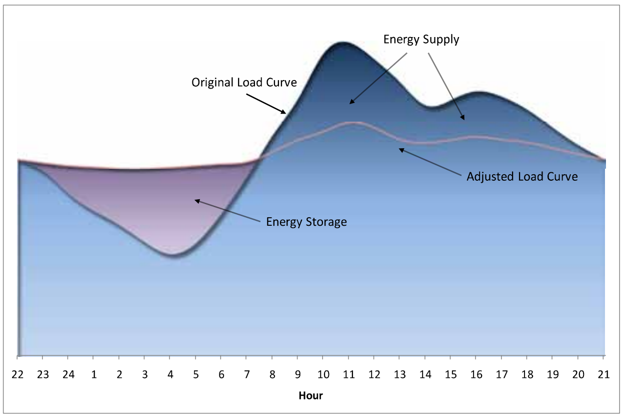
5.2.3 Demand Side Management

Smart Grid can allow reductions in peak load, either by bringing forward some expected demand, based on advanced forecasting, or by delaying load from non-essential services, or by load shedding, during demand peaks. Currently the price of electricity increases sharply during high demand periods (see Part 2) and decreases during low demand but these variations in price are absorbed by the electricity retailer, and ultimately passed on to the consumer. Thus, the incentive for consumers to adjust demand is lost.

Smart Grid allows demand-side management. If consumers are equipped with smart grid tools, they can make price-based decisions not to use heating and cooling, charging of cars, etc. during times when the demand would otherwise be high, or when supply is low. This provides an incentive to ease system congestion and reduce the need for new infrastructure.

In the future, incorporating technology that allows common appliances to communicate with smart meters may offer

FIGURE 5.5
Hypothetical Daily Demand Profile Including Storage



the opportunity for innovative ways of managing the load to help smooth the peaks in demand.

Figure 5.5 shows an illustrative example of smoothing the load peaks, in an area of the network where demand from commercial buildings in Summer peaks around midday. The "Original Load Curve" shows normal demand peaking before lunch. The "Adjusted Load Curve" (pink line) shows a reduction in the peak, that might be created by bringing forward the demand from some loads[9]. Some examples of loads that could be re-scheduled for peak smoothing are given in the next section. All of these examples have some form of energy storage, and so have the potential to be intelligently re-scheduled either earlier or later in time.

General Electric estimates that installing smart meters in 25% of American homes would be an equivalent energy reduction to removing 1.7 million cars from the roads[10].

5.2.4 Examples of Scale

Some examples of the scale of the proposed contribution to load management are:

Cars—The ZCA2020 Transport Plan involves a significant modal shift from private passenger vehicles to shared electric rail vehicles, with the car fleet reducing by around 50%. The result is that the average car travels 8,000 km per annum instead of 15,000 km today. It is estimated that, across Australia, there would be six million pure electric, plug-in hybrid electric, and battery swap electric vehicles. These can be charged using standard domestic power sockets. Off-peak charging could reduce peak demand on the electricity system by 650 MW or more (where 650 MW is the average charging rate for a full vehicle fleet - see Part 2.2.4).

Usually vehicles are left plugged in for an average of 22 hours per day (at work and home), meaning that charging can be scheduled for any time during that period. Electric car charging would only be scheduled for non-peak times, and assuming that the cars are trickle-charged over a period of 13 hours (so excluding morning and evening peaks), this would require 2,000 MW of capacity. Some or all of this 2,000 MW could be shed at a moment's notice to help deal with peak electricity loads. It has also been suggested that another potential benefit of electric vehicles is the possibility that car batteries can be used to feed electricity *back into* the grid, to increase peak electricity availability (Vehicle-To-Grid charging). However, this is not yet commercial, and the leading electric car infrastructure supplier, Better Place, is not considering this as an option for their cars in the near-term[11].

The most desirable option is to time the charging of cars to coincide with the periods of greatest solar and wind resource, thus helping with load management. When a correlation of high wind and solar incidence occurs across the geographically diverse grid, charging can be used as a "dump load". In this case the "dump load" is useful, profitable and valuable, both to society and to electricity consumers.

Space Heating—Space heating aims to heat buildings to a constant, comfortable temperature, typically 20°C. Under the ZCA2020 project, traditional gas space heating can be converted to electric heat pumps. Suitably equipped households and businesses can have their heating re-scheduled to non-peak times, using low-priced surplus electricity. For example, demand forecasting can be used to predict surplus electricity generation, and buildings can be preheated to 24°C during the lower demand period before the peak arrives, and then allowed to cool slowly over several hours during the high demand period.

Hot water systems—Hot water systems that use heat pumps or direct electric-boost could also be useful for load management, by accepting redirected surplus electricity. Assuming, for example, 5 million households with hot water heat pumps and typical power consumption of 500-1,000 W each[12], the potential flexibility in peak load is 2,500-5,000 MW. This is an extension of traditional off-peak hot water where households had separate meters for peak and off-peak power consumption.

Refrigeration—Existing refrigerators could be supplied from dedicated smart meter circuits to allow for central grid management, and new smart refrigerators can progressively replace the existing stock to interact more directly with the network, pre-empting and deferring refrigeration loads while keeping temperatures within acceptable tolerances. Domestic refrigeration can be switched off during periods of high demand or low supply, with limited impact on performance. Commercial refrigeration systems can be adapted to make ice for 12 to 16 hours per day and then melt ice for 8 to 12 hours per day in order to smooth the overall demand.

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Part 6

Resourcing the Transition — Implementation

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The transition to 100% renewable energy in ten years is achievable, given Australia already has a large industrial capability. Our human and material resources are far in excess of those required to implement the ZCA2020 Stationary Energy Plan.

The ten-year timeline has been mapped out taking into account a gradual scale-up of the renewables industry, which would see most of the proposed infrastructure completed in the second half of the decade.

The large-scale conversion to renewable energy technologies globally will require large amounts of material, technological and human resources. In Australia, we are in an enviable position to exploit renewable energy sources, given not only our abundance of wind and solar resource, but also an abundance of the raw materials needed to construct wind and solar plants.

The bulk of raw materials required for the construction of a 100% renewable grid are not in short supply domestically or globally. Over 99.5% of all materials required to construct new renewable energy systems are "basic construction materials and metals abundantly available"[1]. Studies in the Australian context indicate that the supply of core materials will not be constrained during the construction of the ZCA2020 Plan, because the resources required only represent a fraction of Australia's total production capacity.

At the peak of installation, the Plan would require over 80,000 construction workers, only 8% of Australia's existing construction workforce, which has already shown it is capable of ramping up at a faster rate than called for by the Plan.

The Plan calls for expansion in our manufacturing industry to include the production of heliostats and wind turbines. This would create over 30,000 new jobs, setting Australia up with new renewable industries, ready to take part in the global clean energy economy.

In transitioning from an energy industry based on extracting and using fossil fuels to an energy industry based on solar plants and wind farms, more jobs will be created than lost. Renewable energy power plants, in most cases, are somewhat more labour intensive in their operation and maintenance than fossil fuel power plants, which is offset by not having fuel costs. The Plan will require over 45,000 ongoing people in operations and maintenance jobs. This compares with current employment of approximately 20,000 people in producing stationary energy from fossil fuels.

The amount of greenhouse emissions due to constructing the new system are not insignificant, but these emissions are recovered in only 2 months of operation of the new system, because the new system avoids the continuing emissions of the present fossil fuel system.

6.1 Implementation Timeline

The implementation of the ZCA2020 Stationary Energy Plan will require a scale-up of construction and manufacturing capability. It is recognised that with any moves to new industries, changes do not happen overnight, and this has been taken into account in the modelling of the ten year implementation period.

The timeline for installation under the Plan has been modelled over the period January 1, 2011 to December 31, 2020, representing a ten-year transition period. An initial ramp-up in the first few years leads to a constant rate of construction in the later years until completion of the Plan. The modelling has been carried out over 6-monthly intervals. Alternative scenarios could see a slow growth rate in earlier years with continued higher growth in later years.

Significant economies of scale and efficiencies can result from the planned roll-out of modular equipment. The engineering for solar power towers does not need to be repeated for each single unit. Once the design and planning is complete for one of the 13 Solar 220 modules that will be built at each of the 12 solar sites, all that is required is the replication of the same construction job another dozen times. As the companies and workforce scale up and gain experience, it is expected that the installation timeline will become faster and more efficient.

A constant pipeline of projects ensures that component factories for producing wind turbines and heliostat mirrors can run with continuous output, making the most efficient use of their capacity, as opposed to stopping and starting for individual projects. Sourcing of some components that are cheaply and easily transported from overseas may be an economical option, however there is significant advantage to be gained from doing a portion of manufacturing onshore. Large components such as 60-metre wind turbine blades (in 30-metre sections) and 12m x 12m heliostats are well-suited to being assembled close to their point of installation to minimise transport. It is also expected that as other countries ramp up renewable energy installations, there will be greater demand and competition for overseas components. Onshore manufacturing will ensure greater reliability for sourcing components on time. As domestic installation declines, Australia would be well set-up to export components and skills to the rest of the world, positioning itself as a renewable energy leader.

FIGURE 6.1
Windpower Installation Timeline

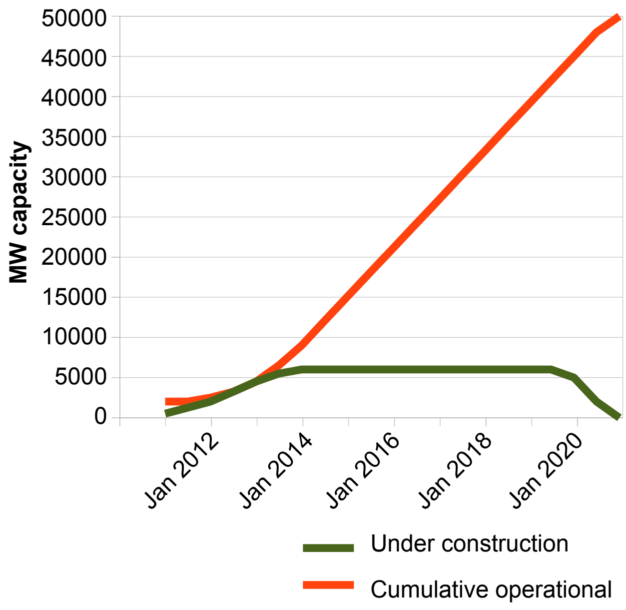
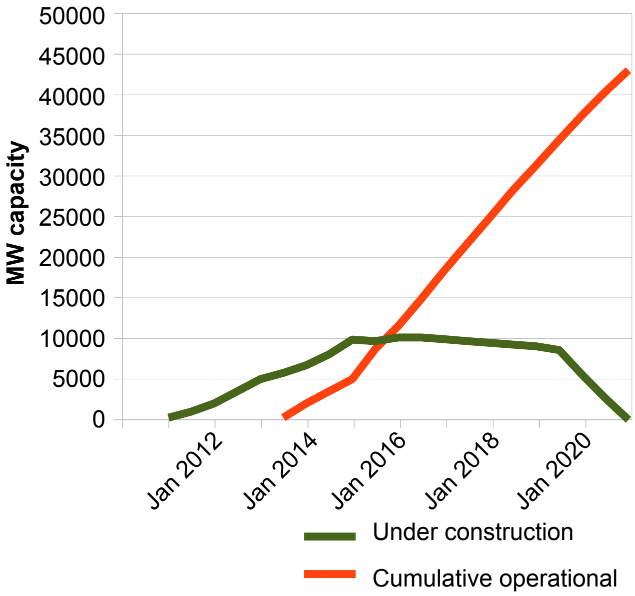


FIGURE 6.2
Solar Thermal Installation Timeline



6.1.1 Wind Power Timeline

The proposed installation timeline for wind turbines is described in Part 3, and summarised in Figure 6.1. This shows the capacity under construction at any one time (green line), and the cumulative completed capacity (red line).

By January 2015, operational wind capacity will be 15,000 MW (which meets 14% of total electricity demand). From 2014 onwards, the installation rate is 6,000 MW per year. This equates to 800 turbines of 7.5 MW capacity per year. Currently in Australia the operational wind power capacity is 1,700 MW[2]. With the addition of projects currently under way this capacity will be around 2,000 MW by the end of 2010. As noted in Part 3, coordination is required with the 11,000 MW of wind projects already at various stages of development and planning around Australia, many of them with projected completion dates in the period 2011-2014[3].

6.1.2 Solar Thermal (CST) Power Timeline

The proposed timeline for on-grid CST is shown in Figure 6.2. CST capacity is projected to grow initially at a slower rate than wind capacity. By January 2015, the operational CST capacity (on-grid) will be 5,000 MW (which meets 11% of total electricity demand). From 2015 onwards, the installation rate is constant at about 10,000 MW per year at the 12 main sites.

In addition to this on-grid CST, the Plan calls for construction of 4,475 MW of CST capacity at off-grid sites during the 2015-2020 period.

The early timeline allows 2.5 years for the construction of a plant, as with the Solar Reserve projects. The later part of the timeline allows 1.5 years construction timeline per CST plant, as with the Andasol projects[4]. At the peak of construction, this will require the installation each year of 30 large concrete towers, and 600,000 148 m^2 heliostats.

6.1.3 Transmission Installations

The Plan requires construction of 23,300 km of high-voltage 500 kV transmission line (HVAC and HVDC) by 2020, as some of the proposed transmission lines are double-circuit. The highest priority is for lines that allow connection of the new solar and wind sites to the grid—7,500 km of lines, which need to be completed by 2015. From that time onwards, the Plan calls for 4,500 km/year of new line.

6.2 Material Resources

6.2.1 CST — Concrete, Steel and Glass

The main resource requirements for large-scale CST plants incorporating power tower technology and molten salt storage are:

- Concrete
- Steel
- Glass
- Sodium/Potassium Nitrate Salt (Fertiliser)

All of these materials are already produced in very large quantities in Australia and globally. The Stationary Energy Plan would require on average 7% of Australia's annual output of concrete, for construction of solar thermal and wind plants. Australia's construction industry already uses over 60 million tonnes of concrete per year. The Plan would require only minor growth in concrete production, or alternatively a small re-scheduling of activities.

Over 95% of the materials in a solar thermal plant are contained within the heliostat field[5]. The type of heliostat currently specified in the Plan consists of a large mirror surface of around 50–150 m^2, mounted on a steel pedestal which is held in the ground with concrete foundations. Large heliostats of this type tend to be more resource efficient and cheaper than smaller heliostats (with the notable exception of the eSolar type racked heliostat field). The resource requirements for the Plan have been calculated using available data for the ATS 148, a 148 m^2 heliostat designed by Sandia Laboratories[6].

Though costing and design is based on the conventional large heliostat model, for comparative purposes the resource requirements for eSolar mirror fields have been calculated as well. This very innovative approach to heliostats uses much less in the way of materials, land and installation labour. While the eSolar technology is currently only used for daytime direct-steam generation in small modules (46 MWe), if their mirror field design could be adapted for large-scale molten salt power towers, it could significantly save on resource requirements, installation time and ultimately cost.

For the entire 47 GWe of concentrating solar thermal installations under the Plan, the total basic resource requirements are shown in Table 6.2.

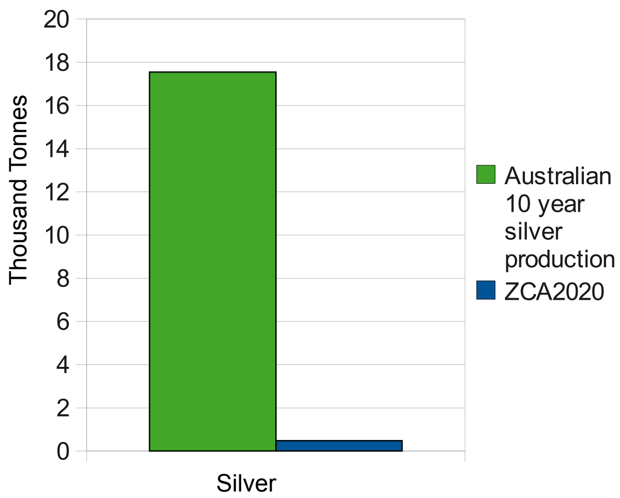
TABLE 6.1
Heliostat Resource Requirements

Heliostat resource requirements kg per mirror square metre		
	ATS 148	eSolar
Steel	31.9	15.8
Glass	10.0	7.8
Concrete	31.0	23.9

TABLE 6.2
Total CST Resource Requirements

Total CST resource requirements Millions		
	ATS 148	eSolar
Steel (tonnes)	18.2	9.0
Glass (tonnes)	5.7	4.5
Concrete (tonnes)	21.8	17.8
Concrete (m^3)	9.1	7.4

FIGURE 6.3
CST Silver Requirements



Mirror Silver

Mirrors are manufactured with a thin film of silver on the back of the glass. However the silver requirements are very low. Even high-quality precision glass, specially made for concentrating solar power, only requires 75mg of silver per square foot of glass[7]. Australia was the world's 4th largest producer of silver in 2008 with 62 million ounces[8], or 1,755 tonnes per year. In context, the ZCA2020 Plan would require only 460 tonnes over the ten years.

Solar Salt

Solar salt is a mix of 60% sodium nitrate with 40% potassium nitrate. These materials are very common—nitrate salts are made by the oxidation of ammonia, one of the world's highest volume production chemicals, while sodium and potassium are also very common components of the Earth's crust. Initial CST projects use a two-tank molten salt system, with separate hot and cold tanks. However Sandia Laboratories have run successful trials on a single tank thermocline system, where the layering effect due to density differences keeps the hot salt floating on top of the cold salt. Low cost quartzite is used as a filler for thermal mass, displacing a significant amount of the salt required with even more

TABLE 6.3
Material resources for 2 MW wind turbine installed in La Rioja, Spain[10]

			Materials (t)						
Component	**Sub-component**	**Weight (t)**	**Steel**	**Concrete**	**Iron**	**Resin**	**Fibreglass**	**Copper**	**Silica**
Rotor	Three blades	19.5				11.7	7.8		
	Blade Hub	14			14				
	Nose cone	0.31				0.186	0.124		
Foundation	Footing	725		700	25				
	Ferrule	15	15						
Tower	Three sections	143	143						
Nacelle	Bed frame	10.5			10.5				
	Main shaft	6.1	6.1						
	Transformer	5	3.3					1.5	0.149
	Generator	6.5	4.29					2	0.195
	Gearbox	16	8		8				
	Nacelle cover	2				1.2	0.8		
	Total	**962.91**	**179.69**	**700**	**57.5**	**13.086**	**8.724**	**3.5**	**0.344**

readily available materials. This system uses only 32% of the salt of a regular two-tank molten salt system[9]. The ZCA2020 Plan would require 17.5 million tonnes of nitrate salts if two-tank systems were used, or only 5.6 million tonnes for thermoclines. The Plan recommends the use of thermocline systems for this reason.

6.2.2 Wind — Concrete and Steel

The main raw materials required in the construction of wind turbines are steel and concrete. Relatively smaller amounts of glass fibre reinforced plastics (fibreglass) and resin are also required.

Studies are available quantifying the raw resources (tonnes) needed for wind turbines. However, due to market maturity, comprehensive data is only readily available for 2 MW turbines. The results of one study into the requirements of a 2 MW wind turbine are in Table 6.3.

6.2.3 Transmission Lines — Concrete, Steel and Aluminium

The ZCA2020 plan requires construction of 23,300 km of high-voltage 500 kV transmission line by 2020. This is made up of 16,700 km of HVAC, 9,600km of HVDC and requires 39,000 transmission towers.

The main resources required for manufacturing transmission lines are concrete, steel and aluminium. A summary of the required resources is shown in Table 6.4.

Further detailed information on Resource Requirements can be found in Appendix 8.

TABLE 6.4
Transmission Resource Requirements

Transmission materials	
0.67	million tonnes steel for transmission
0.18	million tonnes aluminium for conductors
1.81	million tonnes concrete for transmission

FIGURE 6.4
Aluminium Requirements

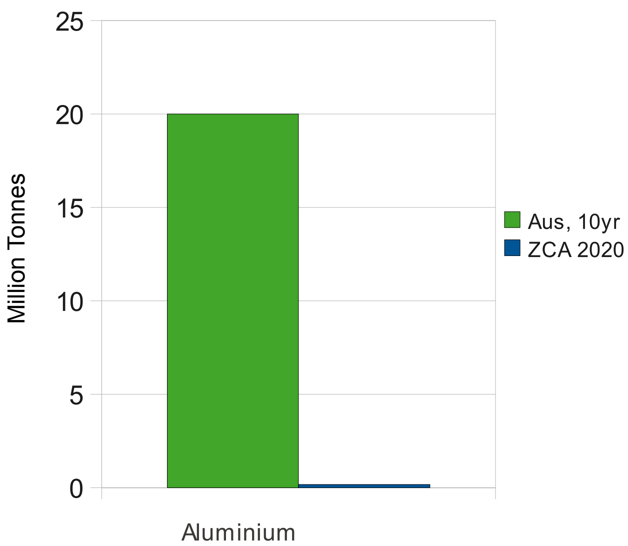


FIGURE 6.5
ZCA Concrete Requirements

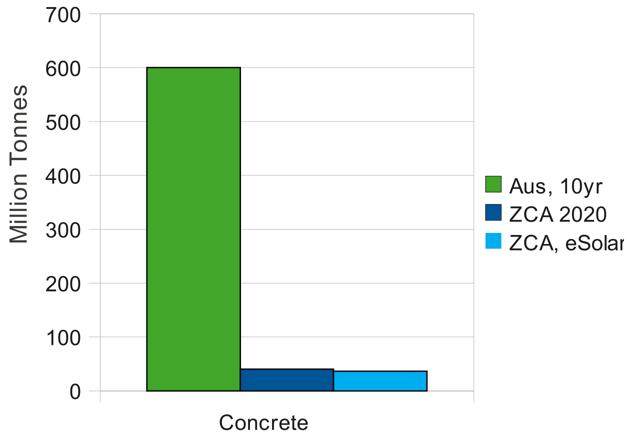


FIGURE 6.6
ZCA Steel requirements including Steel and Ore Exports

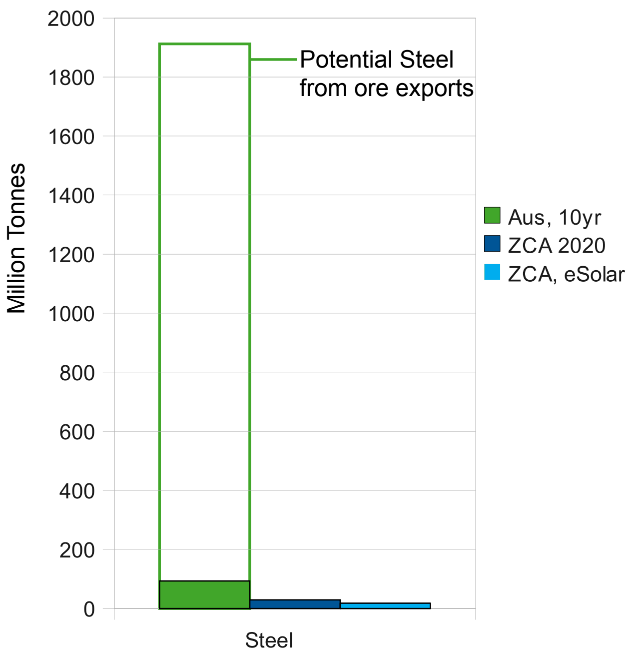
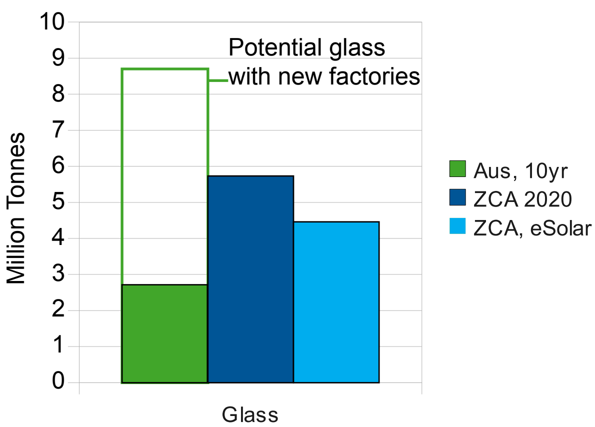


FIGURE 6.7
CST Glass Requirements including new factories



6.2.4 Total Concrete, Steel and Glass

The following results show the total material resources required for CST, Wind and Transmission lines.

Concrete

Australia currently produces 25,000,000 cubic metres of concrete[11] (60,000,000 tonnes) per year. Over the 10 year period of construction, the ZCA2020 Plan requires 40,500,000 tonnes. This comprises the concrete for CST plants, wind plants and transmission lines. This total is only 6.8% of Australia's total concrete production over the 10 year time frame. It is therefore realistic that the required amount of concrete could either be supplied from current production, or by a small expansion of production capacity.

Steel

Australia currently produces 7,860,000 tonnes per year of steel[12]. Therefore, over ten years, it is assumed that at least 78.6 million tonnes could be produced. Construction of solar thermal, wind power plants and associated transmission lines for the Plan requires 24.6 million tonnes of steel (or 15.8 million tonnes if eSolar-style mirror fields were deployed—this demonstrates the value of investing more R&D into exploring the eSolar heliostat option). While the Plan may appear to require a sizeable proportion (20%-30%) of Australia's steel production, it must be pointed out that some of this requirement could be met by imports, or by expanding the domestic industry. Australia exported 267 million tonnes of iron ore in 2007 alone[13], which would eventually be smelted into 183 million tonnes of steel[note 1]. When taking this 'potential steel' into account, it is clear that meeting the ZCA2020 steel requirements from domestic and international sources should not impose any significant constraint.

Glass

The amount of glass required for manufacturing heliostats under ZCA2020 is large compared with current domestic production. The Australian glass industry however is relatively small, with Viridian (CSR) being the single major manufacturer (270,000 tonnes/year[14]). The required quantity of 5.8 million tonnes (or 4.5 million tonnes for the eSolar heliostats) could be met from the output of two large (300,000 tonne/yr) glass factories, similar to that recently announced by glass manufacturer Saint-Gobain in India at a cost of INR 10 billion, or $AU250 million[15].

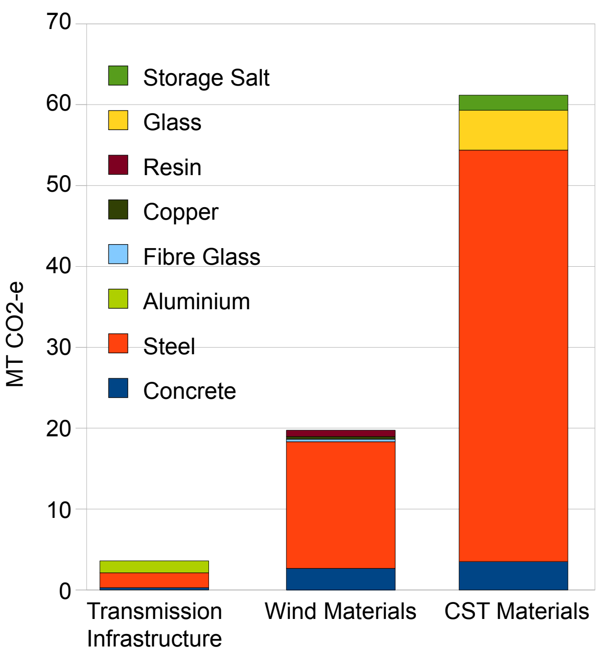
6.3 Emissions Resulting from Construction

Stationary energy, including electricity, is responsible for more than half of all Australian emissions[16]. Implementing this Plan could therefore reduce Australia's emissions by more than half. The total emissions produced in commissioning the Plan (materials, construction, etc.) are only a fraction of the overall reductions achieved—a tiny "emissions-investment" with a huge return in emissions-saving.

For conventional fossil fuel energy sources, most of the lifetime emissions originate from the fuel that is consumed in operating the plant. The emissions are produced in mining, processing and transporting the fuel to the plant, and then in the final consumption of fuel in the plant. In contrast, wind and CST sources need no fuel for their operation. Therefore their emissions per kWh are low (see section 2.5.9), with over 90% of their lifetime emissions coming from manufacture of the required construction materials. The remainder comes from transport of the materials, and from plant construction and ongoing maintenance.

The bulk of the materials-associated emissions are due to the iron/steel and concrete requirements for both wind and CST. Minor contributions come from resin, fibre glass and copper (for wind), and glass and the thermal storage salt (for CST), as well as materials for the transmission infrastructure. The contribution from other building materials (such as plastic insulation, protective paint, silver and other metals, etc.) is marginal by comparison[10,17,18].

FIGURE 6.8
Manufacturing Emissions



6.3.1 CST Related Emissions

Using the data for the ATS 148 heliostat design (slightly more materials intensive than the eSolar design) and the thermal storage requirements for the proposed 47 GW of CST power, the material manufacture results in emissions of some 60 Mt CO_2-e. The majority of this is due to the steel requirements of the mirror fields which could be reduced as proposed by the eSolar option.

TABLE 6.5
CST Materials and Associated Emissions

Materials	Mt required for 47,000MW	$t(CO_2\text{-e})/t(\text{material})$	Mt CO_2-e
Concrete	22.1[6]	0.159[19]	3.51
Iron and steel	18.5[6]	2.75[19]	50.88
Glass	5.8[6]	0.85[19]	4.93
Storage salt	5.6[9]	0.33[20]	1.85
		Total	61.17

6.3.2 Wind Related Emissions

Based on the data available for the material requirements of the above mentioned 2 MW facility in La Rioja, Spain, and scaled to meet the proposed additional construction of 48,000 MW of wind power, the manufacture of the materials would result in some 20 Mt CO_2-e.

TABLE 6.6
Wind Materials and Associated Emissions based on 2MW facility in La Rioja, Spain

Materials	Mt required for 48,000MW	$t(CO_2\text{-e})/t(\text{material})$	Mt CO_2-e
Concrete	16.8[10]	0.159[19]	2.67
Iron and steel	5.69[10]	2.75[19]	15.66
Resin	0.31[10]	2.5[19]	0.79
Fibre glass	0.22[10]	1.53[19]	0.33
Copper	0.08[10]	3.83[19]	0.32
		Total	19.75

6.3.3 Transmission Infrastructure

The linking of CST plants and wind farms to the grid, as well as the requirements to upgrade the existing grid, involve the building of new transmission line infrastructure. The emissions resulting from this are mainly associated with the required steel and concrete, as well as the aluminium used for power transmission lines.

6.3.4 Combined Total

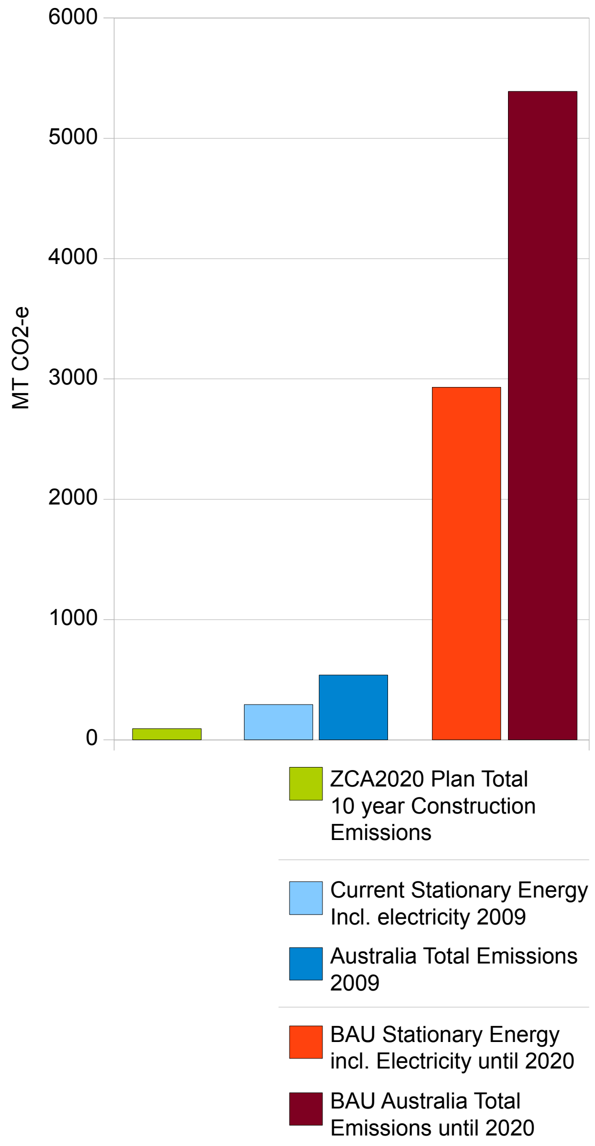
The combined emissions resulting from the manufacture of the listed materials in the sections above are therefore around 85 Mt CO_2-e. Assuming that the above mentioned numbers amount to 90% of all of the emissions, the construction of all wind farms, CST plants and the required transmission upgrades as outlined in this Plan would result in around 94 Mt CO_2-e. This obviously is a significant amount of emissions, but should be seen in context with emissions that would be emitted under the BAU scenario, due to the continued burning of fossil fuels, and the construction of new conventional power plants. These BAU emissions would be several tens of times higher.

Considering that Australia's current annual emissions are around 540 Mt CO_2-e,[16] the proposed 10 year roll-out corresponds to about 2 months of current Australian emissions (or 6 days of emissions per year for 10 years—i.e. 1.6%). Because electricity and stationary energy are currently responsible for over half of Australia's emissions, the final result of these "investment" emissions is that Australia's emissions are reduced by more than half. All of this can be achieved using technology that is currently available.

TABLE 6.7
Transmission Infrastructure Materials and Associated Emissions

Materials	Mt required	$t(CO_2\text{-e})/t(material)$	Mt CO_2-e
Concrete	1.81	0.159[19]	0.29
Iron and steel	0.67	2.75[19]	1.84
Aluminium	0.18	8.24[19]	1.48
		Total	3.61

FIGURE 6.9
Comparison of Emissions[15]



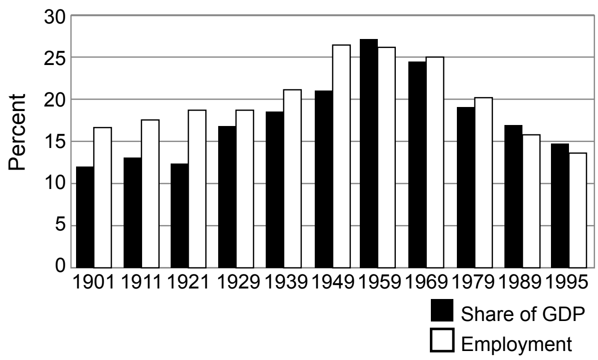
6.4 Manufacturing

Australia's domestic manufacturing capacity will need to be ramped up quickly to enable the broad-scale roll-out of a 100% renewable electricity grid. The manufacture of CST and wind components domestically has the potential to create thousands of job opportunities in areas that currently rely on coal- or gas-fired power plants, and coal or gas extraction, for direct and indirect job benefits. Unlike the construction, operations and maintenance jobs in CST plants and wind farms, jobs in factories are not tied to regions with high solar or wind incidence. The factories can therefore be sited strategically for smart regional development.

In the 1960s manufacturing accounted for approximately 25% of our GDP. Since then it has been steadily decreasing as seen in Figure 6.10[25]. The last decade has been no exception, with Australia's manufacturing industry currently accounting for approximately only 10% of our GDP[26]. This has led to the closure of numerous factories, as manufacturing overseas becomes a cheaper alternative. The movement has left factories empty, and an estimated 100,000 jobs lost from the sector in the past 10 years[27]. This gives Australia excess capacity that can be utilised by the ZCA2020 Plan. The Australian Federal Government supports this view when it states that:

"There is no doubt that clean energy development and manufacture represents a significant opportunity for Australia, building on existing strengths in research, innovation and production technologies."[28].

FIGURE 6.10
Australian manufacturing as percentage of GDP[25]



6.4.1 CST Manufacturing Capacity

The ZCA2020 CST system has been designed based on Solar-Reserve/Torresol power towers, receivers and molten-salt-as-working-fluid technologies, with 148 m^2 heliostat mirrors. At the peak of construction activity, installation of the CST infrastructure will require the following quantities of component parts:

Torresol Gemasolar solar thermal power tower under construction, May 2010 SOURCE: TORRESOL ENERGY

- 30 concrete towers per year
- 30 receivers per year
- 600,000 ATS 148 heliostats per year
- 30 steam turbines and associated ancillary equipment per year, readily available from industrial suppliers
- 60 insulated tanks for molten salt storage system per year

The concrete towers use exactly the same continuous-pour system that is currently employed to construct smokestacks for conventional powerstations—the company employed to construct Torresol's Gemasolar tower already has years of experience in the conventional fossil industry[21]. One tower would take a crew of ten workers about 2 months to complete, once the ground is prepared along with all the other associated civil works[22].

Existing factories can be re-tooled and refurbished to manufacture CST component parts. The first factory manufacturing CST components in the United States was opened in an old furniture factory in 2008 by Ausra. The Ausra plant will produce 700 MWe of solar electricity equipment each year, including reflectors, absorber tubes and other components for Ausra's Compact Linear Fresnel Reflector system. While employing only about 50 people, the factory supports over 2,500 jobs in construction[23].

For SolarReserve's newly announced project in Alcazar, Spain, as well as the 750 jobs for direct construction of the

Enercon rotor blade factory in Viana do Castelo, Portugal[32]

project, a new heliostat production facility is built nearby to employ an additional 50 skilled workers and introduce new technology manufacturing to the region[24].

The modelling for ZCA2020 has assumed that 50% of the heliostat production is done in Australia. This could also reflect having some components (such as individual mirror panels) manufactured overseas and having the final assembly carried out onshore to reduce the transport of bulky heliostats. Manufacturing industries are generally broken down into two groups—elaborately transformed manufactures (ETM) and simply transformed manufactures (STM)[25]. Whilst heliostats would still be classified as an ETM, the manufacturing process is nowhere near as complex as that required for a car. In 2008 Toyota Australia manufactured over 140,000 vehicles[29] and in comparison with overseas plants the automotive manufacturing plants in Australia are relatively small. In 2009 over 500,000 vehicles rolled off the production line at the Audi plant in Ingolstadt[30]. It is therefore reasonable to expect that a single manufacturing plant in Australia, when equipped with the correct tools could easily produce and assemble the 300,000 heliostats suggested for local manufacture, and possibly even the full 600,000 required.

Based on the manufacturing labour requirements detailed in studies from Sandia National Laboratories[31], the production of 300,000 heliostats per year could create another 7,000 manufacturing jobs. If Australia then positions itself well with manufacturing expertise, we could continue to produce components for export after the surge of domestic CST installation declines.

6.4.2 Wind Manufacturing Capacity

The ZCA2020 wind system design is based on the Enercon E-126 wind turbine. This turbine has a nameplate capacity of 7.5 MW, is 138m high and has a rotor diameter of 127m. The quantities of component parts of the Enercon E-126 wind turbines for the ZCA2020 Plan at peak installation rates are:

- 800 turbines per year
- 2400 blades per year
- 800 nacelles per year
- 800 towers per year

These parts can all be manufactured in fairly conventional factories after the requisite re-tooling.

There are examples, globally, of wind turbine manufacture being ramped up quickly. Enercon has established a manufacturing hub in less than two years for wind turbine manufacture in Portugal. In the harbour of Viana do Castello, a rotor blade factory and a concrete tower factory are producing 250 towers and 600 rotor blades (for the E-82 turbine) each year. In nearby Lanheses, the production lines have all been set up with the completion of plants for generator manufacturing, e-module assembly and final assembly. Eventually Enercon expects to export 60% of the production output from these factories, hence their harbourside location.

As mentioned in Part 3.2 the Chinese have begun construction of the world's largest wind farm dubbed the "Three Gorges on the Land", in Gansu Province[33]. The wind farm will have 20 GW installed capacity by 2020 and 40 GW eventually (representing just under two-thirds of the

Enercon rotor blade manufacturing in Magdeburg[35]

Inside the Enercon permanent magnet factory[35]

Enercon E126 under construction

ZCA2020 overall wind requirement). A series of wind turbine and blade manufacturing plants are being built by the Chinese government to remove supply constraints on the project and keep costs down[34].

In the United States, Vestas has completed the world's largest wind turbine tower factory in Pueblo, Colorado. The factory is producing 900 towers a year. Vestas' first America-based wind turbine blade factory opened in 2009 with a capacity of 1,800 wind turbines per year[36]. While these Vestas factories are producing wind turbine equipment of smaller capacity than the 7.5 MW turbines recommended for the Plan, it must be pointed out that manufacturing is a modular process that can be scaled up by simply installing more equipment. Enercon E-126 turbine blades are actually transported as two separate sections which are shorter than the blades of smaller model turbines.

These international examples indicate how it is possible to install a large manufacturing base very quickly, even under a lukewarm regulatory environment. Vertical integration appears to aid a speedy roll-out. The large companies favour vertical integration in order to lower costs, maintain quality and ensure that project timelines are not disrupted by production line problems. However the ZCA2020 Plan represents such a broad scale construction and implementation project that vertical integration may be a strategy that could be debated for the Australian context.

To manufacture the required wind components for the ZCA2020 Plan, Australia would require slightly more than the equivalent production capacity of the Vestas tower factory in Colorado USA (which produces 900 towers a year), and less than double the capacity of the existing Vestas blade manufacturing plant in Windsor, Colorado (which produces 1,800 blades a year), or 1.5 times the manufacturing capacity being installed by China in just Gansu province alone over the next decade.

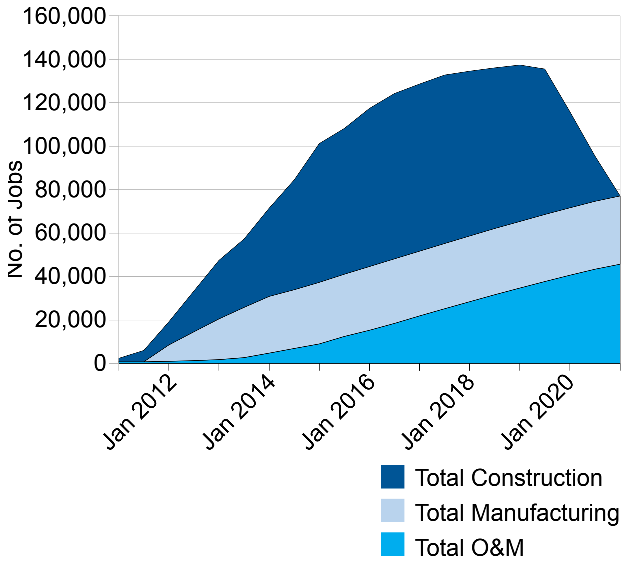
Of course, Australia would not need to produce all these turbines domestically. Many of the turbines and component parts could be imported, particularly to take advantage of lower-cost turbines being produced in China. However there are significant advantages in developing a substantial turbine manufacturing industry in Australia: to be a part of the global boom in renewable energy technology, and to develop domestic jobs, expertise and capacity. The Plan recommends a mix of locally manufactured and imported turbines. Factories producing wind turbine components could be geographically dispersed throughout Australia, depending on labour market capacity and proximity to rail transport.

6.5 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 (see Appendix 7). In this modelling only the direct jobs are included, and so the model estimates are considered conservative. From 2010 to 2020, the ZCA2020 Stationary Energy Plan will create just over 80,000 jobs from installation of renewable energy infrastructure at the peak of construction, plus over 45,000 continuing jobs in operations and maintenance, which will continue for the life of the plant (see Appendix 7). These jobs will be in a diverse range of fields including, but not restricted to, construction, manufacturing, engineering, trades and plant management. Over 30,000 jobs would also be created in manufacturing of wind turbines and heliostat mirrors, assuming for this scenario that 50% of manufacturing is done onshore. If Australia moves to export these components as domestic demand begins to taper off towards the end of the transition decade, we can ensure that we are well-positioned to be a leader in the global renewable energy economy. These figures refer only to direct jobs involved in the renewable energy systems.

In comparison, around 20,000 jobs in stationary energy production from coal and gas will be lost in the same period, including those in the extraction of coal and gas for electricity production and end-use gas for heating[37,38,39] (see details in Appendix 7). The job creation figures are broadly consistent with the findings of a recent study by the Australia's CSIRO[40], which estimated overall job growth of 230,000—340,000 jobs over the next 10 years in making the transition to an environmentally sustainable society. The loss of 20,000 jobs is comparable to average monthly fluctuations in employment levels, for example the change of 19,480 jobs in January 2010[41].

FIGURE 6.11
Overall construction, manufacturing and O&M jobs directly created by the ZCA2020 Plan



As can be seen from Figure 6.11, over half of the jobs created in the installation of the renewable energy plants under the Plan will be ongoing after the construction phase is complete. The decline in construction jobs at the end of the period is to be expected, as all individual construction projects have a short lifetime, and people employed in this industry are used to transitioning from one job to the next.

Australia's solar thermal and wind industry would then be well-placed to export expertise and skills to assist other countries around the world in the shift to a renewable energy future.

Construction workers installing heliostats at a Brightsource solar thermal power tower[42]

FIGURE 6.12
Jobs created by the ZCA2020 CST plants.

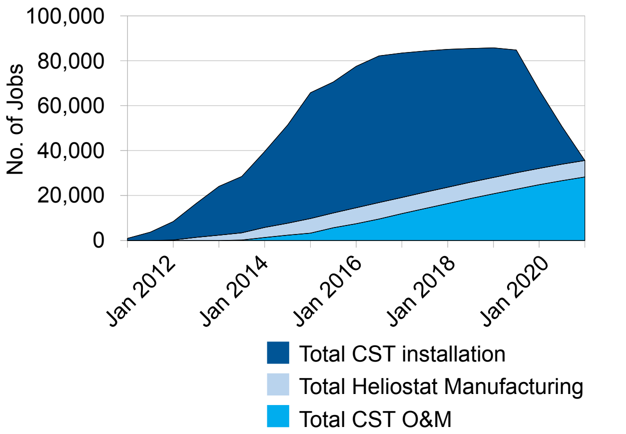
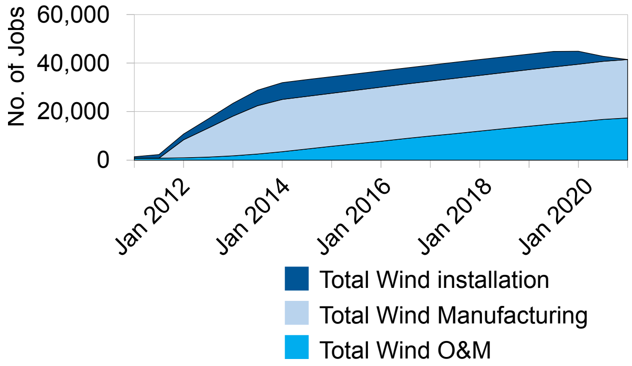


FIGURE 6.13
Jobs created by the ZCA2020 wind component.



6.5.1 Current Employment in Stationary Energy Production

It is estimated that there are just over 20,000 people directly employed in the production of stationary energy (electricity and heat) from fossil fuels currently. Most of those (just under 8,000) are employed in coal mining (not including coal for export). 6,300 are directly employed in fossil-fuel-fired power stations and around 6,100 are employed in the extraction of natural gas for domestic purposes[38,39]. The majority of Australia's coal and natural gas reserves are extracted for export. Only the people employed in the extraction of these resources for stationary energy production domestically have been included in this study.

6.5.2 Jobs in Solar

The construction and operation of the CST plants will create many high-quality skilled and unskilled jobs. Due to the geographical diversity of the CST sites these job opportunities will be dispersed throughout Australia. By coincidence many of the sites with high solar incidence where CST plants will be installed are in regions that support a great deal of mining activity. This means that many jobs lost in the mining sector can be replaced by jobs in the new solar power industries. The construction and O&M jobs for CST have been based upon real-world employment figures for SolarReserve's announced molten salt power tower projects in Rice, CA[43] and Tonopah, NV[44].

As shown in Figure 6.12, construction of the solar plants will create around 65,000 direct jobs in the peak installation phase (2017), after a ramp-up of manufacturing and construction capacity[note 2].

Assuming that half of the heliostat manufacturing is done in Australia, a further 7,000 jobs could be created in this industry, which can then be directed to offshore exports as domestic demand declines [note 3]. Once plants are brought online, over 28,000 people will be employed in operation and maintenance. This includes both grid-connected and off-grid CST (see also Appendix 7).

6.5.3 Jobs in Wind

The best wind sites in Australia are located along the coast. This means that many of the wind sites chosen under ZCA2020 are situated in areas close to population centres. During the construction phase of the ZCA2020 wind component this will be convenient in terms of tapping into large labour markets. Traditionally, construction and maintenance jobs in the wind sector can be very well-paid due to the heights at which some of the work is done.

Manufacturing of wind turbines and components is the most significant source of jobs in wind power[46]. Assuming 50% of the turbines are manufactured domestically, over 22,000 manufacturing jobs could be created by the time the installation rate reaches 6,000 MW per year. The ZCA modelling has assumed that the wind manufacturing industry continues to grow at 1.5% p.a., as Australia begins to export high-quality wind turbines.

During the construction and installation phase, up to a further 7,000 jobs in installation will be created after the initial ramp-up to 2014, then a continuous steady rate of installation until completion in 2020. This matches the ramp-up that has been achieved in other areas internationally, such as Texas[47,48].

Over 17,000 permanent jobs will be created in the ongoing operation and maintenance of the wind farms (see Appendix 7).

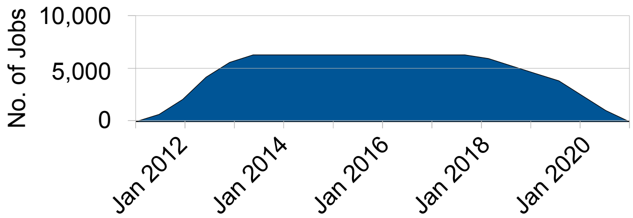
Wind farms can bring a range of benefits to local communities and families. They create a significant change in the dynamics of local towns, offering employment and more secure, steady incomes, supporting population growth instead of decline, and allowing families to stay together. They can help to reverse the trend of people leaving rural areas at times of drought and hardship on the land. Many can now enjoy a rural lifestyle without the hardships of toiling on the land.

SUZLON—POWERING A GREENER TOMORROW[49]

6.5.4 Jobs in New Transmission Lines

Jobs required in the construction of transmission lines are shown in Figure 6.14. The priorities in installation are, first to connect new generator sites into the grid, and second to create the interconnects for the complete national grid. The job numbers are based on employment rates reported for two 500 kV transmission line construction projects in the US[50,51].

FIGURE 6.14
Jobs created by the ZCA2020 transmission lines

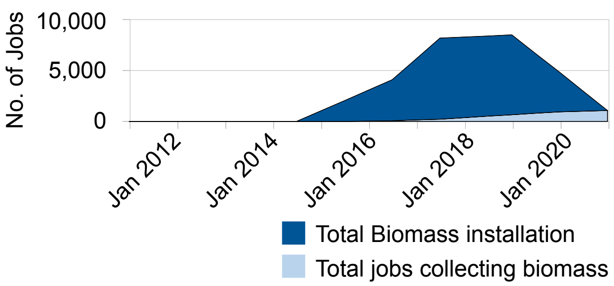


6.5.5 Jobs in Biomass

The biomass plants will be installed alongside the CST plants so that biomass can be used to co-fire the boilers (when there is concurrent low-wind and low-solar incidence). Due to the biomass back-up being installed as supplements to the CST plants, the installation of the total 15 GWe of biomass heaters will occur at the same rate as, and in conjunction with, the CST plants. Over 8,000 jobs will be created during the construction, manufacturing and installation phase, which for biomass will begin in 2015, as the large-scale Solar-220 plants are being built. The extra labour force for construction of biomass heaters will be located mainly at the southern-latitude CST sites.

It is expected that the biomass backup will only operate for 1-2 weeks each year, for example during winter, when low solar incidence may coincide with low wind incidence and high electricity demand. Since the backup will only be used on the CST sites when solar thermal activity is low, it is expected that its contribution to overall O&M labour will be relatively small (assumed to be zero here). The more significant job numbers are in biomass fuel collection and general CST plant O&M labour. The biomass plants proposed under the ZCA2020 Stationary Energy Plan consist of large-scale pelletised biomass boilers (very similar to existing pulverised coal boilers). As an illustrative example, each 220 MWe CST turbine with biomass backup can be likened to one-eighth of Victoria's eight-unit, 1540 MWe Hazelwood power station, in terms of output capacity and operational labour requirements.

FIGURE 6.15
Jobs created by the ZCA2020 biomass component



6.5.6 Ramp-up and Comparison with Current Employment

The ZCA2020 Plan will create an ongoing 77,000 jobs in manufacturing and O&M. At the peak of construction, there will be over 80,000 people employed in installation of the solar, wind, transmission and biomass sites. The bulk of these will be in construction, these figures are not necessarily inclusive of all jobs in engineering, financing, management and administration.

The graph of Figure 6.17 compares the labour requirement of the ZCA2020 Plan with the size of the existing Australian workforce—showing a selection of industries that are relevant to the jobs in the Plan.

Actual industry figures up to 2009 are shown to the left of the dotted line. This includes a flat line in job growth after the Global Financial Crisis of 2008. To the right is the projected growth in jobs, published by the Department of Education, Employment and Workplace Relations. The total job requirements for the ZCA2020 Plan are shown in blue.

FIGURE 6.16
Total Jobs created by the ZCA2020 Plan

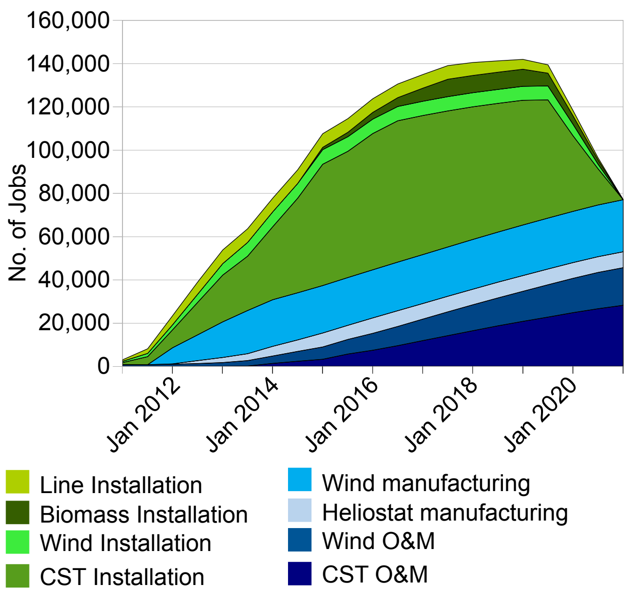
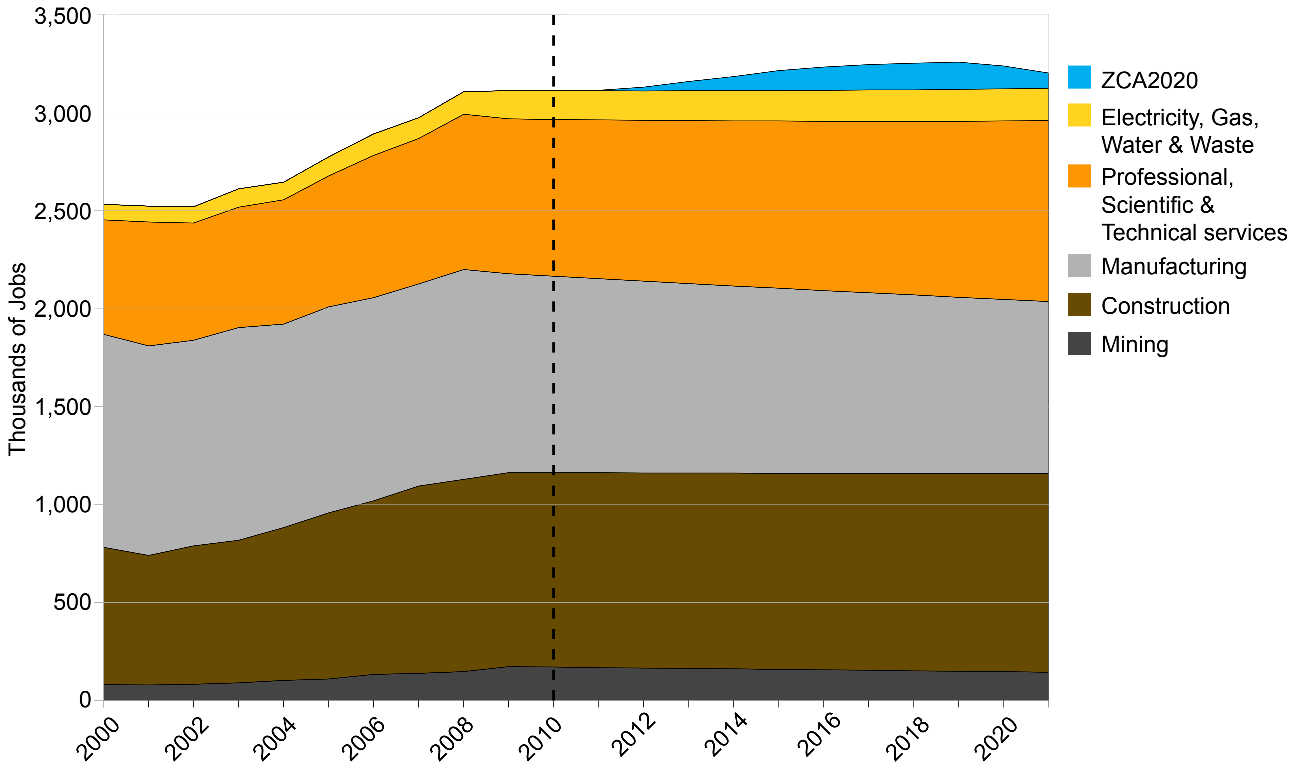


FIGURE 6.17

Jobs in context. Jobs prior to 2010 are actual figures from DEEWR[52] for relevant sectors, with official mid-term projections post 2010, and total ZCA2020 jobs from Figure 6.16 shown in blue.



Already one million people are employed in construction in Australia, with a further one million in manufacturing. In the five years before 2008, the number of construction jobs was growing at 50,000 new jobs per year[52]. The construction jobs component of the Plan requires an average of 9,000 new jobs per year (ranging from 8,000 to 13,000 with a peak in 2015). This appears to be entirely achievable in the context of Australian industry capabilities.

People employed in existing industries can readily switch and adapt to the new jobs in renewable energy, says Kevin Smith, CEO of the U.S. company Solar Reserve. He was recently interviewed about the rapidly expanding green economy, and was asked how a company like his can deal with the crucial aspect of training. He discussed the issue of finding appropriate people as the business goes through a rapid expansion—doubling or tripling in 6 months. People can be recruited with broad skills in business and engineering, and trained in 6 to 12 months. The dynamics are much the same as any normal expansion phase in the economy[53].

6.6 Conclusion

The ZCA2020 Plan is clearly achievable, using available technologies, and within Australia's currently available material, human and economic resources. We already have construction and manufacturing sectors that are large enough to supply the resources for the ten year transition period.

The material requirements for steel and concrete are a fraction of Australia's current annual production. Production of float glass for the heliostats would need a significant increase in capacity—of approximately 600,000 tonnes per annum—but this is equivalent to a couple of new factories of 300,000 tonnes/year capacity[15].

The manufacturing requirements are well within Australia's capabilities. The Plan calls for several new factories to produce components for wind turbines and solar thermal plants, of similar size to factories that already exist overseas.

The Plan would require only a fraction of Australia's existing cosntruction and manufacturing workforce, and yet would create more ongoing jobs in renewable energy than would be lost in old fossil fuel industries.

Footnotes

1. Australian iron ore is primarily hematite (Fe_2O_3) and magnetite (Fe_3O_4), ~70% elemental iron (Fe), by weight steel is >98% iron.
2. Job numbers are based on total 700 job-yrs/MW for Rice SolarReserve, a 450,000 GWh/yr solar power tower plant (normalised to 75% capacity factor), but for plants with a shorter construction time of 1.5 years, the number of construction jobs/yr has been increased. i.e. total manpower has been kept constant at 700 job-yrs/MW, so for a shorter timeframe, more people are needed at any one time. Total job-yrs has been calculated from average construction numbers (not peak numbers), because the average gives the more meaningful total for job-yrs, which can be adjusted to different timeframes, and it is not specified how long peak construction takes place. As there will be many plants under construction in various places at any one time, peaks will occur at different times.
3. Heliostat manufacturing data[31]. For a heliostat size of 148 m^2, the manufacturing workload is 46 man-hrs per heliostat. This is based on factories running at 223 production days per year (like an Australian Toyota factory), see Electric Vehicle section in Part 2. Single 8-hour shift per day is modelled. See further details in Appendix 7 Manufacturing 50% of the heliostats in Australia would create just over 7,000 jobs.

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Part 7
Economic Comparisons

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A commonly cited reason for stalling action on climate change is the cost of mitigation, even though we are warned that the eventual cost of adaptation will be far higher. While implementation of the ZCA2020 Stationary Energy Plan will require a higher upfront investment than Business-As-Usual, it avoids future fuel costs. Moreover, when measured over the long term, the ZCA2020 Stationary Energy Plan has an approximately equal net present cost to the Business-As-Usual scenario.

The purpose of Part 7 is to detail the financial dimensions of the ZCA2020 Stationary Energy Plan and examine whether the economic arguments for inaction have any merit. In particular, this section:

- provides an economic comparison of the ZCA2020 Plan with a modelled Business-As-Usual (BAU) scenario.
- identifies the economic challenges of implementation and their potential solutions.
- contextualises the scale of expenditure required by the Plan by comparing it against other areas of past and present Australian economic activity.

"...a solar thermal power plant has no fuel cost, but it does have a high initial cost because you basically, once you build the plant, you have all the fuel for the 30 or 40 years of the design life. If you had to buy 30 or 40 years of coal, along with your coal plant, the price might be quite a bit different..."

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7.1 Summary of Economic Findings

The ZCA2020 Stationary Energy Plan (the Plan) requires a total capital expenditure of $AU370 billion over the 2011-2020 period, in contrast to a BAU capital expenditure of $AU135 billion. While the Plan's up-front investment is relatively high when compared to BAU, its lower ongoing cost results in dramatically reduced expenditures in the long-term. In fact, over a longer timeframe (2011-2040), the ZCA2020 Stationary Energy Plan and BAU have an approximately equal Net Present Cost (taking into account capital, operations, and fossil fuel costs).

The savings expand significantly if the broader benefits of the Plan on the economy are included. The use of electricity to power transport instead of oil realises fuel cost savings under the Plan of $AU1,170 billion. Furthermore, a conservative estimate of the savings realised by avoiding CO_2 emissions charges suggests that the Plan could negate the need for a further $AU370 billion of expenditure, raising total savings to almost $AU1,550 billion. Most importantly of all, if the Plan helps to stimulate global action on climate change mitigation, then the Stern Review suggests that by 2050, 20% of GDP will be saved annually ($AU240 billion/yr)[2].

The average annual capital investment to fund the Plan over 2011-2020 amounts to $AU37 billion per year, approximately 3% of Australia's GDP. As this section demonstrates, the financial scale of the Plan is comparable to several other areas of large public and private expenditure suggesting that the Plan is within the capacity and capability of the Australian economy. Furthermore, the additional $AU260 billion of up-front investment required by 2020 under the Plan, when divided by 21 million Australians over ten years, only equates to $AU3.40 per person per day and moreover this expense is readily recouped in future years by avoiding fossil fuel costs.

Although the Plan does require a high degree of up-front investment, in the longer term it aims to release Australia from the twin threats of rising fuel costs and the potentially immense expenditure associated with future climate change. There are no roadblocks to implementing the Plan given Australia's economic capacity.

A preliminary analysis of the potential impact on electricity prices indicates that the renewable energy system proposed would raise the price of electricity by 6.5c/kWh over today's levels by 2020. This is based only on one potential funding scenario, and as such should not be taken as a recommendation of the Plan. However, it gives a benchmark of the likely relative cost of the Plan, with this price increase amounting to only an extra $AU8 per week for residential households. This rate of electricity price rise is similar to what has already been experienced in Australia's electricity market.

7.2 Economic Comparison: The ZCA2020 Plan vs Business-As-Usual

To allow a valid comparison of Net Present Costs of the Plan versus the BAU scenario, economic models were constructed for both scenarios over the 2010-2040 period. The purpose of this section is to present and explain these models, analyse the results and discuss some other economic impacts of the transition that are excluded from the modelling. For comparison, both systems have been sized to meet an electricity demand of 325TWh/yr in 2020, which is enough to either supply BAU electricity growth with no efficiency or fuel-switching measures, or to supply all energy needs if these extra measures are implemented.

Section 7.2.1 introduces the modelling, explains the key assumptions and presents the key findings for each model; section 7.2.2 provides an analysis of the payback period of the Plan when compared to the BAU scenario; and finally, section 7.2.3 introduces the unmodelled impacts, primarily focusing on the benefits derived from transitioning oil-dependent transport to electrified transportation.

7.2.1 Modelling ZCA2020 and BAU: Which Provides Lower-Cost Energy?

Only the most fundamental and easily measurable economic impacts, such as fuel, capital and maintenance costs, are modelled quantitatively in this analysis. Social and environmental externalities arising from, for example, fossil fuel pollution, road trauma, and water use, are not included. Indeed, even climate change is excluded from the analysis, despite Stern's warning that it may reduce GDP by up to 20% each year by 2050[2]. Were these externalities to be included, their economic value would heavily favour the Plan.

In the BAU scenario, it is assumed that future growth in energy demand is met by conventional energy technologies, with electricity primarily generated from coal combustion, heating mostly derived from natural gas, and transport dependent on oil. The ZCA2020 Plan scenario is principally based upon wind and solar technologies that have high upfront capital expenditure but low ongoing costs. Both models explore the option of an increasing price on greenhouse gas emissions with a $AU10/tonne impost assumed for 2011 and rising thereafter. A discount rate of 1.4% is used as per the Stern report. A detailed examination of all the assumptions underlying the models is provided in Appendix 9.

Extra generating capacity and growth in electricity demand beyond 2020 is not included in either the BAU or ZCA2020 scenario. The analysis compares capital expenditure out to 2020, and the ongoing costs of the two 325TWh/yr systems out to 2040. The Plan assumes that beyond 2020, implementing energy efficiency measures, rather than installing new power generation, will be the most economically viable way to meet the increasing demand for services; even with such measures, Australia's per capita electricity generation will still be significantly higher than other developed economies (see Part 2). However, future demand growth is beyond the current scope of the analysis.

Modelling Business-As-Usual

To allow a fair and reasonable cost comparison between fossil fuels and renewable energy, this section examines the projected expenditure associated with sizing the Business-As-Usual model to generate 325TWh/yr of electricity from fossil fuel resources by 2020.

Under BAU, no significant adjustments in technology choices are made in response to rising oil or carbon costs. Thus, in order to supply the projected demand growth, additional conventional coal and gas-fired power plants are constructed and old coal-fired power plants are replaced as needed. The use of energy supply infrastructure remains inefficient, with large investments continuing to be made to supply energy during short demand peaks. Outside of peak demand times, more than a third of Australia's total electricity generation infrastructure is idled or throttled back.

While capital expenditure for fuel-switching and efficiency has not been included, the analysis shows the future costs of oil for transport and gas for heating that would be incurred, under either BAU or ZCA2020, if these switches do not take place and the extra electricity supply is used to meet a growing demand for current services with no efficiency measures. This future energy 'bill' can be considered a fund that is available for efficiency and fuel-switching investments.

Under BAU, resources such as natural gas are consumed in ever increasing quantities. The cost of natural gas is expected to nearly double, in real terms, by 2050[3]. The price of oil is also likely to rise rapidly, although for the purposes of this modelling, it is assumed that the oil price will plateau at $AU130 per barrel. This is based on the likely probability that oil price rises above this point would, under BAU, incentivise energy companies to undertake more costly and environmentally destructive ways of securing oil supplies, such as coal-to-oil technologies, tar sand processing, and oil from shale.

Modelling the ZCA2020 Stationary Energy Plan

As detailed in Part 3 of this report and in Table 7.1, the Stationary Energy Plan requires capital expenditure of $AU370 billion in the 2011-2020 timeframe. This will provide a new, renewable grid able to supply at least 325TWh/yr of electricity, 40% higher than today's electricity consumption. The Stationary Energy Plan excludes the costs associated with building retrofitting (to be described in the Commercial and Residential Buildings Sector Plan), electric cars and

TABLE 7.1
ZCA2020 Stationary Energy Plan Total Cost

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**

expanded public transport (to be described in the Transport Sector Plan) and industry retrofitting (to be described in the Industrial Processes Sector Plan).

With the Plan heavily reliant on freely available energy sources such as solar insolation and wind, there are no ongoing fuel costs. As such, the rising prices of oil and gas have only a marginal impact on the Plan during the transition period 2011-2020 as these fossil fuels are phased out.

A complete switch to renewable energy will leave the owners of fossil fuel infrastructure with stranded assets. The economic models do not include provisions for any compensation payments. The question of financial compensation to generators is a political one that is not addressed in this report however two points are made. Firstly, many fossil fuel power plants in Australia will be at least 40 years old and due for replacement during the time of the transition[4]. Given the age of these assets, they are fully depreciated[5]. Secondly, when many of these assets were privatised and purchased by the current owners, climate change and its implications for fossil fuel power generation were a known business risk. Due diligence by the purchasers of these assets at the time of acquisition would therefore have alerted them to the risk of these assets becoming stranded.

7.2.2 Comparing the Models

Figure 7.1 compares net present costs (2011— 2040) under Business-As-Usual versus the ZCA2020 Stationary Energy Plan. Net present fuel, operations, maintenance and capital costs required are approximately equal for both BAU and ZCA2020, at $AU500 billion. The ZCA2020 scenario is more capital intensive, while most of the costs under BAU are for purchasing coal and gas. The full results are shown numerically in Appendix 9.

However, if the net present costs of meeting Australia's BAU demand for domestic and foreign-sourced crude oil (~ $AU1,300 billion for 2011— 2040), gas for heating ($AU140 billion) and potential emissions permits (~ $AU420 billion for 2011— 2040) are included, this brings the total net present costs under BAU to approximately $AU2,350 billion.

The equivalent net present costs under the ZCA2020 Stationary Energy Plan bring the total to $AU800 billion (2011— 2040) representing a net present cost savings of nearly $AU1,550 billion.

These different scenarios are summarised in Table 7.2.

FIGURE 7.1
Economic Model Comparison

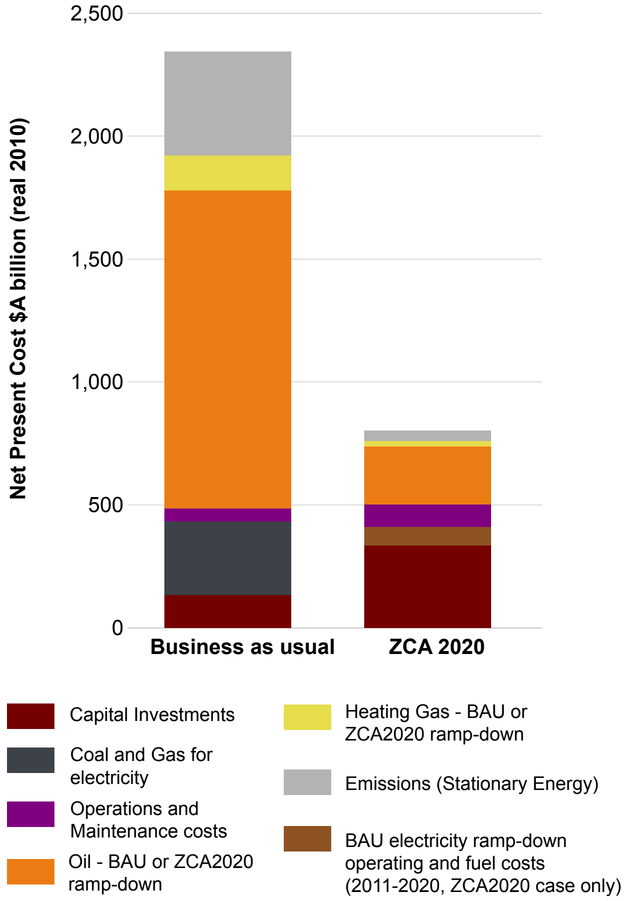


TABLE 7.2
Results of Economic Model (real 2010 $AU billion)

	BAU	ZCA2020	Difference
Total	$2,354	$806	$1,548
Sum Excl Oil & Gas	$914	$546	$368
Sum Excl Emissions	$1,930	$765	$1,165
Sum Excl Oil, Gas & Emissions	$490	$504	-$15

FIGURE 7.2
Net Present Costs: BAU minus ZCA2020

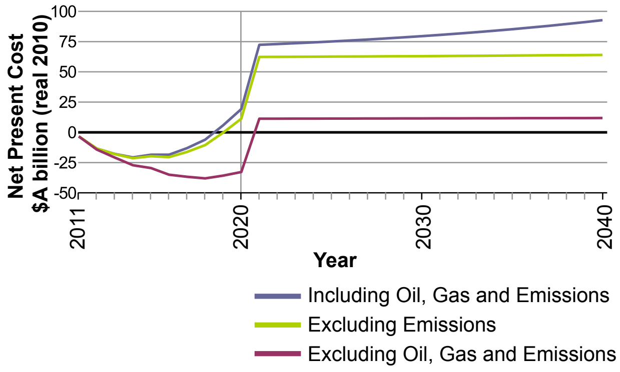
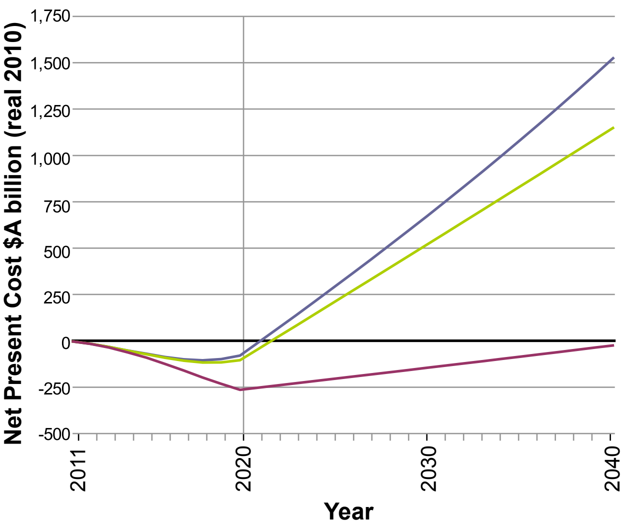


FIGURE 7.3
Cumulative Net Present Costs: BAU minus ZCA2020



Economic Payback Period

The Plan requires a capital expenditure of $AU370 billion over the period 2011-2020 as renewable energy systems are sequentially installed to provide Australia with an essentially new and expanded electricity supply system.

Over this same 2011-2020 period, the BAU scenario requires capital investment of $AU135 billion for electricity system expansion and ongoing replacement of fossil fuel plants. However, the BAU scenario incurs higher ongoing costs due to increasing coal and natural gas consumption over the full 2011-2040 modelling period whereas the Plan phases out the use of fossil fuels.

Figure 7.2 and Figure 7.3 show the range of various economic payback curves for the Plan scenario. In the narrow terms of capital and operating expenditure for electricity generation, the avoided costs of fossil fuels under the Plan allow the inital capital costs to be recouped by 2040. However, if the full potential costs for oil, gas and emissions are included, the Plan will have an economic payback time of only a few years after its completion in 2020.

Applying Different Discount Rates

As previously mentioned, the economic comparisons have been calculated using the Stern Review discount rate of 1.4% which is regarded as a representative measure for long term societal costs. However, similar results are produced when other discount rates are applied. For example, using either the Government bond rate of 6% or the standard infrastructure investment rate of 8%, the comparison reveals that the ZCA2020 plan is only marginally more costly than BAU when oil, gas and emissions costs are excluded - $AU 100 billion over the 30 years (refer to Appendix 9).

7.2.3 Other Unmodelled Economic Benefits

Transitioning to an electrified transport system of electric vehicles and expansion of the rail network will require investment in addition to the $AU370 billion for the Stationary Energy Plan, which will be outlined in the ZCA2020 Transport Plan. However, given the very large costs that the continuation of oil imports imposes on the Australian economy, transport electrification will be a very attractive investment.

Oil is not, however, the only cost of Australia's current transportation system. Establishing a transport network based around electric cars and electrified public transport brings many co-benefits in reducing the social and medical burdens imposed by today's oil-based transport system.

Soot particle pollution costs the Australian economy between $AU1.6 and $AU3.8 billion per year in premature death and disease[6]. Taking the central estimate of this range ($AU2.7 billion), this adds up to a cost of $AU80 billion (in 2009 dollars) between 2011 and 2040, without accounting for growth in vehicle and population numbers.

Medical, insurance, and the clean-up cost risks associated with the extraction, transportation and storage of oil are low in typical years (the cost of cleaning up oil spills in Australia was $AU5 million in 2007-2008)[7], but can be extremely high. A single large incident, such as the Exxon Valdez oil spill in 1989, cost ExxonMobil $US 3.8 billion in clean-up costs.[8] Such spills are always a risk when producing oil in, or transporting oil over, the sea.

Traffic congestion was estimated to cost Australian businesses $AU9.4 billion annually in 2005, rising to $20 billion per year by 2020[9]. Road construction costs are around $AU14 billion annually Australia-wide.[10] The level of expenditure required to maintain roads is largely dictated by the volume of heavy axle-weight vehicles. A doubling of axle-weight increases road-damage costs by sixteen times.[11] [12] Under the ZCA2020 Plan, heavy road freight and passenger bus transport are transferred to heavy and light rail. This change, combined with large reductions in the volume of traffic will significantly lengthen the period between resurfacing of roads. The modal shift to electrified rail will also eliminate the need for large extensions to the road network.

FIGURE 7.4
ZCA2020 Stationary Energy Plan capital cost compared to other economic activity

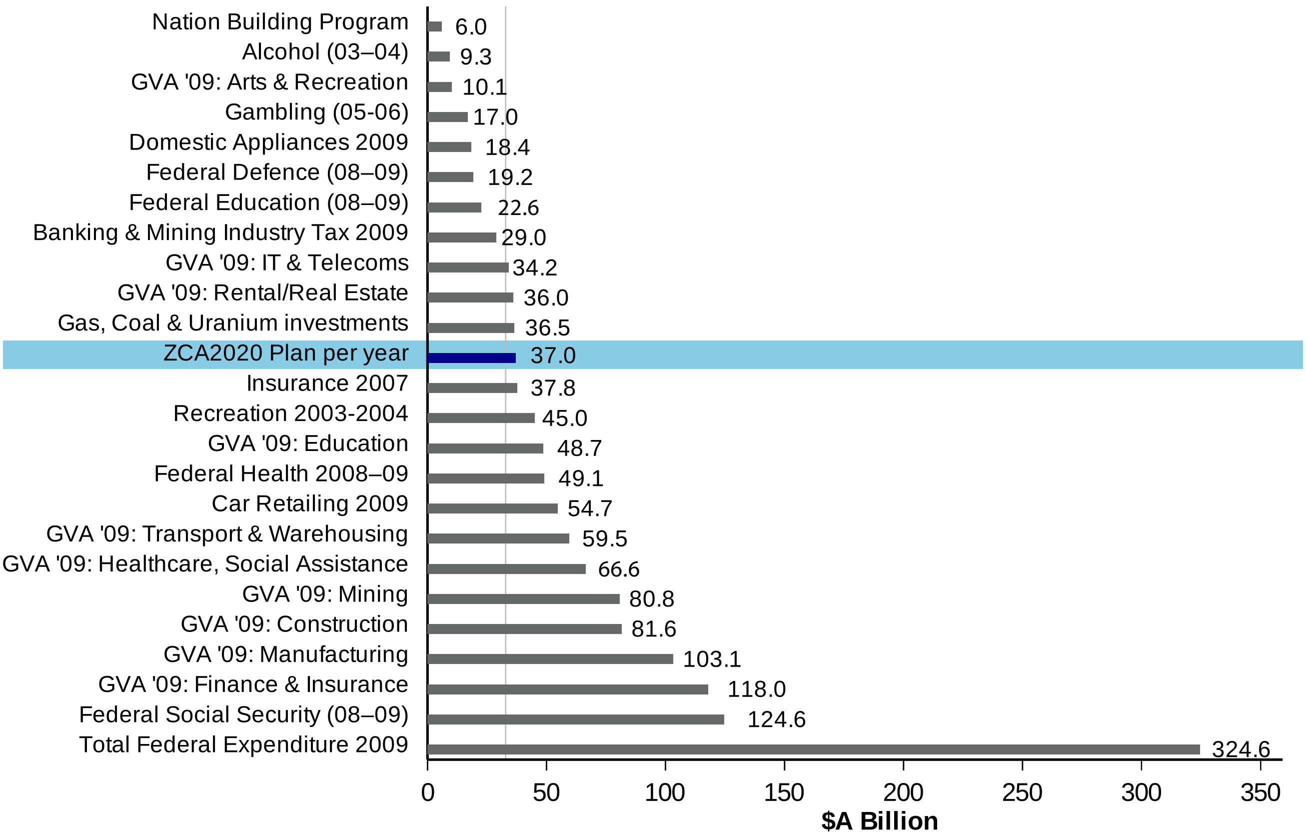
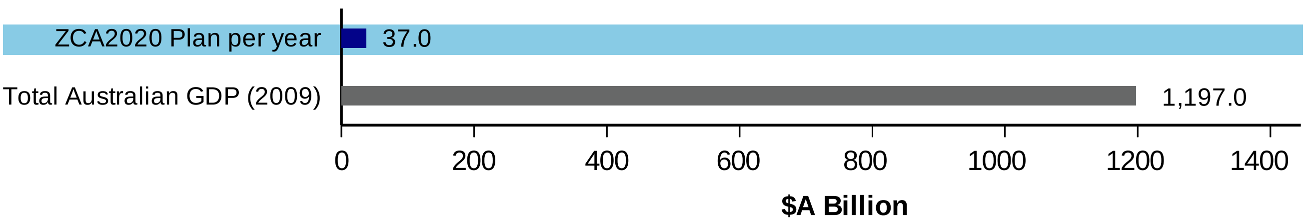


FIGURE 7.5
ZCA2020 Stationary Energy Plan capital cost compared to Australian GDP



In 2006, road trauma in Australia cost $AU17 billion annually, or 1.4% of GDP[13]. With a modal shift of passengers and dangerous heavy road vehicles to electrified rail, road trauma costs will be substantially reduced.

Co-benefits also exist for a phase-out of coal and natural gas extraction such as improved air quality and the associated benefits for health, agriculture and the natural environment.

7.3 The ZCA2020 Stationary Energy Plan Investment in the Context of Other Economic Activity

As outlined above, the implementation of the ZCA2020 Plan results in considerable savings when compared to Business-As-Usual over the coming decades. The initial expenses are recouped by eliminating fossil fuel costs and by reducing other externalities such as congestion, pollution and dependency on foreign oil imports.

Despite these evident economic benefits, the frequently quoted reason for not investing in large scale renewable technologies to reduce Australia's emissions is that this would be too expensive.

Certainly, the Plan's required up-front capital expenditure of $AU370 billion (averaged at $AU37 billion per year over the coming decade) is significant. However, when this is compared to other expenditures within the Australian economy, it becomes evident that this is neither unachievable nor unrealistic.

The required annual ZCA2020 investment will not originate from any single source but rather will be a combination of public and private investment. The goal of both sectors will be to benefit from being a part of this future industry, in the same way that others benefited from conventional energy production in the past.

Figure 7.4 compares a range of micro and macroeconomic annual figures from the Australian economy (see Appendix 9 for references) and shows that the ZCA2020 investment of $AU37 billion per year is not extraordinary when compared with other public or private spending. Of particular significance are the Gross Value Added (GVA) measures for Construction and Manufacturing. GVA represents the value of goods and services produced in a given area and can be seen as quantification of the size and production capacity of the sector. Figure 7.4 clearly shows that the scale of the Plan is fully within the capacity of the Construction and Manufacturing industries while at the same time it would contribute significantly towards both sectors.

At approximately 3% of the 2009 Australian Gross Domestic Product, the implementation of the Plan is not only within the capacity of the Australian economy but it would significantly contribute to it. Jobs and new industries will be created, dependencies on foreign oil imports will be minimised and Australian greenhouse gas emissions will be substantially reduced.

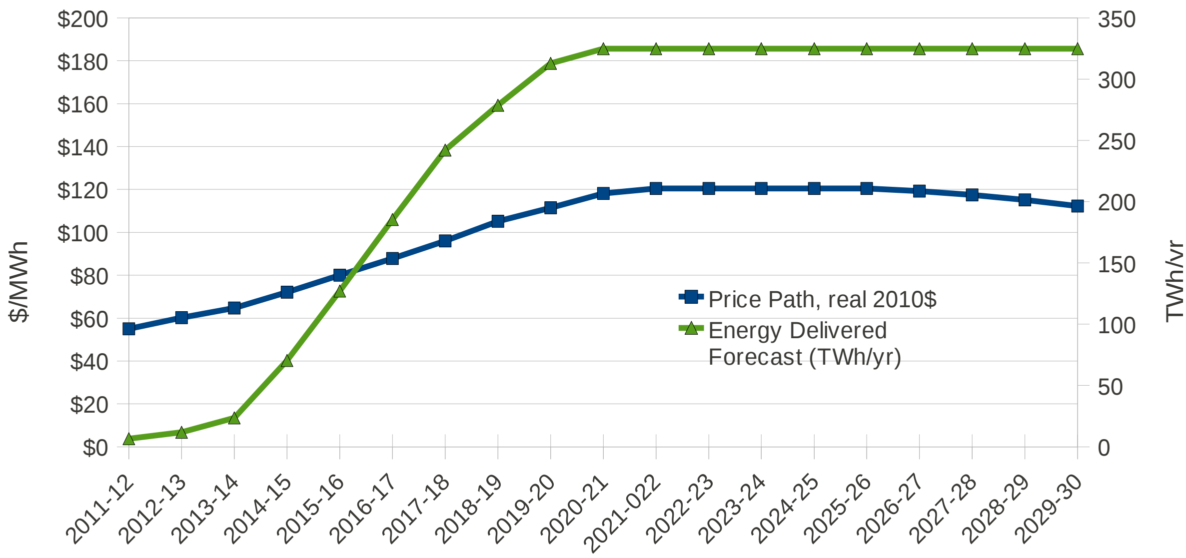
7.4 How much would electricity cost under ZCA2020?

Analysis of the proposed ZCA2020 renewable energy infrastructure based on current market financial parameters indicates that electricity prices would rise by approximately 6.5 cents per kWh (real 2010 currency) by 2020, or about 33% of the current domestic consumer price of 20c/kWh. While not prescriptive, this is indicative of the relative costs of the ZCA2020 Plan. 6.5c/kWh is a similar premium to today's cost of GreenPower, and would only impose an extra $AU8 per household per week in direct electricity costs. This rate of increase is similar to the price increase expected under Business-As-Usual. The wholesale electricity price would also increase for businesses and industry, creating incentives to increase their energy efficiency.

The $AU370 billion investment required for the installation of the 100% renewable energy grid under ZCA2020 is not a cost to the economy. It is an investment that will generate returns over the lifetime of the infrastructure. The exact impact of the investment on electricity prices depends entirely upon the financing mechanisms used, of which there are many. Some policies would allow for the infrastructure to be built with minimal impact on electricity prices. For example the current policies in the U.S.A. include a 30% Investment Tax Credit on new solar plants, which lower the initial cost of capital through a tax concession and thereby lowers the cost of electricity required for these projects to be profitable.

However, to aid understanding of how the impacts of the $AU370 billion investment are in fact spread over 30+ years, a single example is given below of one potential funding scenario, to gauge the actual costs that would be involved.

FIGURE 7.6
Projected electricity price path modelled for ZCA2020 Stationary Energy Plan



This investigates the potential impact on electricity prices if the ZCA2020 Plan was funded in the same way that existing power transmission and distribution assets are funded under current regulated market arrangements.

The price of electricity to consumers is made up of several components:

- wholesale price – the price of power dispatched from a power plant.
- transmission – charges for using the high-voltage transmission network to transport the electricity.
- distribution – charges for using the low-voltage network that conveys electricity to consumers, mainly residential and commercial (industrial customers often plug directly into the transmission grid).
- retail margin – charges from the electricity retailing companies.

Of the above four cost components, the natural monopolies of the transmission and distribution charges are regulated under determinations of the Australian Energy Regulator, according to agreed regulatory revenue models. These models are built up from payment for regulated return on debt and equity portions of invested capital, as well as operating and maintenance costs of the regulated transmission and distribution assets. The generation cost component of electricity in the National Electricity Market (NEM) is not determined by the AER but rather by a competitive auction process in which generators bid, are scheduled and dispatched under the central coordination of the Australian Energy Market Operator.

This study has modelled the long term wholesale cost of electricity which would apply to generation assets foreseen under the ZCA2020 plan, and transmission to nodes of the existing HVAC grid via the new ZCA2020 HVDC and HVAC upgrades. The model used has amalgamated the capital and operating costs of the new renewable generation assets and new transmission grid assets, and applied these costs to the AER regulated asset pricing model in conjunction with typical financial model parameters which have been used for recent AER price determinations.

It is recognized that generation businesses are not regulated assets, and would in practice use other economic models to determine their required revenue to achieve target economic performance. Nonetheless, the AER model's inclusion of terms for capital repayment, return on equity and debt, operation and maintenance costs and treatment of imputation credits is considered by this study to provide a reasonable estimate of long term marginal costs of power which would be required to finance the ZCA2020 generation and transmission grid assets.

The Australian Energy Regulator provides a publicly available 'post-tax revenue model' that is used to calculate electricity prices for regulated power assets[14]. This has been used to model the investment and ongoing costs for the ZCA2020 generation and transmission infrastructure. Financing parameters used for the ZCA2020 model were set as currently specified by AER in recent regulated pricing determinations for Victorian power companies , giving a "nominal vanilla" WACC (Weighted Average Cost of Capital) of 9.68%[15] (see Appendix 9 for details).

Current average NEM wholesale electricity prices are about $AU55/MWh, or 5.5c/kWh. It is calculated that funding the ZCA2020 renewable energy infrastructure including the extra high-voltage transmission lines would raise the equivalent wholesale price to $AU120/MWh (12c/kWh) after 2020. Figure 7.6 shows the projected price path in real (2010) dollars, as well as the nominal (inflation adjusted) price. On completion of the Plan the wholesale electricity price would be 6.5c/kWh greater than today.

The results of the modelling are consistent with the current cost of renewable energy in Australia.

While it is expected that the costs of solar thermal power would drop to 5-6c/kWh, this only applies to plants that are run at 70-75% capacity factor. Due to the extra capacity specified, under the Plan CST plants would only be required to run at slightly over 50% capacity factor. With further optimisation of the proposed infrastructure, it is expected that this over-design would become smaller and lower the overall costs.

The higher price of 12c/kWh also takes into account the costs for the new ZCA2020 high voltage transmission links, which are required to deliver the wholesale power to relevant nodes of the existing high voltage transmisson grids.

The price premium of 6.5c/kWh is equivalent to the current premium that already exists in Australia today for GreenPower, which ranges from 5-6.5c/kWh[16].

This increase is less than electricity price increases already experienced by household consumers. For example the Independent Pricing and Regulatory Tribunal in NSW has proposed annual tariff increases of between 7 and 10% over 3 years to June 2013[17]. This rise was motivated by the need to "enable higher levels of investment in the electricity distribution networks". The price increases mean that after 3 years the price of electricity will increase by up to 42% which equates to a 8.6 c/kWh increase.

With an estimated 9.8 million households in 2020[18], consuming 63TWh/yr of electricity under ZCA2020 (see Appendix 1), this price rise would impose a cost of around $AU420 per household per year, or $AU8 per household per week. The wholesale price rise of electricity for businesses and industry would also have a flow-on effect that has not been determined with this preliminary analysis, however, such a price rise would also create an incentive for them to improve their energy efficiency.

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Conclusion

Enercon wind turbines, Albany, WA[1]

Transitioning to a zero carbon future in Australia is achievable and economically feasible using the technology of today.

The ZCA2020 Stationary Energy Plan demonstrates that converting Australia's energy sector to 100% renewable sources by 2020 is achievable using commercially available technology. Wind, solar, hydro and biomass resources can be combined with energy efficiency measures to adequately meet Australia's projected future energy demand.

The strategic investment of $37 billion per year required to transition Australia's stationary energy sector to renewable sources, is equivalent to a stimulus of just 3% of GDP over 10 years. In the long term, however, the lower fuel costs of renewable energy recoup the upfront investments. Achieving the ten-year transition is well within Australia's existing industrial capacity. Adoption of this plan promises health benefits, long-term energy security, and significant economic benefits. The ZCA2020 Plan will position Australia as a global leader in the zero carbon economy of the 21st century – the economy required for effective mitigation of climate change.

Australia is ready for a zero carbon future. The challenge now lies firmly in the hands of decision-makers, who must put in place strong future-oriented policies that will allow this transition to occur – starting today.

Rapid action is essential to achieving the ZCA2020 goals: the 'ramp up' needs to begin by 2011 to achieve a 100% transition in ten years. Commercially available renewable energy technologies can be immediately utilised to supply 100% reliable baseload power without needing to wait for further research, development, or demonstration. Positioning solar thermal power generation as a critical component of this technology mix is important because there are no technical barriers to its deployment, and it is perfectly suited to Australia's geography and climate. Australia should follow the lead of other sun-drenched countries such as USA, Spain, Italy, United Arab Emirates, Algeria, Israel, Morocco and Egypt. These countries are currently operating or constructing solar thermal plants in order to exploit their most abundant natural resource.

Other mature technologies specified by the Plan are wind energy, high-voltage direct-current transmission, biomass from agricultural waste, small-scale photovoltaic and solar hot water, electrified rail and road vehicles and electrified heating and cooling with heat pump systems. All these technologies are proven, mature and ready to be rolled out on a national scale.

Currently more than half of all Australian emissions come from the stationary energy sector. The ZCA2020 Plan reduces these emissions to zero, by converting electricity production to 100% renewable energy, improving demand side efficiency and switching from less efficient oil and gas furnaces and engines with measures that are inherently more efficient, while delivering the same, if not better, services to the Australian public.

Modelling conducted by the ZCA2020 team and Jack Actuarial Consulting using two-years of actual half-hourly data found that the electricity generation mix will meet 100% of Australia's electricity demand for every hour of the year. Seasonal and daily variability is accommodated by geographic diversity of renewables sites and the flexibility of solar thermal's dispatchable-on-demand electricity. The combination of backup reserves from existing hydro power and biomass firing with solar thermal is able to meet the 2% yearly energy shortfall that the modelling indicates will occur during infrequent low sun and wind periods.

Upgrades to the electricity transmission grid with commercially available high-voltage direct current and alternating current (HVDC/HVAC) technologies will be used to connect the new wind and solar sites. Not only are these transmission upgrades viable and economically feasible, but they will also strengthen and modernise the grid.

The scale of the construction, manufacturing, resource, and workforce requirements is well within the capability of the Australian economy. For example, the 80,000 construction jobs which will be required at the peak of the Plan installation represent only 8% of Australia's present construction workforce. During the recent resources boom until 2008, new construction jobs increased at the rate of 50,000 per year – far in excess of the Plan's requirements. Jobs lost in the existing fossil fuel supply industry will be more than replaced by the many jobs created in renewable energy manufacturing, operations and maintenance.

The Plan's requirement for concrete, steel, glass and other materials is minor when compared with the quantities currently available. Furthermore, the life-cycle emissions resulting from the production of these materials, as well as those from the construction of wind farms, solar plants, grid upgrades, etc., are negligible. After an initial 'emissions investment', the payback time, in terms of emissions saving compared with business-as-usual, is approximately two months. Wind and solar thermal plants are built from components that can be mass-produced, and the resultant economies of scale that will develop during ramp-up will drive down the cost of renewable electricity. Furthermore, the Australian manufacturing industry will benefit from the growth in renewable energy and the potential for ongoing exports, providing tens of thousands of jobs.

The total investment to transition Australia's stationary energy sector to renewable electricity production is $370 billion over the next ten years, or an average of $37 billion per year. This is equivalent to 3% of Australia's $1,200 billion annual Gross Domestic Product. While this is about $260 billion more than the capital spending required under business-as-usual by 2020, this investment is easily recouped over the longer term as the costs of purchasing oil, gas, and coal are avoided. The net present cost of the ZCA2020 Stationary Energy Plan is approximately equal to the net present cost of business-as-usual to 2040. The economic cost-benefit analysis is therefore attractive, even without considering the enormous value of avoiding climate change costs which, as Sir Nicholas Stern warns, could reach 20% of yearly GDP by 2050.

As demonstrated by the electricity price analysis, which indicates that electricity prices may increase by only 6.5c/kWh, the ZCA2020 investment will ensure that the transition to 100% renewable energy is affordable. Whatever mechanism is used to achieve the Plan, a cost of $8 per household per week is an impressively low benchmark, considering the enormous benefits of making the transition.

In summary, transforming Australia's energy sector to 100% renewable electricity production in ten years is achievable using today's commercially available technologies, and is economically attractive. It would deliver the benefits of zero energy-related greenhouse gas emissions and eliminate dependence on foreign oil imports while strategically positioning Australia as a world leader in the emerging renewable energy economy. This plan offers a pragmatic and realistic vision for a zero carbon future. Converting this vision into reality requires an immediate commitment to change from Australian policymakers to deal decisively with these pressing climate and energy issues.

"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[2]

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Appendix 1 Energy Demand

Steps for converting 2006-07 Australian energy usage to ZCA2020 final energy use.

This outlines the top-down analysis that has been used to project 2020 energy and electricity demand under the ZCA2020 plan, taking into account efficiency measures and electrification of services currently provided by gas and petroleum. In summary, Australia's grid electricity demand will increase by 42% from 228 TWh/yr in 2008 to 325 TWh/yr in 2020, however the overall end-use energy demand will drop by more than half due to the increased efficiency of electrified services.

Figure A1.1, "Australian Energy Flows 2006-07 from the Office of the Renewable Energy Regulator"[1], is a graphical representation of the data found in ABARE's Energy in Australia 09 Report[2]. End-use energy consumption is shown as "Utilisation". This is used in Table A1.3 as a base for calculating energy demand under the ZCA Plan (see the columns referred to as "Set 1" for 2006-2007).

The energy values in columns "Set 2" are scaled up for 2007-08 using a 2% GDP growth rate, so that they can be crosschecked with the most recent ESAA Electricity Gas Australia 2009 Report, with data from 2007-08 (available in hardcopy[3]). This scaling of ABARE numbers crosschecks with ESAA—228 TWh of electricity generation in 2008, from on-grid electricity sources. **2008 is used as the benchmark year for this analysis** due to the availability of data at the time of working. However, while historically energy consumption has been tied to GDP growth, ZCA2020 intends to decouple energy use from GDP growth. Energy use per capita is used as a reference, taking into account medium-range population growth.

"Set 3" columns—adjusting industrial energy consumption to reflect the ZCA Plan.

In the "Set 3" columns, an adjustment is made for energy associated with the existing fossil fuel industry that does not require replacement under ZCA2020. In summary these energy savings arise from:

- fossil fuels used to generate off-grid and embedded electricity—there is an extra 4,810 MW of off-grid and embedded capacity in Australia (ESAA[3] p14), however in ABARE's accounting, the fuel used to fire these is counted as industrial primary energy use (ABARE09[2], p15, see footnote).
- parasitic electricity used by fossil fuel power stations to run their own processes
- coal used in smelting of iron ore (counted as industrial coal)
- diesel and electrical energy used in coal mining
- natural gas used domestically to process LNG for export—10% of exported natural gas energy

Parasitic electricity

ESAA[3] reports that 228.6 TWh of electricity was generated in 2007-08. However only 213 TWh was ultimately delivered to the grid - an average loss of 7% (15.6 TWh), due to the parasitic electricity requirements of power stations. In the ZCA2020 Plan, CST generation plant parasitic loads have been allowed for in the designed capacity of the CST facilities.

Off-grid generation

The actual electricity generated by the 4,810 MW of off-grid capacity is not reported in ABARE09[2], so the numbers in ABARE10[4] are used to crosscheck. This reports 265 TWh of total electricity generation in 2007-08, but only 229 TWh of this is on-grid[4]. Therefore the difference (36 TWh) is off-grid. Much of this off-grid electricity is generated by reciprocating engine and open-cycle gas turbine plant located at remote mine sites and off-grid towns. Assuming an average thermal efficiency of 35%, these are using 103 PJ of oil and gas to generate the 36 TWh of electricity. 103 PJ of oil and gas is therefore removed from the industrial energy usage column. The 36 TWh will be provided from solar thermal and dedicated biomass backup, costed into the Plan separately. In reality, some of this could also be provided from small-scale remote solar PV/battery systems. This is an area for further research..

Coal for smelting

Coal is used as the carbon source for smelting of iron ore to iron. As outlined in Part 3, preliminary work suggests that replacing coal blast furnaces with Direct Reduced Iron utilising biomass gasification is a feasible zero-emissions alternative.

ABARE09[2] lists 13.2 PJ of coal used in coke ovens, and 55.7 PJ used in iron and steel. However, this may not reflect the extra energy produced as a byproduct of the conversion of coal to coke. The ZCA2020 analysis uses data directly from the source to determine how much coal is entering the smelters. Illawarra Coal, a BHP subsidiary, supplies premium quality coking coal to the domestic and export markets. According to their reports, 4 million tonnes per year of coking coal are delivered to the Port Kembla and Whyalla steel works[5]. At an energy content of 27.7 GJ/tonne for black coal[6], this represents 110 PJ of coal energy

FIGURE A1.1
Australian energy flows 2006–07 (Petajoules)

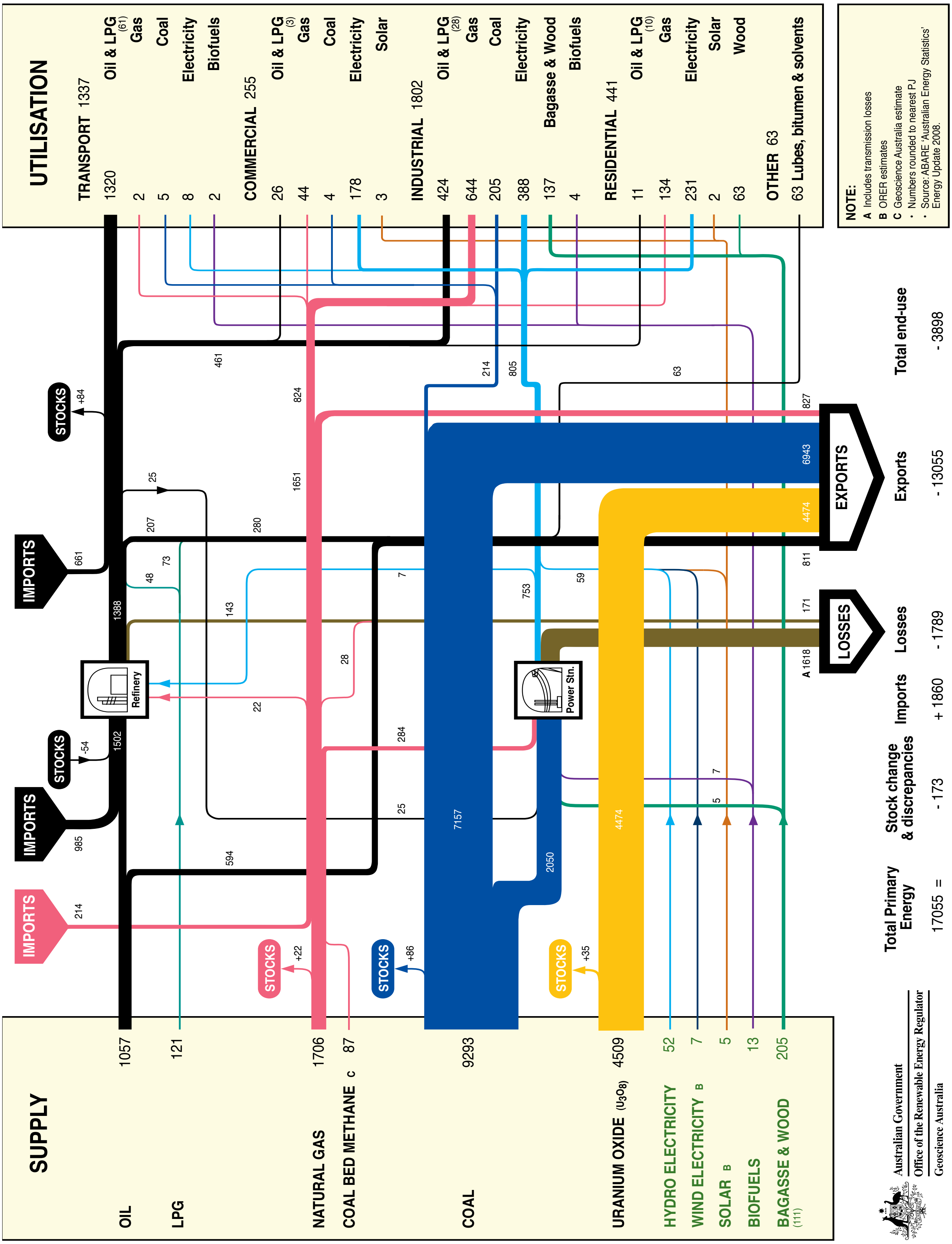


TABLE A1.3
Calculation detail for 2020 Energy Estimates

	SET 1		SET 2		SET 3		SET 4		SET 5		SET 6			
	2006-2007		Adjust for GDP Growth to 2008		Exclude gas for LNG export, smelting coal, offgrid fuel & power plant parasitics.		Electrifying Transport Adjustment		Other Fuel Switch Adjustments		Efficiency Adjustments and Onsite Solar Use			
	PJ/yr	TW-hr/yr	PJ/yr	TW-hr/yr	PJ/yr	TW-hr/yr	PJ/yr	TW-hr/yr	PJ/yr	TW-hr/yr	PJ/yr	TW-hr/yr	GW-hr/d avg	GW avg
Energy savings from each step					577		1132		269		278			
TOTAL	**3834**	1065	**3915**	1087	**3338**	927	**2206**	613	**1936**	538	**1659**	461		
Transport	1337		1365		1365		233		233		233			
Oil & LPG	**1320**		1348		1348		0		0					
Natural Gas	**2**		2		2		0		0					
Coal	**5**		5		5		0		0					
Electricity	**8**		8		8		180	**50**	180		180	50	137	5.7
BioLiquids for Transport	**2**		2		2		**53**		53		53			
Commercial	254		259		259		259		225		180			
Oil & LPG	**26**		27		27		27		0					
Natural Gas	**44**		45		45		45		0					
Coal	**4**		4		4		4		0					
Electricity	**178**		182		182		182		**223**		**161**	45	122	5.1
Wood	**1**		1		1		1		1		1			
Biogas	**0**		0		0		0		0		0			
Solar Heating	**1**		1		1		1		1		**18**			
Industrial	1802		1840		1263		1263		1094		928			
Oil & LPG	**424**		433		**209**		209		0		0			
Natural Gas	**644**		658		**391**		391		0		0			
Coal	**205**		209		**108**		108		0		0			
Electricity	**388**		396		**339**		339		**833**		**599**	167	456	19.0
Wood & Bagasse	**137**		140		**212**		212		**212**		212			
Biogas	**4**		4		4		4		**50**		50			
Solar Heating	**0**		0		0		0		0		**67**			
Residential	441		450		450		450		384		**318**			
Oil & LPG	**11**		11		11		11		0		0			
Natural Gas	**134**		137		137		137		0		0			
Electricity	**231**		236		236		236		**317**		**228**	63	174	7.2
Wood	**63**		64		64		64		64		64			
Solar Heating	**2**		2		2		2		**2**		**25**			
Electricity Subtotal	**805**	224	**822**	228	**765**	212	**936**	260	**1553**	431	**1169**	**325**	889	**37.1**

to be replaced by biomass-gasified DRI. From the working in Section 3, the replacement energy required is 72 PJ of biomass, as well as 3.3 TWh of electricity for Electric Arc Furnace smelting.

Gas used for export LNG

LNG requires a large amount of energy to compress, cool and liquefy natural gas. Typically, an extra 10-15% of the energy value of LNG is required for liquefying, which is provided by extra gas. 827 PJ of LNG was exported in 2008, therefore an estimated 10% (83 PJ) of gas was used in industrial onshore preparation processes. It is assumed that there is no place for LNG exports in a low-carbon future, so this has been removed from the analysis.

Energy used in coal mining

Brown coal mining uses electricity from the associated power plant to directly deliver coal using conveyor belts and equipment running on the plant's own electricity, which is already included in the 15.6 TWh of parasitics.

Australia produced 327 Mt of black coal in 2007-08[7]. Of this, 77% is from open-cut mines, with the remainder from underground mines[8]. Of this total, 135 Mt was export coking coal, for steel production. For this analysis, it is assumed that all domestic coal consumption is phased out by 2020, along with thermal coal exports. For conservatism, it is assumed that the 135 Mt coking coal exports may still be in operation.

Open-cut coal mining uses 0.23 GJ of onsite energy per tonne of coal mined, of which 90% is from diesel fuel[9], the remainder being mostly from electricity. Underground mines have similar extraction efficiencies[10], so this has been used as the basis for coal mining parasitics.

Phasing out of 190 Mt of coal mining for domestic and thermal coal exports will save 39 PJ of diesel and 1.2 TWh of electricity.

"Set 4" columns—Electrification of Transport

50 TWh is allocated for 2020 transport electrification - see separate explanation below.

"Set 5" columns—Electrification improves delivered energy efficiency

The energy currently provided by fossil fuels is replaced by electricity. However, the conversion efficiency is not 1:1, as electricity is inherently more efficient in energy delivery than combustion of fossil fuels. It is assumed that, to deliver the same services of heating, less electricity is required, with the following breakdown:

Commercial and Residential sector—x 0.55

Most fossil fuel use in the residential and commercial sector is for cooking and for space heating. Cooking with natural gas wastes heat that is lost to the surrounding air, not transferred to the pot. Electric induction stovetops directly transfer electrical energy to the metal base of the saucepan, a highly efficient process. Induction stovetops require only 50% to 80% of the energy of a gas stovetop to deliver the same amount of heat energy to food.

However, space heating using heat pumps is even more energy efficient. Heat pump heaters are like airconditioners run in reverse. They use only one unit of electricity to deliver three units of heat, as the refrigeration cycle is actually drawing energy from the surrounding ambient environment[11]. This means that switching from a gas heater to a heat pump would require less than 33% of the energy to deliver the same heating service. Under some conditions, heat pumps can achieve even higher efficiencies, however this has not been modelled.

Taking into account the fact that there is a mix of heating and cooking requirements with different conversion efficiencies, it is assumed that the switch from gas to electricity in commercial and residential use requires 55% of the original energy to deliver the same service.

Industrial sector—x 0.75

Most industrial gas and fossil fuel is used for high temperature heating in furnaces. These lose a lot of energy in the flue gases which are a by-product of the combustion. Old heaters may only be 60-70% efficient, newer heaters 70-85%[12]. Many industrial facilities in Australia are several decades old, and without modern monitoring equipment cannot be run with the tight parameters required for high efficiency operation[13]. In the ZCA2020 Plan, electrical resistance heating is used instead, which can directly transfer heat via efficient heating elements without the flue losses. A 25% energy reduction is considered reasonable given both the lack of flue losses, and the potential for some low-temperature applications to be met via heat pumps.

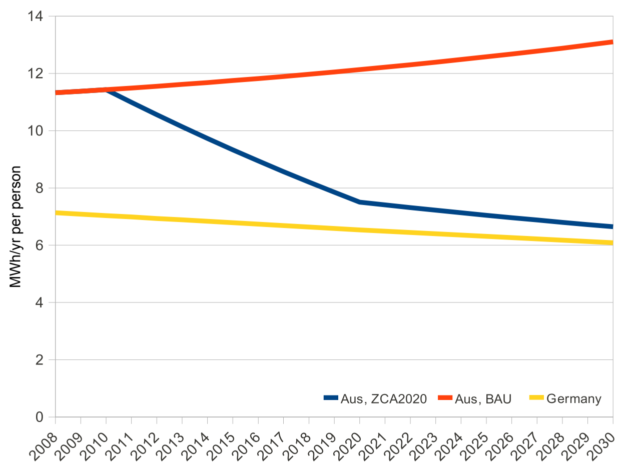
"Set 6" columns—Energy Efficiency in utilised energy—x 0.8, economy-wide

If 1 MJ of heat is delivered to a room, either by 1 MJ of gas, or by 0.3 MJ of electricity via a heat pump, much of that heat will escape if the room is not insulated properly. Based on a broad range of efficiency improvements, such as insulation, upgraded appliances, and improved industrial processes, the ZCA2020 Plan projects that, in 2020, total end-use of energy is reduced by 20% from 2008 levels. This translates to a per capita efficiency gain of 33%, taking into account mid-range population growth as project by ABS[14].

Per capita electricity

As shown in part 2, with a per capita efficiency gain of 33%, Australian electricity use per capita in 2020 will approach that of Germany. Germany has ongoing targets for reduction in overall electricity consumption. This particular dataset is based on standardised data from the IEA[15], and the official efficiency targets of the German Meseberg Report[16].

FIGURE A1.2
Per-capita electricity consumption, existing services only illustrating efficiency measures (IEA standard data)



This compares existing electricity uses **only** and ignores the ZCA2020 strategy of fuel-switch electrification for transport, residential and commercial heating (and others) as described elsewhere.

Onsite solar—x 0.9

It is assumed that 10% of the electricity requirements can be displaced through the use of onsite solar, over the commercial, residential and industrial sectors.

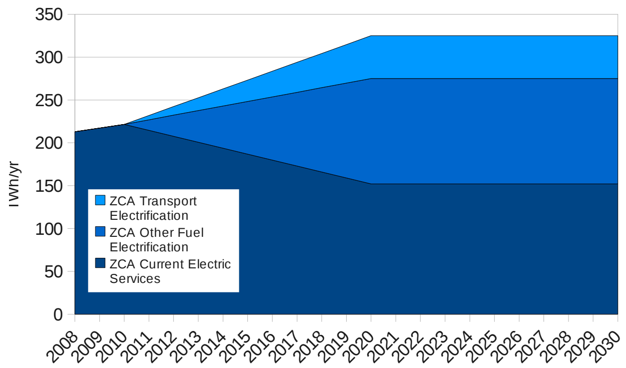
Use of solar PV onsite at the point of use avoids losses in transmission and distribution from centralised sources. Also low-temperature (< 100°C) solar hot water is well suited to hybridisation with heat pumps. It is reasonable to increase the amount of solar energy at point-of-use, though this is still backed up by the 100% renewable grid.

What does this all mean?

This analysis has found that, with appropriate efficiency targets, Australia's energy requirements could be met with 325 TWh/yr of grid electricity in 2020 and beyond. Figure A1.3 shows how this electricity demand is made up of existing electricity services (which become more efficient over time), electrification of transport, and electrification of other services presently fueled by fossil fuels (especially natural gas). This 325 TWh/yr by 2020 is more electricity than would be required under BAU growth of 1.8%/yr (as reported in AERA) and with no fuel switch electrification. The ZCA2020 Plan 100% renewable energy mix has been sized to deliver this 325 TWhr/yr.

ZCA2020 does not propose expanding electrical generating capacity from 2020 through to 2030. Rather, continuously improving efficiency measures will counter demand increases caused by increasing population.

FIGURE A1.3
ZCA2020 Total Electricity Demand including fuel switching/electrification

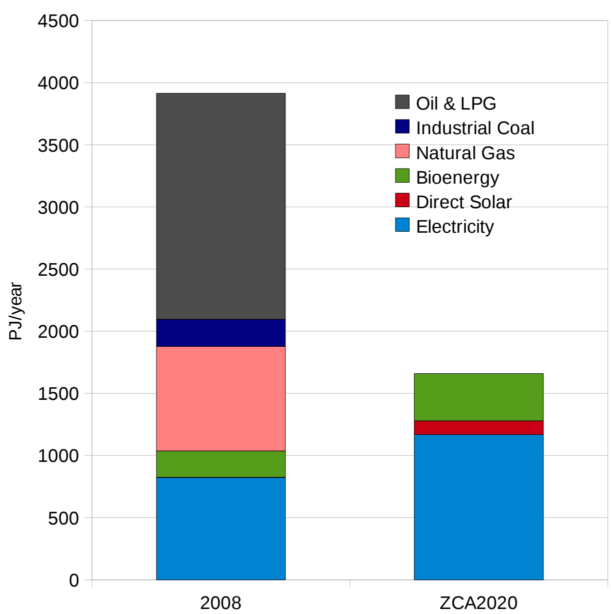


Transport electrification

This high-level analysis investigates the electricity requirements to supply the Australian transport function using electrified vehicles and rail. A small allowance (5%) is made for non-electrified transport services to be provided through liquid biofuels. Non motorised transport measures (e.g. cycling, walking) are not considered in this analysis, though modal switches of this kind would further reduce transport energy demand.

Energy and transport data is all sourced from Apelbaum Consulting's Australian Transport Facts 2007—latest data is for 2004/05[17]. Analysis has been on the basis of supplying the equivalent passenger-kilometres (p-km) and tonne-kilometres (t-km) of the existing transport system with an electrified system.

FIGURE A1.4
Australian End-Use Energy: Present and ZCA2020



Total end-use liquid fuel consumption in 2004/05 was 1301 PJ. All data has been scaled up to reflect the 1337 PJ used in 2007/08, as shown in Table A1.1. This analysis indicates that this could be reduced to 210 PJ for land-based transport using electrification, and with increased modal shift to electric rail for both passenger and freight, this could be further reduced to 160 PJ of electricity (45 TWh) for today's entire domestic passenger and freight task (including domestic aviation and shipping). **50 TWh of electricity is allocated for transport in 2020.**

TABLE A1.1
Transport Energy Use 2007/08 (scaled from 2004/05 data using a factor of 1.027)

Category	Urban (PJ)	Non-Urban (PJ)	Total (PJ)
Passenger Vehicles	474.2	181.4	655.6
Motorcycles	2.6	1.1	3.7
Light Commercial Vehicles	99.9	67.2	167.1
Rigid Trucks	55.3	32.4	87.7
Artic. Trucks	36.9	98.7	135.6
Other Trucks	1.7	0.7	2.4
Buses	15.2	6.9	22.1
Total Road	686	388	1074
Passenger Rail	0.3	2.2	2.5
Freight Rail		23.6	23.6
Ancillary Freight			6.3
Total Rail (liquid fuel)			32
Domestic Aviation			91.1
Domestic Shipping			19.4
Electric Rail (Light and Heavy)			6.5
TOTAL Domestic Liquids			1217.2
International Aviation			119.8
TOTAL Liquids			1337

Electrification of transport results in 5:1 energy reduction, due to the inherent efficiency of electric motor vs internal combustion engine[18]. Internal combustion engines are around 15-20% efficient under normal driving conditions, whereas electric motors are around 85% efficient at converting energy into motion.

However, switching from road vehicles to electric rail (light and heavy, passenger and freight) has the advantages of:

- steel-on-steel wheels to tracks reducing vehicle rolling resistance
- overhead electric cables eliminating the need for batteries—especially relevant for long-distance freight and passenger corridors
- higher loadings (passengers or freight-tonnes) per vehicle further increasing the efficiency of travel.

Modal switching to rail is best suited to cities where a lot of people are travelling along central corridors (e.g. commuting), and for long-distance travel between towns outside of cities. The following modal switches are assumed:

In this analysis, a further **5:1** efficiency gain is projected for modal switch to urban public transport. An electric vehicle operating at 22 kWh/100km, 1.5 average persons/vehicle, delivers 0.15 kWh/p-km. An efficient light rail public transport system can achieve 0.024 kWh/p-km[19], a ratio of more than 6:1 (based on the Siemens Combino tram in Switzerland, 1.53 kWh/vehicle-km, average passenger loading of 65 (out of crush capacity 180)).

Non-urban transport with high-efficiency highspeed rail, can achieve 0.07-0.08 kWh/km[20], a **2:1** efficiency gain over electric vehicles.

Freight rail can achieve 0.07 kWh/t-km[21]. Based on current energy intensities (derived from Apelbaum data), it conservatively modelled that freight rail has an extra efficiency gain per tonne-km of 3:1 (urban) and 2:1 (non-urban), versus electrified trucks. With the exception of Light Commercial Vehicles, which are a highly energy intensive way to transport goods—5:1 (urban) and 10:1 (non-urban) is assumed.

TABLE A1.2
Fraction of p-km shifted to electrified rail

Category	Urban	Non-Urban
Passenger Vehicles	50%	25%
Motorcycles	20%	20%
Light Commercial Vehicles	50%	80%
Rigid Trucks	50%	80%
Artic. Trucks	50%	80%
Other Trucks	50%	80%
Buses	100%	100%

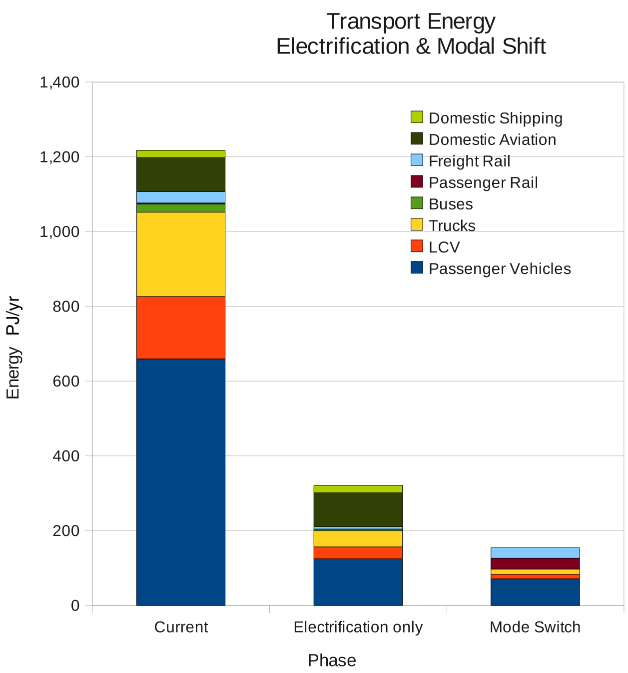
Table A1.2 shows the fraction of passenger-km that would be shifted to an electrified rail transport (light and heavy) system under the ZCA2020 Plan.

International Aviation and Shipping is beyond the scope of this analysis. Domestic aviation and shipping is moved to electric rail. Domestic shipping freight task (excluding petroleum) is 86.8 billion t-km, primarily for ore. This is shifted to high-efficiency bulk rail, with the 0.02 kWh/t-km efficiency currently seen by ancillary rail in Australia (e.g. dedicated rail for iron ore transport in northern Western Australia). Domestic aviation is moved to high-speed rail, 41.8 billion p-km at an efficiency of 0.07 kWh/p-km.

TABLE A1.4
Results of switching transport from liquid fuels to electric vehicles and rail

Final results (PJ)	Current		Electrification only		Rail Mode Switch	
	Liquids	Electricity	Liquids	Electricity	Liquids	Electricity
Passenger Vehicles	655.6		31.9	124.6	31.9	70.9
Motorcycles	3.7		0.2	0.7	0.2	0.6
Light Commercial Vehicles	167.1		8.1	31.7	8.1	12
Rigid Trucks	87.7		4.3	16.7	4.3	6.5
Artic. Trucks	135.6		6.6	25.8	6.6	7.3
Other Trucks	2.4		0.1	0.4	0.1	0.2
Buses	22.1		1.1	4.2		0
Passenger Rail	2.5			0.5		28.9
Freight Rail	23.6			4.7		28.3
Ancillary Freight	6.3			1.3		
Domestic Aviation	91.1		91.1			
Domestic Shipping	19.4		19.4			
Existing Elec Rail		6.3		6.3		6.3
Totals	1217	6	163	217	51	161

FIGURE A1.5
Transport Energy Electrification and Model Shift



The final transport energy requirement after electrification and mode switch is 160 PJ, or just under 45 TWh of electricity. Taking into account further population growth, **50 TWh** of electricity is allocated for Transport in 2020. A further 51 PJ of bioliquids is reserved for land transport that is not electrified, and some hybrid vehicles. This is additional to the 2 PJ of biofuels used currently.

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Appendix 2
System Design and Costing

Wind		
40%	percent	of annual electricity to come from wind
130	TWh/yr	from Wind per year
30%	percent	Annual average Capacity Factor (ref)
49,412	MWe	Total Wind Turbine capacity required
50,000	MWe	Proposed installed capacity
6	MWe	Nameplate wind turbine rating
15,768	Mwhe/yr	annual average per turbine
2,000	MWe	existing wind turbine capacity (end 2010)
48,000	**MWe**	**Actually installed new capacity**
8,000	no.	Number of 6MWe turbines
15%		Of wind capacity that is reliable & firm (i.e. 'baseload wind')
7,500	MWe	Wind capacity reliable at peak times
66	TWh/yr	Wind electricity that is 'baseload'

Solar Thermal - Based on Solar 220 plant with air-cooling		
12	sites	Number of geographically different sites
8,700	MW	Gross Capacity needed to achieve Solar 220 Cost reductions
725	MW	Amount of small-capacity CST at each of 12 sites
13	no.	Solar 220 modules per site excluding scaleup
3,585	MW	Total gross output per site (before air-cooling)
217	MW	Actual Solar 220 output (with aircooling)
3,537	MW	Net output with aircooling
156	no.	Solar 220 modules total
43020	MW	Total grid CST capacity without aircooling
42,461	**MW**	**Total CST capacity with aircooling**
60%	percent	of annual electricity to come from CST
195	TWh/yr	from CST
52%	C.F.	Actual capacity factor required (to meet 60% of energy)
72%	C.F.	Design capacity factor (annual average)
267.8	TWh/yr	Max annual electricity available
73.0	TWh/yr	Extra TWh available per year

Biomass Backup Basis		
7.0	TWh/yr	from biomass (TJ grids modelling)
40%	net turbine efficiency	
17.54	TWh/yr thermal energy	
85%	Heater thermal efficiency	
20.6	TWh/yr primary biomass energy	
74	PJ biomass stored energy for Australia	
4,475	MW of off-grid CST	
5.3	TWh thermal biomass stored energy for off-grid	
19	PJ energy for off-grid	
93	PJ biomass stored energy for Australia	
15.5%	of Australia's wheat crop waste	

Capital Costs		
Wind		
48000	MWe	New wind turbine capacity
71.68	AU$Bn	Billion Australian Dollars - Total Wind Cost
CST		
8700	MWe	Gross capacity needed to achieve Solar 220 Cost reductions
$60	AU$Bn	Cost of first 8700Gross/8587Net MWe
739.0	AU$M	Cost for Solar 220 plant, 2010 currency
3.41	AU$M/MWe	per unit MW
115	AU$Bn	Cost of Solar 220s
$175.4	AU$Bn	Billion Australian Dollars - Total CST Cost

Off-grid CST with biomass backup		
4,810	MWe	Gross off-grid
7.00%		parasitic energy (average from ESAA)
4475	MWe	net off-grid
$15.2	AU$Bn	Off-grid CST (not including biomass backup)
$500	AU$	AUD per kWe biomass boiler
$2.24	AU$Bn	Off-grid biomass backup
17.5	AU$Bn	Total off-grid cost, CST and biomass

Backup Heater Capital Cost		
15	GWe	biomass heater capacity required (TJ model)
0.5	AU$m/MWe	Million AU$ per MWe equivalent biomass backup heater cost [4]
7.5	$Bn	Total grid backup capability

Waste pelletisation plant costs	
9662754	tonnes of wheat crop residue required for 60 PJ
4	months - period of pelletisation after/during harvest (assumed)
2880	hours - pelletisation period
3355	tonnes/hr pelletisation capacity required
10	tonnes/hr average plant size [8]
336	10 tonne/hr plants required
8.3	AU$M per 10 tonne/hr plant [8]
2.79	AU$billion - total cost for all pelletisation plants

Air cooling Capital Cost & Performance adjustment			
Total Plant Capital Cost			
Wet cooling, $k	$267,747 [3]	US$k	
Dry cooling, $k	$279,120 [3]	US$k	
Difference, $k	$11,373	US$k	extra cost for air cooling
Plant size, MWe	80	MWe	
Aircooling, $/MWe	**$142.20**	**US$k/MW**	**(2005 dollars)**
CPI 2003-->2005	1.06 [5]	CPI	
Air cooling, $/MWe	$134.10	US$k/MW	(2003 dollars)
	$186.20	**AU$k/MW**	**(2010 dollars)**
Nominal Solar 220 plant size	220	MW	
Extra cost for air-cooling	$29,505	US$k	(2003 dollars)
Add 10% contingency (as per S&L)	**$32,456**	**US$k**	**(2003 $) extra capital for air cooling**
Initial Plant size	220	MW	With wet cooling
Air-cooled performance penalty	1.30%	(tower)	U.S. DoE Water Study
	217	MW	Net output with dry cooling
Capital costs for SunLab Solar 220 Solar Thermal Plant (Table E-1, Sargent & Lundy[1])			
Structures & Improvements	$7.20	US$M	
Heliostat field	$198.80	US$M	
Receiver	$34.40	US$M	
Tower & Piping	$24.30	US$M	
Thermal Storage	$57.20	US$M	
Steam Generator	$9.30	US$M	
Elec Power Block	$83.60	US$M	
Master Control	$1.60	US$M	
Balance of plant	$9.90	US$M	
Direct Cost	$426.30	US$M	
Eng, Mgmt, Dev (7.8%)	$33.30	US$M	
Land at $5000/ha	$7.00	US$M	
Contingency	$34.30	US$M	
Total Cost	**$500.00**	**US$M**	**The summed cost is $499.9 (Reference[1] presents $599.9 as the total.)**
Add in air cooling	$32.46	US$M	
Cost with air cooling (2003 US$M)	$532.36	US$M	
Consumer Price Index (2003 to 2010)[5]	1.18	CPI	
Solar 220 Plant Total Cost (2010 US$M)	**$628.18**	**US$M**	
Solar 220 Plant Total Cost (2010 AU$M)	**$739.04**	**AU$M**	**Assumed ForEx $0.85US = $1.0AU**

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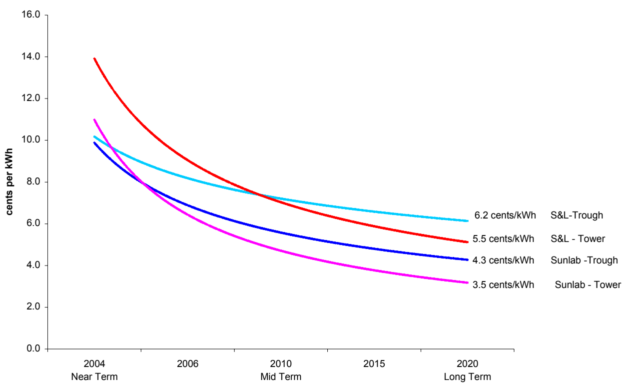
Appendix 3A
Scaling up Solar Power Towers

Cost reduction trajectories of power towers

Both the US Department of Energy's SunLab (Sandia/NREL) program, and the engineering consultancy firm Sargent & Lundy have modelled the economics of CST energy systems in the document Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts, compiled by Sargent & Lundy[1].

The cost reduction trajectory from the Sargent & Lundy report[1] is repeated in Figure A3.1.

FIGURE A3.1
Cost reduction trajectory for solar thermal power



The red curve on the chart above represents the Sargent & Lundy cost projection for towers, while the mauve curve represents the SunLab tower projection. The main difference between the two projections is the cumulative installed capacity assumed by each. In the original report, these were referenced to an installation timeline from 2004—2020, but the key factor in achieving the cost reductions was not the timeline but the total installed capacity.

The key finding from this was that the levelised cost of electricity would come down to $US3.5c/kWh (or 5c/kWh in 2010 Australian currency) once global installed capacity reaches 8,700 MWe of power towers. Most of these cost reductions would come from simple economies of scale—i.e. when the industry is able to build 75% capacity factor 200-220 MWe towers, it is much cheaper than the first-of-a-kind 10-50 MWe plants. There are also significant cost reductions to be achieved from mass-manufacturing of heliostats. The mirror field makes up about half the capital cost of a Solar Power Tower plant, therefore tooling up for large-volume production of these components on a continuous basis (as opposed to start-stop, one-off constructions) has a huge cost-reduction potential.

In summary, 49% of cost reductions from first-of-a-kind plants to more advanced 220 MWe plants comes from economies of scale, a further 28% of cost reductions from high-volume component production, and the remaining 23% from continuous technology improvements, for example from the continued R&D by Sandia Laboratories, and breakthrough innovations such as eSolar's low-cost mirror field design. Sargent & Lundy projected that as costs of towers come down, tower installed capacity would overtake trough installations. Given that troughs are a more mature technology with less scope for cost reductions than towers, and that tower installation capacity is already about to overtake troughs, building trough plants in Australia would not represent the best value for money.

Optimum Plant Size

In Spain, where there are ten solar thermal plants in operation and over fifty under construction[2] the Feed-in-Tariff only applies to plants below 50 MW. However, better economies of scale will come from plants larger than this. Designs are detailed by Sargent & Lundy and NREL for tower plants sized at 13.5 MW, 50 MW, 100 MW, 200 MW and 220 MW with storage. This progression of larger tower projects is being implemented at the time of writing by concentrating solar thermal companies, with Torresol's 17 MW Gemasolar tower with 15h storage currently in construction near Ecija, Spain and Solar Reserve's latest announcements comprising:

- 150 MW, 450 GWh/yr tower plant in Rice, California[3].
- 100 MW, 480 GWh/yr project at Tonopah, Nevada[4].
- And a 50 MW, 300,000 GWh/yr plant in Alcazar de San Juan, Spain[5].

The nature of progress in tower plants, however, is to build a larger plant than the last. For example, Abengoa built a 10 MW power tower, PS10, followed by a 20 MW tower, PS20.

The 220 MW tower described by Sargent & Lundy with 17 hours of storage is approaching the optical limits of a single mirror field to reflect sunlight onto a single tower—at the outer heliostats the reflected light is too diffuse to heat the solar receiver on top of the tower. However, to construct a larger power plant, for example 2,200 MW, you simply construct 10 modules of the 220 MW power tower. It is standard for a power station to consist of a number of smaller operating modules—for example, Hazelwood in Victoria's Latrobe valley has a total generating capacity of 1,680 MW (gross)[6], but this is actually composed of 8 separate 210 MW (gross) generating turbines.

Mirror Field Size and Electrical Output

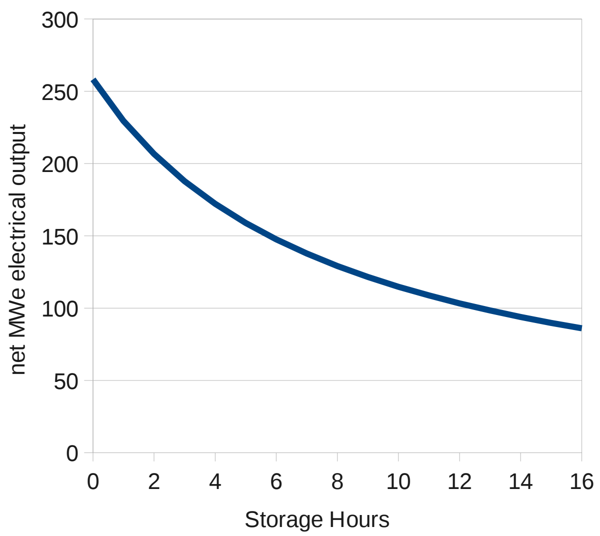
The amount of energy that a mirror field and receiver tower can collect ultimately determines the amount of electricity that can be generated, and is a more relevant comparison of solar thermal power plant size than the rated turbine capacity. For example—a Solar 100 heliostat field as specified by the U.S. Department of Energy's Sandia Laboratories/Sargent & Lundy can collect enough energy to provide 2,066 MWh of electricity per day. If the plant did not have storage, then a 258 MW turbine could be run for the average 8 hours a day that the sun is shining at full strength. However this electricity would not be available overnight, and the plant would have an average annual capacity factor of only 30%. Alternatively, if the plant has storage, it can deliver the electricity over a longer time period and into the night. The trade-off is a smaller turbine size, but it will still deliver the same total amount of electricity.

As an example, the different configurations to deliver the same total of 2,066 MWh per day are explored in Table A3.1 and Figure A3.2, using numbers from the Sargent & Lundy report discussed in section 3.1.

TABLE A3.1
Comparisons of plant capacity (turbine size) and storage for the same mirror field size.

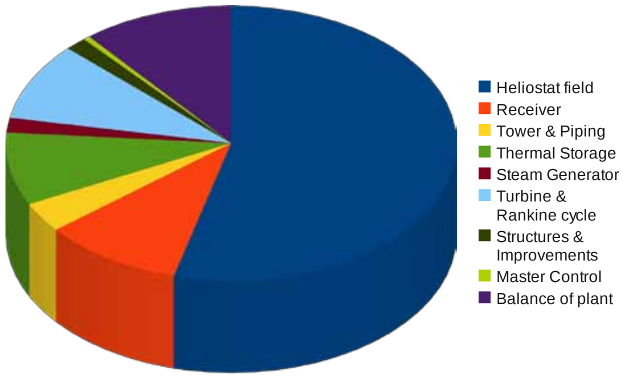
Mirror Field Size (m2)	Total Electricity Per Day (MWh)	Storage Hours	Turbine Size (MW)	Hours of Operation/ Day	Annual Capacity Factor
1,366,100	2,066	16	86	24	75-80%
1,366,100	2,066	8	130	16	50-60%
1,366,100	2,066	0	258	8	30%

FIGURE A3.2
Turbine size vs storage for same size mirror field (2,066 MWh/day)



A graphical comparison of plant capacity (turbine size) and storage for the same mirror field size.

FIGURE A3.3
Capital cost breakdown of S&L Solar 100 (75% capacity factor)

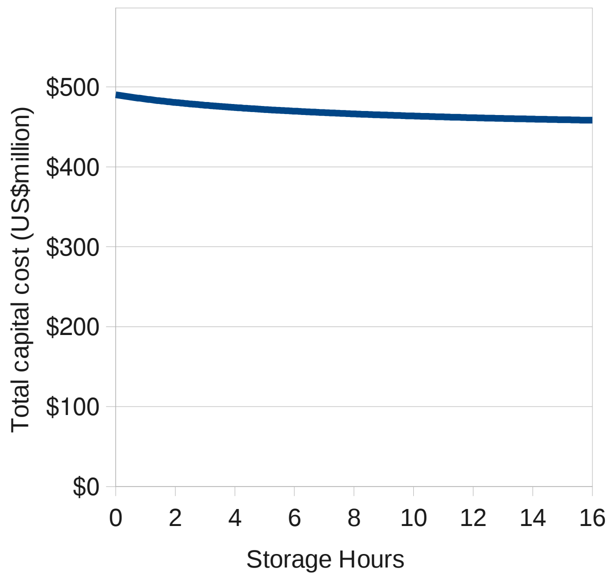


Sargent and Lundy's cost breakdown of a Solar 100 with 16 hours storage.

As shown in Figure A3.3, over half the capital cost of a solar thermal power tower plant is the heliostat field. Therefore, scaling up the storage size while downsizing the turbine for the same sized mirror field will not significantly impact the total capital cost of the plant, as the cost increase and decrease roughly cancel out.

In fact, as illustrated in Figure A3.4, storage is slightly cheaper than turbines, so a plant with 16 hours storage will be about 97% of the cost of a plant with no storage. Again they will both produce the same total amount of electricity from the same mirror field size, but the plant with storage can provide power reliably 24 hours a day.

FIGURE A3.4
Capital cost vs storage for Solar 100 plant (700 MWt tower/field)



In summary, the capital costs and total electricity generation (GWh/yr) are primarily dependent on the size of the mirror field. The turbine size and capacity factor is dependent upon the amount of thermal storage, but does not significantly affect the plant capital cost. This is important when comparing the published costs of today's solar thermal projects. Therefore a plant that produces electricity 24 hours a day can be built for roughly the same price as a plant with the same mirror field size that only operates on sun.

Economics of Solar Thermal Power

The economics and financing of solar thermal power projects are fundamentally different from that of fossil energy projects. Most of the cost of a solar thermal plant is in the capital expenditure, with fixed O&M costs very low, and there is no fuel cost. In fact, for an end-of-the-cost curve plant with a total levelised energy cost (LEC) of 5 AU c/kWh, the ongoing O&M cost component is only around 1c/kWh. As opposed to fossil energy, which has a lower upfront capital, but higher ongoing fuel costs which are subject to variability.

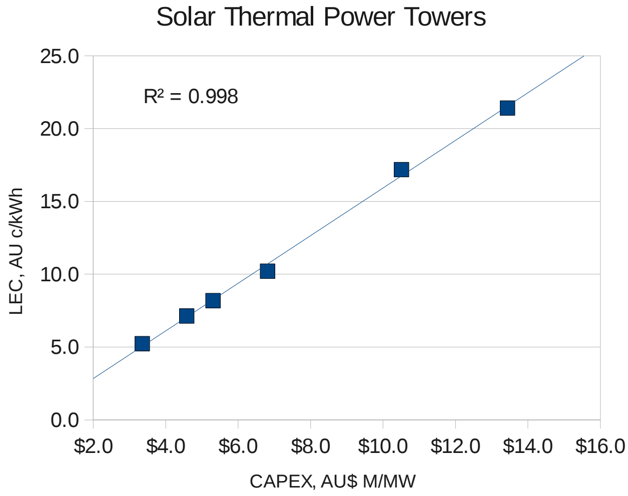
There are a variety of financial policies available for governments to assist the uptake of renewable energy. Two broadly different approaches are: An ongoing subsidy such as a Feed-in-Tariff, which pays the difference between the renewable LEC and the market LEC. An upfront subsidy, such as a direct investment, government loan, or Investment Tax Credit such as that implemented in the U.S., that lowers the debt associated with the capital cost of the plant.

Current cost of molten salt power towers

The cost of a molten salt power tower project today is referenced to the cost of SolarReserve's Tonopah project in Nevada. This will produce 480,000 GWh/year of electricity[7], and will cost over U.S.$700 million[8]. With enough storage (15 hrs) for full 24-hr dispatchable power and 75% capacity factor, a plant this size could have a turbine output of 75 MW. Adjusting for foreign exchange, it can be inferred that the cost of a First-Of-A-Kind plant of this size is $AU10.5 million per MW capacity. (Note that due to economies of scale, a plant producing less than 480,000 GWh per year would be expected to cost more per MW.) SolarReserve also has molten salt power tower projects announced in Rice, California and Alcazar, Spain.

Based on the equivalently priced projects from Sargent & Lundy's cost modelling, these SolarReserve plants should have a Levelised Electricity Cost of AU 20c/kWh, derived from Sargent & Lundy data[1] shown in .

FIGURE A3.5
Levelised Electricity Costs in relation to Capital Expenditure Costs (derived from Sargent & Lundy[1])



Achieving 10c/kWh baseload solar electricity

It is assumed that to be a financially viable renewable energy project in the current Australian market, solar thermal plants will at least need to be able to achieve a wholesale price (after any subsidies) equivalent to or less than wind power (10c/kWh). After achieving such a price, solar thermal could fit into a wider renewable energy incentive policy, for example an expanded version of the current Australian Mandatory Renewable Energy Target (would need to be much greater than 20%), an appropriately structured Feed-In-Tariff or similar.

From the same Sargent & Lundy cost modelling, a CST plant with a LEC of 10c/kWh needs to have a upfront capital of only $AU6-6.5 million/MW.

As shown in Figure A3.1, Sargent & Lundy predict that once 2,600 MW of towers (with ~15h storage) are installed globally, the levelised energy cost for tower plants will drop to US 5.5c/kWh, which equates to AU 8c/kWh today. Adjusting for Australian labour costs, we project that after 2,600 MW of 75% capacity factor solar power tower plants with molten salt storage are built, power towers will be cost-competitive with wind, conservatively estimated at 10c/kWh. This takes into account continued cost reductions in wind turbine technology.

The investment costs of these first plants have been modelled as such:

- First 1,000 MW priced at SolarReserve Tonopah equivalent, $10.5 million per MW—$10.5 Bn investment
- Next 1,600 MW priced at midway cost of $9 million per MW—$14.4 Bn investment

As seen in Spain, a true pipeline of projects is necessary within Australia to avoid stop-start of component factories, and achieve cost reductions and economies of scale.

TABLE A3.2
Cost Trajectory for Solar Thermal

Phase		Phase 1	Phase 2	Phase 3	Phase 4	
Price reference		Solar Reserve	SunLab First-of a-kind	Solar 100	Solar 200	TOTAL
Incremental installation	MW	1,000	1,600	2,400	3,700	
Cumulative installed capacity	MW	1,000	2,600	5,000	8,700	
Capacity Factor	%	72%	72%	72%	72%	
Produced Electricity	GWh /yr	6,300	16,400	31,535	54,870	
Unit Capital cost	$M/MW	$10.5	$9.0	$6.5	$5.3	
Total Phase Capital Cost	$Bn	$10.5	$14.4	$15.6	$19.6	$60
LEC	c/kWh	20	16	10	8	5

Cost parity with conventional fossil energy

Again, as shown in Figure A3.1, further expansion to a total of 8,700 MW of global installed tower capacity would allow CST tower plants with storage to hit cost parity with conventional new coal & gas plants: AU 5c/kWh (US 3.5c/kWh).

Once parity with wind is achieved, the price will continue to drop. The stage of installments has been costed as:
- 2,400 MW at wind price parity, $6.5 million per MW—$15.6 Bn investment
- 3,700 MW at Solar 200 price, $5.3 million per MW—$19.6 Bn investment

Note on conservatism: These costs and required subsidies are very conservative. In reality, it is likely that the initial costs of tower plants will come down much more rapidly from the current $AU10.2million/MW, due to continuous industry improvement elsewhere in the world. In addition, the requirements of building 2,600 MW and 8,700 MW to bring costs down should take into account total global installed capacity, the projects being built in the U.S.A. & Spain. However, we have assumed that this is the maximum industry size that will need to be developed in Australia to achieve the Sargent & Lundy cost reductions.

Therefore, the required phases of installation given here represent the upper bounds of the initial higher-cost investment that will be necessary to introduce cheap baseload solar electricity to Australia.

Conclusion

From this trajectory, it is projected that building the first 8,700 MWe of solar thermal power towers with >15hrs molten salt storage will cost a total of $AU60 billion. Initial plants in the range of 50-200 MW will be scaled up in size until 220 MW modules are built which will achieve a levelised electricity cost of 5c/kWh when run at 70-75% capacity factor.

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Appendix 3B
Projected Wind Energy Capital Costs

Current costs of wind power

Table A3.3 gives the average capital costs from 7 large current wind farm projects in Australia. This gives the total capital costs of $2.5 Million/MW. This figure has been confirmed by Australian wind developers Pacific Hydro and turbine manufacturer Suzlon. The large variation between each wind project is due to differences between each wind farm project, such as grid connection, planning requirements, and terrain (which will alter the construction costs).

While turbine costs have historically reduced over the past decade with increases in turbine sizes and improvement in technology, in recent years prices have gone up.

This price increase was caused by a slower than expected expansion of the wind industry in 2001-2004, followed by a sharp increase in the global market for wind turbines (30-40% annually) until around mid 2008. This was combined with an increase in raw material prices and later the Global Financial Crisis.[6]

In addition to this the current capital cost of wind farms in Australia is much higher than it is in Europe. This is because Australia has seen a much slower growth in wind power than in other countries such as Europe and America. There are currently no turbine manufacturers located in Australia, with most turbine components needing to be shipped from overseas, which increases the costs.

Short Term Wind Turbine Costs

A 2009 report by the EWEA on the Economics of Wind Energy, incorporated the effect of current demand and supply on the changing costs of wind turbines to obtain a long term estimate of wind capital costs.[6] This study assumes the wind industry will grow to 180 GW internationally by 2020 and that half of all new investments in 2020 will be for offshore wind farms.

This work took into account the recent increases in wind turbine costs due to market constraints to extend the work of the European commission to produce a forecast cost reduction for wind turbines.

Based on this study the 2010 forecast capital costs of onshore wind is approximately €1,200/kW (2006 prices) or $AU2,200/kW (current prices). By 2015 the European capital costs of onshore wind is estimated at around €900/kW (2006 prices, $AU1,650 in current prices) and forecast to drop to €826/kW (2006 prices, $AU1500) by 2020.

The report also gathered information from a number of wind farms in Europe to show the relative costs of each component in the installation of a wind turbine. This is presented in Table 2. The report found that the turbine accounted for 68-84% of the total share of capital costs, with a typical amount for an average turbine installation in Europe of 75.6%. The second largest figure was Grid Connection.

The ZCA2020 Plan has calculated the transmissions costs separately to the capital costs of the wind farm projects, but given the large range possible for this figure, we have not excluded this cost from the total average capital cost of a wind farm. Therefore it is expected that wind farm capital costs used in the Plan are conservative and the final cost may be slightly lower than quoted.

Long Term Capital Costs – the influence of China

The European Wind Energy Association research however has not taken into account the impact that China's wind turbines will have on the global market in the near future.

TABLE A3.3
Capital Costs of Major Wind Farms in Australia

Developer	Location	Operating Date	Capacity (MW)	Capital Costs ($Million)	$M/MW	Reference
Origin	Stockyard Hill	2011	484	1400	2.89	1
Acciona	Waubra	2009	192	450	2.34	2
AGL	MacArthur	2011	365	800	2.19	3
Silverton Wind Farm Developments	Silverton	2011	1000	2200	2.20	4
AGL & Windlab Systems	Coopers Gap	2011	440	1200	2.73	4
AGL	Hallet 5	2011	52	120	2.31	5
Roaring 40s	Waterloo	2010	111	300	2.70	4
				Average	**2.48**	

TABLE A3.4
Cost Breakdown for a Medium Sized Turbine - Based on Data from Germany, Denmark, Spain and UK[6]

	Share of Total Cost (%)	Typical Share of Other Cost (%)
Turbine (ex works)	68-84	-
Grid Connection	2-10	35-45
Foundation	1-9	20-25
Electric Installation	1-9	10-15
Land	1-5	5-10
Financial Costs	1-5	5-10
Road Construction	1-5	5-10
Consultancy	1-3	5-10

Current industry estimates suggest that wind turbines manufactured in China are 20-25% of Australian wind turbine prices.

In 2005 the Chinese Government passed the Renewable Energy Law. This law mandated that new wind farms must have at least 70% of all wind power equipment manufactured in China. The Chinese National Energy Administration has indicated that it plans to remove this requirement in the near future, although no date has been set.[7]

Nonetheless this law has created an incredible boom in Chinese manufactured turbines, with total domestic installations from Chinese manufacturers growing from only 18% in 2004 to 62% in 2008.[7]

Companies such as Goldwind, which is one of the largest and most reliable wind turbine manufacturers in China, are planning to start selling a 3 MW wind turbine on the global market from 2011 onwards.[8]

The Chinese government has recently announced plans to build seven wind power bases, each with a minimum capacity of 10,000 MW, by 2020. The planned combined capacity of these wind bases will be 120GW.[9]

The first of these wind bases, dubbed the "Three Gorges Wind" project, is the 20,000 MW wind farm to be constructed in Jiuquan city in the Gansu Province. Construction of the wind farm is now under way at an estimated capital cost of $US 17.6 Billion (120 Billion Yuan).[9] This equates to roughly $AU 1 million/MW, more than half the current capital cost for wind farms in Australia.

Estimated costs for ZCA 2020 Plan

Due to the planned nature of the ZCA2020 program, turbine suppliers would be given significant forward notice of orders for the Australian market. This significantly reduces the risk of capacity constraints, as the turbine suppliers are able to address their supply chain, and ensure that components and materials are available to meet the significant upswing in demand. Implementation of the plan would involve forward contracting for the supply of turbines in order to guarantee this.

Alternatively government investment could help set up a local wind turbine manufacturing industry to supply some or all of the necessary components.

For the first 6 years of the Stationary Energy plan, the capital costs of wind turbines are expected to transition from the current Australian capital costs – $2.5 million/MW to the forecast 2015 European amount - $1.65 million/MW. This is because it will require some time before manufacturers can ramp up production and for orders to be fulfilled in Australia.

It is expected that the final 5 years of the plan will make the most of the influence of Chinese manufacturers on the market, either indirectly or directly (by purchasing from a Chinese wind manufacturer).

Given that the Three Gorges of Wind project will take a number of years to construct, it is expected that the Chinese capital cost estimate will remain relatively stable at $1 million/MW. Accounting for differing labour costs and adopting the 25% rule of thumb, we can reliable expect the capital costs to drop to approximately $1.25 million/MW in Australia.

Table 3.9 in Section 3.2 gives the yearly expected costs of turbine installations.

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Appendix 4
Water Use at CST sites

This appendix outlines in more detail, the availability of water for consumption as well as current water use in each of the concentrating solar tower (CST) plants proposed in the Plan. The total water consumption of the proposed CST plants combined is far less than the amount of water consumed through Australia's power generation currently. However, it is important to demonstrate that there is sufficient water availability at the proposed CST plant sites which each consume 6.3 GL/yr.

This investigation focuses on the availability and use of surface water (water from above-ground rivers and lakes) although in some instances ground water and desalinated sea-water are also considered. The **average total surface water availability** is the mean annual outflow of water. This is generally measured at the points of maximum available flow within a region or surface water management authority (SWMA)[1]. SWMAs are regions of water management, which are generally defined by the catchment of a river system.

Not all surface water is available for use however, as some must be allocated to the environment. Hence, the "sustainable yield" of water is a more useful figure. The **sustainable yield** of water is defined in the Australian Natural Resource Atlas as "the limit on potentially divertible water that will be allowed to be diverted from a resource after taking account of environmental values and making provision for environmental water needs"[2].

In some regions either the total surface water availability or the sustainable yield is unknown, hence the average water use is also noted to indicate the potential availability of water. This figure must be considered cautiously, however, as current water use is not necessarily at a sustainable level. These figures are summarised in Table A4.1.

Carnarvon

Surface Water Management Authority: Gascoyne River

Although the sustainable yield in this catchment is 196 GL/yr with 98% reliability in 95% of years[3], the current maximum allocation limit is 18 GL/yr[4]. Of this 18 GL/yr, 80% is allocated to irrigation and new industries in the region[4]. Current water use is below this allocation limit, hence there is potentially sufficient water in this region to supply a CST plant.

Kalgoorlie

Surface Water Management Authority: Salt Lake

The nominal estimate of the sustainable yield of surface water in this catchment is 1.03 GL/yr[5]. The actual water use is much higher however (approximately 11.4 GL/yr), which consists almost completely (>99%) of imported surface water from nearby catchments and is allocated

TABLE A4.1
Water Use at Solar sites (with Sustainable Yield for some sites)

Proposed Site	Surface Water Management Authority	Current Available Surface Water (GL/yr)	Sustainable Yield (GL/yr)	Current Water Usage (GL/yr)
Carnarvon	Gascoyne River	646 [3]	196 [3]	< 18.0 [4]
Kalgoorlie	Salt Lake	No data	1.03 [5]	> 11.41 [5]
Port Augusta	Mambray Coast	38 [6]	6 [6]	3.96 [6]
Broken Hill	Darling River	2,944 [1]	No data	299 [7]
Mildura	Mid-Murray River	11,162 [8]	No data	4,045 [8]
Bourke	Barwon-Darling Rivers	3,515 [9]	No data	230 [9]
Dubbo	Macquarie-Castlereagh	1,567 [10]	No data	371 [10]
Moree	Gwydir River	782 [11]	No data	321 [11]
Roma	Condamine-Balonne	1,363 [12]	No data	722 [12]
Charleville	Warrego River	423 [13]	No data	11 [13]
Longreach	Cooper Creek	1,126 [14]	No data	6.9 [14]
Prairie	Flinders River and Belyando/ Suttor	6,718 [15,16]	No data	86.3 [15,16]

mostly to urban and industrial use[5]. In addition to surface water, large volumes of hyper saline groundwater (which is unfit for domestic use) are used by the local mines for mineral processing and dewatering[17]. For example, KCGM, a local gold mine, uses approximately 12 GL/yr, of which 83% comes from ground water and recycled water[18]. Whether or not such saline water could be used directly on the mirrors without treatment, the water demand by CST plants in this region will not need to compete with local domestic or irrigation demands.

Port Augusta

Surface Water Management Authority: Mambray Coast

The sustainable yield of surface water in this region is 6 GL/yr, although the highly variable runoff means that the supply is fairly unreliable[6]. Water use is 3.96 GL/yr of which approximately 40% is imported surface water[6].

Clearly, meeting the demand for a CST plant in this area will be a challenge. Further investigation is necessary to ascertain whether or not water can be imported from nearby catchments or from groundwater in order to supply the CST plant proposed in the Plan at this site. If this proves to be unfeasible, it may be worth considering desalination plants in order to meet the CST plant's as well as local domestic demand for water.

Broken Hill

Surface Water Management Authority: Darling River

Broken Hill falls into the Darling River SWMA. Much of the water supplied to the region is stored in the Menindee Lakes, which are located about 70 km south-east of Broken Hill. The lakes have a combined capacity of 1,794 GL and the average surface water availability, as measured at Menindee is 2,944 GL/yr[1]. Of this approximately 299 GL/yr are allocated to meet the local industrial, domestic and agricultural demand for water along 690 km of the Darling River[7]. There has been some concern about the declining water levels in the lakes, in particular due to the amount of water lost through evaporation from their large surface areas[19]. However data acquisition is underway to research the potential for storing water in naturally occurring underground aquifers (which will eliminate losses due to evaporation) which so far, has been promising.

Mildura

Surface Water Management Authority: Mid-Murray River

Mildura is located on the banks of the Murray River, which, as Australia's largest river means that this site is one of the Plan's more secure sites with regard to water supply. The mid-Murray region spans several major centres along the river's banks from Albury-Wodonga to Goolwa and therefore there is high demand for water for domestic and agricultural use[8]. The average surface water availability for this region is 11,162 GL/yr of which 4,045 GL/yr is used[8]. This level of consumption is quite high (36%) and although a reliable figure for the sustainable yield in the region was not found, it would almost certainly be less than current levels of consumption. Hence, although the demand of 6.7 GL/yr by one CST site in this region could easily be met by current surface water availability, care would need to be taken to ensure that this was balanced with allocations to other water consumers as well as meeting environmental flow requirements.

Bourke

Surface Water Management Authority: Barwon-Darling Rivers

Bourke is located in the Barwon-Darling region of the Murray-Darling basin in north-west New South Wales and shares the region's water resources with several other town centres. The average surface water availability for the entire Darling Basin assessed at Bourke is 3515 GL/yr, however as this is not the sustainable yield, it is not indicative of what can realistically be consumed[9]. Current surface water use for the region is 230 GL/yr and groundwater use is about 10 GL/yr which is thought to be underdeveloped[9]. Hence, meeting the water resource requirements for the proposed CST plant site in this region is feasible.

Dubbo

Surface Water Management Authority: Macquarie-Castlereagh

Dubbo is located in the Macquarie-Castlereagh region, which is also part of the greater Murray-Darling basin. This region includes the Macquarie, Castlereagh and Bogan Rivers which supply water to the centres of Wellington, Mudgee, Orange, Bathurst as well as Dubbo for domestic use, but mostly irrigation[10]. The current average surface water availability is 1,567 GL/yr of which 371 GL/yr are used[10]. Again, meeting the water resource requirements for the proposed CST plant site in this region should not be a challenge, however care will need to be taken to ensure that environmental flows are met together with meeting the demands of other water users.

Moree

Surface Water Management Authority: Gwydir

The Gwydir region, also part of the Murray-Darling basin, is based around the Gwydir River and supplies the town of Moree as well as local agriculture. The current average surface water availability is 782 GL/yr of which 321 GL/yr is used[11].

Roma

Surface Water Management Authority: Condamine Balonne

This region, located mostly in the Queensland share of the Murray-Darling basin, services several centres including Roma. Average surface water availability is 1,363 GL/yr and current use is 722 GL/yr[12]. Groundwater is an additional source of water, with current use at 160 GL/yr[12].

Charleville

Surface Water Management Authority: Warrego

The Warrego region, which is mostly located in Queensland is one of the northern regions of the Murray-Darling Basin. Water availability here is less reliable than in other parts of the Murray-Darling Basin, although the average total water availability is still 423 GL/yr[13]. In the lowest one-year period on record, diversions from this region were 11.3 GL/yr[13].

Longreach

Surface Water Management Authority: Cooper Creek

Longreach is located within the part of the Cooper Creek catchment that lies in Queensland. There is no data for the sustainable yield of water from this catchment however the average total available surface water is 1126 GL/yr[14]. Diversions of water for use are 6.9 GL/yr[14]. As a fraction of the total available surface water, this level of diversion is fairly low. Whilst this might usually be explained by there being a high demand for environmental flows in the region, in this case, it could also be due to the low level of development in the region. That is, there are no major storages or other types of development within the catchment[14] which may be why current diversions of water are significantly less than the total available surface water. More investigation into the actual sustainable yield of this SWMA will be necessary to ascertain whether or not it can supply the CST plant proposed in the Plan for this site without competing with other water users. If sufficient water is available within a sustainable yield, further developments might be necessary to facilitate the extra diversion to the CST plants.

Prairie

Surface Water Management Authority: Flinders River and Belyando/Suttor

Prairie is located in Queensland, on the border of the Flinders River and Belyando/Suttor catchments. There is no data for the sustainable yield of water from these catchments, however their total available surface water is 3,857 GL/yr and 2,861 GL/yr respectively[15,16]. The current water use in these catchments is 7.7 GL/yr and 78.6 GL/yr respectively[15,16].

Further investigation will be necessary to determine the exact location of the proposed CST plant in this region and hence whether it will be more feasible to draw water from the Flinders River or the Belyando/Suttor catchment. Both regions have quite a low level of development meaning that with new or expanded infrastructure, there is potential for diversions to be increased beyond current use as long as environmental flows can be met.

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Appendix 5
Industrial Case Study

Alumina Refinery Cogeneration Case Study

This details and analyses how a series of solar thermal power plants, based on the Solar 220 design, can be adapted to meet the combined heat and power requirements of the Gladstone Alumina Refinery. Combined heat and power, or co-generation, is a commonly used industrial process whereby the excess heat from an electrical generating system is used directly for heating requirements. Solar thermal, like other power stations, also produce excess heat, which can be used for this purpose.

Basis

The information provided in the United Company Rusal's recent public submission[1] to the Australian Government's energy white paper provided the basis for this case study. The annual energy requirements for the Alumina plant, outlined in the submission, can be found in Table A5.1.

TABLE A5.1
Annual Energy Requirements for Alumina Plant[1]

Energy Required	Quantity
Electricity	777000 MWh
Gas	13.5 PJ
Coal	1.42 Mt

The coal is used to generate steam; the required quality of this steam is a significant factor. High pressure steam 5,000 kPa at 270°C is required to operate the digester[1], and must be available from any proposed modified system.

An Australian Exchange Rate of 0.9136[2] was used in the economic basis of the case study.

Modified Design

The energy requirements of the plant were altered to reflect the change in energy use in the modified plant. In the proposed modification, the gas fired kiln is to be replaced by an electrically fired kiln. The electrical requirement was based on an energy grade function of 1 (even though a value of 0.913[3] would be acceptable). The energy content of coal is 30 GJ/tonne and the steam requirement was calculated on 90%[4] conversion rate from coal energy to steam. These numbers are conservative values. The plant's modified energy requirements are shown in Table A5.2:

TABLE A5.2
Annual Energy Requirements for the Modified Plant Design

Energy Required	Quantity
Electrical	4527 GWh
Steam	10650 GWh

The modified system is based on the Solar 220 design. A Co-generation Heat and Power (CHP) system was design to meet the various energy requirements of the plant. Given the steam conditions required in the process, a backpressure turbine with an efficiency of 15% is necessary. The outputs from the Solar 220 systems are shown in Table A5.3 and Table A5.4.

TABLE A5.3
Solar 220 Output

	Efficiency	Output (MW)	Gwh per year
Electrical	0.463	245	2146.2

TABLE A5.4
Cogen Solar 220 Output

	Efficiency	Output (MW)	Gwh per year
Electrical	0.15	79.37	695.31
Steam	0.6	317.49	2781.25

Using this modified design, it was determined that 4 of these modified 220 plants would be required to meet the total steam requirement of the plant. A single unmodified Solar 220 is required to ensure the remaining electrical demand is met. A slight excess of electricity is produced, perhaps suitable for export to the grid.

Capital Cost

The capital costs of the project were based on the results reported in the Sargent and Lundy report[5] for the Solar 220 design. It was assumed that the capital costs for the modified Solar 220 with cogeneration were the same as that for the Solar 220 outlined in the report. The receiver and heliostats represent the largest proportion of the capital cost (74%) and are unmodified in the co-generation design. The inclusion of a backpressure turbine in the power block (the remaining 26% of the cost) is more likely to decrease the cost of this component (backpressure turbines are typically less expensive than their high efficiency counterparts[4]). A break down of the costs can be found in Table A5.5.

TABLE A5.5
Cost Breakdown

	CAPEX (Million $US)
Heliostat	198.8 [5]
Power block	83.6 [5]
Receiver	34.4 [5]
Total	316.8
Total ($AU)	**346.76**
No. Solar 220 modules	5
TOTAL CAPEX ($AU)	**1733.8**

Revenue

The revenue delivered by this project is realised by the reduction in utility expenditure. To determine this reduction, utility prices are required; the prices used were taken from treasury estimates and can be found in Table A5.6.

TABLE A5.6
Utility Prices

Commodity	Price	Unit
Electricity (wholesale)	42.4 [6]	$/MWh
Gas	5.0 [6]	$/MJ
Coal	125 [6]	$/Tonne

Using the prices in Table A5.6, and the current energy usage, the potential savings (via reduction in expenditure on utility costs) were determined. Table A5.7 outlines a breakdown of the realised revenue.

TABLE A5.7
Realised Revenue Breakdown

	Amount	Unit	Realised Revenue (Million $AU)
Electricity	777000	MWh	32.94
Gas	13.5	PJ	67.5
Coal	1.42	Mt	177.5

Operation and Maintenance

The operating costs were based on the results reported in the Sargent and Lundy report[5] for a Solar 220 design. It was assumed that the operating cost for the modified Solar 220 with cogeneration would be the same as that for the Solar 220 outlined in the report. The modified designs would not significantly alter the operational and maintenance cost, due to the similarity in the designs. A breakdown of the costs can be found in Table A5.8.

TABLE A5.8
Breakdown of Operation and Maintenance Costs

	OPEX (Million $US)
Burdened labour rate	0.04 [5]
Staff Cost	2.81 [5]
Material and Service Cost	34.4 [5]
Total	4.71
Total ($AU)	5.16
Total # Solar 220's	5
TOTAL OPEX	25.8

Cashflow Analysis

A cashflow analysis of the project was performed to allow various economic measures (including return on investment, payback period and net present value) to be determined. In the evaluation of the cashflow sheet, several standard assumptions were utilised. The assumptions used in this analysis are as follows:

- Fixed Capital Investment expenditure spread over two years[5] (70% first year, 30% second year[7]
- Flat line depreciation of capital over 10 years[7]).
- Corporate tax rate of 30% [8]
- Operating life of 30 years [5]
- Discount rate of 8%
- Operating Capital equivalent to 10% of the Fixed Capital Investment[7], and redeemable in the final year of operation.

Units: Million AUD

Summary

The above cashflow analysis was used to determine some basic economic measures. These measures provide an indication of the feasibility and economic viability of a project.

Payback Period	9 years
ROI	25.2%
IRR	10.5%
NPV	436 Million $AU

TABLE 5.9
Results of discount cashflow analysis for Alumina Refinery Cogeneration

Year	CAPEX	O and M	REVENUE	DEPRECIATION	TAXABLE INCOME	TAX	PROFIT	CASHFLOW	CUMULATIVE CASHFLOW	DCCF	NPV
-2	-1213.66	0	0	0	0	0	0	-1213.66	-1213.66	-1213.66	-1213.66
-1	-520.14	0	0	0	0	0	0	-520.14	-1733.8	-481.61	-1695.27
0	-86.69	-25.8	277.94	-173.38	78.77	-23.63	228.52	141.83	-1591.97	121.59	-1573.68
1	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	-1363.46	181.4	-1392.28
2	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	-1134.94	167.97	-1224.31
3	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	-906.43	155.52	-1068.78
4	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	-677.91	144	-924.78
5	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	-449.39	133.34	-791.44
6	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	-220.88	123.46	-667.98
7	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	7.64	114.31	-553.67
8	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	236.15	105.85	-447.82
9	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	464.67	98.01	-349.82
10	0	-25.8	277.94	-173.38	78.77	-23.63	228.52	228.52	693.19	90.75	-259.07
11	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	869.69	64.9	-194.17
12	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	1046.19	60.09	-134.08
13	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	1222.69	55.64	-78.44
14	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	1399.19	51.52	-26.92
15	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	1575.7	47.7	20.79
16	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	1752.2	44.17	64.96
17	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	1928.7	40.9	105.85
18	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	2105.2	37.87	143.72
19	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	2281.7	35.06	178.78
20	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	2458.21	32.47	211.25
21	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	2634.71	30.06	241.31
22	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	2811.21	27.83	269.15
23	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	2987.71	25.77	294.92
24	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	3164.21	23.86	318.78
25	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	3340.72	22.1	340.88
26	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	3517.22	20.46	361.34
27	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	3693.72	18.94	380.28
28	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	3870.22	17.54	397.82
29	0	-25.8	277.94	0	252.15	-75.64	176.5	176.5	4046.72	16.24	414.06
30	86.69	-25.8	277.94	0	252.15	-75.64	176.5	263.19	4309.92	22.42	436.49

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Appendix 6
Transmission Upgrades

Costs for transmission have been derived from published industry data.

Distances of transmission lines have been mapped out using highly accurate Google Earth software. These are detailed in Table A6.2.

Costs of HVDC & HVAC cabling, and HVAC reactive compensation stations have been sourced from ABB, a leading power engineering company and pioneers of the HVDC technology.

The cost of the HVDC converter station has been derived from the existing published cost of Siemen's HVDC project from UK to the Netherlands. This is considered a more real-world indicative cost, as recommended by SKM's review. However, as the cabling for this project is underwater, it would be more expensive and is not considered representative compared to ZCA2020's land-based HVDC links.

All costs have been converted to Australian dollars at an exchange rate of 1AUD = 0.85USD, and 1AUD = 0.6EURO.

TABLE A6.1
Converted costs of HVDC substations[2]

	Original Project	Scaled (ZCA2020)
MW	1000	4000
kV	450	500
EUR per substation pair	EUR 220,000,000	EUR 978,000,000
AUD/EUR		0.6
Cost for ZCA2020 pair		$1,630,000,000

FIGURE A6.1
Costs of HVAC and HVDC[1]

table 1. Comparative costs of HVDC and EHV AC transmission alternatives.

Alternative	DC Alternatives + 500 Kv Bipole	DC Alternatives 2 x + 500 kV 2 bipoles	DC Alternatives + 600 kV Bipole	DC Alternatives +800 kV Bipole	AC Alternatives 500 kV 2 Single Ckt	AC Alternatives 500 kV Double Ckt	AC Alternatives 765 kV 2 Singl Ckt	Hybrid AC/DC Alternative + 500 kV Bipole	Hybrid AC/DC Alternative 500 kV Single Ckt	Hybrid AC/DC Alternative Total AC + DC
Capital Cost										
Rated Power (MW)	3000	4000	3000	3000	3000	3000	3000	3000	1500	4500
Station costs including reactive compensation (M$)	$420	$680	$465	$510	$542	$542	$630	$420	$302	$722
Transmission line cost (M$/mile)	$1.60	$1.60	$1.80	$1.95	$2.00	$3.20	$2.80	$1.60	$2.00	
Distance in miles	750	1,500	750	750	1,500	750	1,500	750	750	1,500
Transmission Line Cost (M$)	$1,200	$2,400	$1,350	$1,463	$3,000	$2,400	$4,200	$1,200	$1,500	$2,700
Total Cost (M$)	**$1,620**	**$3,080**	**$1,815**	**$1,973**	**$3,542**	**$2,942**	**$4,830**	**$1,620**	**$1,802**	**$3,422**
Annual Payment, 30 years @ 10%	$172	$327	$193	$209	$376	$312	$512	$172	$191	$363
Cost per kW-Yr	$57.28	$81.68	$64.18	$69.75	$125.24	$104.03	$170.77	$57.28	$127.40	$80.66
Cost per MWh @ 85% Utilization Factor	$7.69	$10.97	$8.62	$9.37	$16.82	$13.97	$22.93	$7.69	$17.11	$10.83
Losses @ full load	193	134	148	103	208	208	139	106	48	154
Losses at full load in %	6.44%	3.35%	4.93%	3.43%	6.93%	6.93%	4.62%	5.29%	4.79%	5.12%
Capitalized cost of losses @ $1500 kW (M$)	$246	$171	$188	$131	$265	$265	$177	$135	$61	$196
Parameters:										
Interest rate %	10%									
Capitalized cost of losses $/kW	$1,500									

Note:
AC current assumes 94% pf
Full load converter station losses = 9.75% per station
Total substation losses (transformers, reactors) assumed = 0.5% of rated power

TABLE A6.2
Technical details and costings of ZCA2020 proposed high-voltage transmission upgrades

Site	Power Station Size	Purpose	Line name	Type	Length	Rating
	MW				km	MW
Carnarvon	4000	Solar Plug-in	Carnarvon to Geraldton	HVAC	499	6000
Kalgoorlie	4000	Solar Plug-in	Kalgoorlie to Perth	HVAC	560	6000
Broken Hill	4000	Solar Plug-in	Broken Hill to Mildura	HVDC	262	4000
Bourke	4000	Solar Plug-in	Bourke to Mount Piper	HVDC	567	4000
Dubbo	4000	Solar Plug-in	Dubbo to Mt Piper Direct	HVAC	249	3000
Moree	4000	Solar Plug-in	Moree to Armidale	HVAC	364	6000
Prairie	4000	Solar Plug-in	Prairie Plug-in	HVAC	296	6000
Longreach	4000	Solar Plug-in	Longreach Plug-in (direct)	HVDC	654	4000
Charleville	4000	Solar Plug-in	Charleville to Roma	HVDC	311	4000
Albany	2000	Wind plug-in	Albany Plug-in	HVAC	430	3000
Esperance	2000	Wind plug-in	Esperance Plug-in	HVAC	363	3000
Geraldton	2000	Wind plug-in	Geraldton to Perth	HVDC	440	4000
Bunbury	2000	Wind plug-in	Bunbury Plug-in	HVAC	10	3000
(Great Aust. Bight)		Wind plug-in	Cleve to Port Augusta	HVDC	201	8000
Ceduna	3000	Wind plug-in	Ceduna Plug-in	HVAC	327	3000
Yongala	2000	Wind plug-in	Yongala Plug-in	HVAC	125	3000
Port Lincoln	2000	Wind plug-in	Port Lincoln Plug-in	HVAC	121	3000
Cape Jaffa	2000	Wind plug-in	Cape Jaffa Plug-in	HVAC	54	3000
Streaky Bay	3000	Wind plug-in	Streaky Bay Plug-in	HVAC	269	3000
Port Fairy	2000	Wind plug-in	Port Fairy Plug-in	HVAC	61	3000
Ballarat	2000	Wind plug-in	Ballarat Plug-in	HVAC	79	3000
Mt Gellibrand	2000	Wind plug-in	Mt Gellibrand Plug-in	HVAC	56	3000
Wonthaggi	2000	Wind plug-in	Wonthaggi Plug-in	HVAC	96	3000
Crookwell	2000	Wind plug-in	Crookwell Plug-in	HVAC	86	3000
Orange	2000	Wind plug-in	Dubbo-Orange-Mt Piper	HVAC	93	3000
Walcha	2000	Wind plug-in	Walcha Plug-in	HVAC	35	3000
Cooma	2000	Wind plug-in	Cooma Plug-in	HVAC	122	3000
Silverton	2000	Wind plug-in	Silverton to Mildura	HVAC	287	3000
Stanthorpe	2000	Wind plug-in	Stanthorpe Plug-in	HVAC	98	3000
Atherton	2000	Wind plug-in	Atherton Plug-in	HVAC	62	3000
Collinsville	2000	Wind plug-in	Collinsville Plug-in	HVAC	18	3000
Georgetown	2000	Wind plug-in	Georgetown Plug-in	HVAC	272	3000
Interstate QLD-NSW		Grid Upgrade	Roma to Moree	HVDC	417	4000
Interstate SA-NSW		Grid Upgrade	Port Augusta to Mount Piper	HVDC	1169	8000
Interstate VIC-NSW		Grid Upgrade	Mildura to Mount Piper	HVDC	708	4000
Intrastate		Grid Upgrade	Mildura to Melbourne	HVDC	544	8000
Interstate SA-VIC		Grid Upgrade	Port Augusta to Mildura	HVDC	461	4000
Interstate SA-VIC		Grid Upgrade	Port Augusta to Melbourne	HVDC	886	4000
Interstate SA-VIC		Grid Upgrade	Port Augusta to Naracoorte	HVDC	560	4000
Interstate SA-VIC		Grid Upgrade	Naracoorte to Portland	HVAC	216	6000
Interstate QLD-NSW		Grid Upgrade	Roma to Armidale	HVAC	662	6000
NEM-Mt Isa		Grid Connection	Mt Isa upgrade	HVDC	847	4000
SWIS-NEM		Grid Connection	Perth to Port Augusta	HVDC	2146	4000
SWIS-NEM		Grid Connection	Kalgoorlie to Port Augusta	HVDC	1586	4000
SWIS-NWIS		Grid Connection	SWIS-NWIS Connection	HVAC	561	6000

Multiple lines – single or double	HVDC station costs ($AU M) – 4 GW Capacity	HVAC station costs ($AU M) - 3 GW Capacity	HVDC Transmission line cost ($AU M/km) – 4 GW Capacity	HVAC Transmission line cost ($AU M/km) – 3 GW Capacity	Total Cost ($AU M) (cable + station)
	$1,630	**$638**	**$1.17**	**$2.34**	
2		$1,275		$2,335	**$3,610**
2		$1,275		$2,620	**$3,895**
1	$1,630		$306		**$1,936**
1	$1,630		$663		**$2,293**
1		$638		$582	**$1,220**
2		$1,275		$1,705	**$2,980**
2		$1,275		$1,385	**$2,660**
1	$1,630		$765		**$2,395**
1	$1,630		$363		**$1,993**
1		$638		$1,005	**$1,643**
1		$638		$849	**$1,487**
1	$1,630		$515		**$2,144**
1		$638		$24	**$662**
2	$3,259		$470		**$3,729**
1		$638		$765	**$1,403**
1		$638		$293	**$930**
1		$638		$283	**$921**
1		$638		$127	**$765**
1		$638		$630	**$1,267**
1		$638		$143	**$780**
1		$638		$186	**$823**
1		$638		$131	**$769**
1		$638		$224	**$862**
1		$638		$202	**$839**
1		$638		$217	**$854**
1		$638		$81	**$719**
1		$638		$285	**$923**
1		$638		$672	**$1,310**
1		$638		$230	**$867**
1		$638		$145	**$783**
1		$638		$43	**$680**
1		$638		$636	**$1,274**
1	$1,630		$488		**$2,117**
2	$3,259		$2,735		**$5,994**
1	$1,630		$828		**$2,458**
2	$3,259		$1,273		**$4,533**
1	$1,630		$539		**$2,169**
1	$1,630		$1,036		**$2,666**
1	$1,630		$655		**$2,285**
2		$1,275		$1,011	**$2,286**
2		$1,275		$3,096	**$4,372**
1	$1,630		$991		**$2,620**
1	$1,630		$2,510		**$4,140**
1	$1,630		$1,855		**$3,485**
2		$1,275		$2,625	**$3,900**
				TOTAL:	**$92,440**

Sinclair Knight Merz (SKM) Review of ZCA2020 Stationary Energy Plan

Keith Frearson, 20 May 2010

Background

SKM has reviewed the ZCA2020 Stationary Energy plan prepared by Beyond Zero Emissions and the Climate Emergency Network in terms of the connection of the proposed Zero Carbon generation and its connection to the transmission network.

The review finds that 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.

Key Review Findings

General Arrangements

The transmission connection arrangements have been designed based on using large centralised generation centres for both solar thermal installations and wind farms – typically 3500 MW and 2000 MW respectively. As a consequence, the transmission arrangements are sized to accommodate these power levels.

Due to the magnitude of the generation and the distances involved, the transmission connection for the solar thermal plant has been assumed to be HVDC at +/-500 kV and 4000 MW capability. This makes sense in terms of Node-Node transfer capability of large amounts of energy.

For wind farms, the connection has been assumed to be HVAC at 500 kV with 3000 MW capability (per circuit) to allow for easier connection of dispersed sites. For example, the south western coastline of South Australia has been identified as a major wind-resource area. As there are a number of wind generation centres proposed for that area, it is preferable to use HVAC as distributed connection points can be more easily arranged.

Overall Generation/Load Balance

The plan provides a reasonable balance between generation and load in each state as shown in the following table:

Important points to note from the table are:

- The total installed Solar thermal generation is 42,500 MW; note – Numbers in table have been rounded, each CST solar thermal site is in fact 3,537 MW
- The total load is 58,200 MW;
- Wind and existing Hydro provide a further 53,000 MW;
- The major source for Hydro generation is the Snowy Mountains scheme;
- Victoria and New South Wales have a slight deficit in terms of Solar Thermal generation and peak demand but this is compensated for by wind generation, hydro generation and enhanced transmission interconnections to other regions. Furthermore, additional Solar Thermal stations could be installed in both Victoria and New South Wales should the need arise.

Transmission Concept

The transmission concept is to use the existing network wherever possible and to develop major HVDC hubs in South Australia, Victoria and New South Wales (at Port Augusta, Mildura and Mt Piper respectively). The HVDC transmission will provide full access to the Solar Thermal generation located across a number of time zones. HVDC at voltage levels in excess of +/-500 kV is used extensively throughout the world and is considered a "mature" technology. The major technical drawback with HVDC is the difficulty in creating connections between the terminating hubs. In this study, it has been assumed that all HVDC links are Hub-Hub and no off-takes are provided.

The location of the hubs has not been optimised but they are viable locations, given the sources of generation (Solar and Wind) and the underlying transmission network.

Where HVDC is not practical (for example where a significant number of connections are required), 500 kV HVAC transmission has been used (eg for wind farms across South Australia). 500 kV HVAC is currently employed in both Victoria and New South Wales and is being proposed for Queensland.

TABLE A6.3
Power Generation Supply and Demand Analysis by State

State *	Solar (MW)	Wind (MW)	Hydro (MW)	Total Generation (MW)	Peak Demand (MW in 2020)
Western Australia	7,000	8,000	-	15,000	7,500
South Australia	3,500	14,000	-	17,500	4,300
Victoria	7,000	8,000	500	15,000	12,800
NSW	10,500	10,000	3,750	24,250	19,600
Queensland	14,000	8,000	700	22,000	14,000

*Tasmania has been neglected from this analysis as the possible use of solar thermal generation is limited

In addition, AEMO has recently published reports entitled "Network Extensions to Remote Areas: Parts 1 and 2". In these reports, the concepts of major enhancements to the 500 kV grid are examined, as well as using long-distance HVDC to connect remote renewable generation and upgrading interstate transmission capability. To some extent, these reports validate the transmission concepts proposed for the various renewable energy sources.

Generation Sources

Solar Thermal stations have been sited across Australia in a number of different time zones. This feature, together with using locations having high solar incidence, will act to ensure high availability of output from the solar thermal generators.

The proposed centres for wind farms are located along over 6,000 km of coastline from Albany to Cairns. This diversity should ensure that there will be a significant wind resource available at one or more locations.

The hydro generation can be used to provide a buffer to the variability of the wind generation. Alternatively, the wind generation can be thought of as preserving the hydro resources for periods when it can most usefully be used. This also applies to solar thermal power – in periods of high wind output, excess heat can be stored in the molten salt tanks for later use.

System Demand

The system demand for 2020 has been estimated based on load forecasts in the various annual planning reports publicly available. Where necessary, the data has been extrapolated to 2020 using the growth rate assumed in these forecasts.

Network Development

The transmission network as proposed will not appear overnight – it will be staged over many years. As a consequence, there will be a need to consider the staging options to provide the most efficient and practical outcome over time. For example, it may well be the case that the Western Australian connections to South Australia would be the last connections to be made – if found to be of value.

The development of a 500 kV network to capture the wind potential of South Australia could well be the first project requiring major capital investment but would provide access for proven wind farm technology.

A number of the CST plants and wind farms could be completed without the requirement for major transmission upgrades, at least in the initial phases of development. Three examples demonstrate this:

- Moree Solar Thermal plant is situated within 200 km to Armidale in NSW and Bulli in Queensland. These two stations form part of the Queensland-NSW Interconnector (QNI). If the QNI is to be upgraded to 500 kV then taking the 500 kV QNI via Moree would represent an efficient solution.
- Dubbo Solar Thermal plant is 180 km from Mt Piper while Orange Wind Farm is approximately 80 km from Mt Piper and almost in a direct line to Dubbo. Mt Piper is already a major transmission hub in NSW so connection costs can be kept to a minimum. The possibility of using one Double Circuit 500 kV line to service both Dubbo CST and Orange Wind Farm, at least in the initial development stages, creates opportunities for significant savings.
- Port Augusta Solar Thermal plant is close to the Davenport 275 kV substation. Assuming the proposed Olympic Dam load eventuates, Davenport 275 kV substation could accommodate significant injection from the CST (say 500 MW) without the need for major inter-regional transmission development. Thus, initial development could proceed in a staged manner at minimal initial cost.

Hydro

No new hydro power stations have been proposed but the presence of existing hydro generation will provide a reliable and easily controlled generation source should it be required.

Transmission Costs

The costing of the proposed transmission connections has been carried out using figures derived from past projects but no formal evaluation has been made in this regard. It is recognised that the costs presented are very high – but not unrealistic if the development timeframe is considered. The costs could amount to $10 B/year over a 10 year development horizon with much of the cost "back-ended".

Disclaimer

The review has considered connection feasibility in terms of capacity and security. The network examined has not been optimised and constraints on the underlying (existing) transmission system have not been specifically addressed. The costing of the proposed transmission connections has been carried out using figures derived from past projects but no formal evaluation has been made in this regard.

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Appendix 7
Implementation – Timeline and Jobs

Implementation Timeline Modelling

The ten-year timeline for implementing the ZCA2020 Plan has been modelled from January 2011 to December 2020. The plan takes into account a ramp-up of the renewables industry over a number of years. This analysis is intended to demonstrate the scale of installation that would be required to achieve the transition. It is recognised that there are social and political constraints that would need to be overcome to allow this timeline to occur, along with fast-track planning approval for projects.

The installation of the various components of the renewable energy system (wind, CST, transmission etc) have been modelled in six monthly time intervals, to approximate a steady stream of projects. Construction timelines vary with each particular technology.

Jobs calculation methodology

The methodology for calculating the jobs requirements is based on similar work completed by Rutovitz and Atherton analysing the rollout of renewable energy on a global scale[1].

Construction jobs are calculated on the basis of the required job-years per MW of capacity, using referenced industry data. One job-year is the equivalent of one person employed for one year, and is considered the most relevant measure of the labour task required for construction projects. For example, a project that requires 50 job-years to construct, could be completed in one year with 50 workers, or two years with 25 workers.

Operations and Maintenance (O&M) jobs are calculated on the basis of jobs per MW of commissioned capacity. These job numbers progressively increase during the project period, in line with the progressive increase in commissioned capacity.

'Decline factors' are used to describe the way employment intensity (job-years per MW) reduces gradually over time, as skills and technology efficiency improve. This factor accounts for the projected reduction in employment per MW of renewable and fossil fuel technologies over time, as the technologies and companies become more efficient, and as economies of scale are realised. The decline factors are applied to all categories of jobs (manufacture, installation, and operation and maintenance).

Annual Decline Factors for Various Technologies

Technology Type	Annual Decline in Job Factors
Coal	1.00%
Gas	0.40%
Solar thermal	1.60%
Wind (on-shore)	1.40%
Biomass	1.00%
Solar PV	7.72%
Hydro	-0.60%

* These decline factors are based on Greenpeace's Energy [R]evolution scenario which has a global (if more limited) roll-out of renewable energy technologies. There are considerable uncertainties in deciding how much these factors would change under the ZCA2020 scenario, but they give a reasonable indication of the employment pattern over time.

Manufacturing Industry employment

It is assumed that as domestic demand declines towards the end of the construction period, we are able to continue manufacturing renewable equipment, and export it into the emerging international markets.

CST parameters

As of 2010, there is not yet a CST industry in Australia. It is therefore expected that it will take a number of years to grow.

SolarReserve currently expects a 2-2.5 year construction timeline for its first CST tower plants in the USA[2]. The Rice Solar Energy Project is a tower plant that will produce over 450,000 MWh/yr of electricity in California. As outlined in more detail in Appendices 3A and 3B, this is equivalent to a 75 MW plant running at 70-75% capacity factor, as with the configurations specified for ZCA2020. Official project documentation gives the labour requirements as an average of 280 construction jobs over a 2.5-year construction period, equivalent to 700 job-years – 9.33 job-years/MW, or an average of 3.73 jobs per year per MW. For later stages of the ZCA2020 Plan, employment for the shorter construction timelines has been modelled as still requiring the same total labour (job-years/MW), but with a larger number of jobs over the period, to complete the task in a shorter timeframe.

Parameter	Value	Reference
Construction time (2011 projects)	2.5 years	SolarReserve Rice[2]
Construction time (2012-2013 projects)	2 years	Mid-term estimate
Construction time (2014 onward)	1.5 years	Andasol[3]
Installation Job-years/MW	9.33	SolarReserve Rice[2]
O&M Jobs/MW	0.7	SolarReserve Rice[2]

Construction period years	Construction Jobs/yr/MW
2.5	3.73
2	4.67
1.5	6.22

CST Heliostat manufacturing

Sandia National Laboratories[4] have completed studies and costing regarding labour requirements (person-hours) for manufacturing assembly of heliostats of various sizes. This has been used as the basis for estimating direct manufacturing labour requirements for heliostat production. A 148 m^2 heliostat requires 46 person-hours of shop assembly. Based on 223 production days per year, and single 8-hour shifts per day, job requirements have been calculated at 25.8 jobs per 1000 heliostats per year. However it has also been assumed that only 50% of the manufacturing task is carried out in Australia. This could reflect an arrangement such as shipping individual mirror panels for assembly in Australia.

Wind parameters

Wind power is already a fast growing industry in Australia, with a current operational wind power of 1,700 MW[5], and another 11,000 MW of projects at various stages of planning and development[6].

With fast tracking of existing wind power projects and continued growth, it is expected that by 2014, wind power installation can reach a constant rate of construction of 6,000 MW per year.

It is also assumed that 50% of manufacturing is done onshore. As of mid-2010 there is no domestic wind manufacturing in Australia.

The following parameters were used in the modelling of ZCA2020 wind installation:

Parameter	Value	Reference
Construction time	1 year	Industry standard
Installation Job-years/MW	1.2	EWEA[7]
Manufacturing Job-years/MW	7.5	EWEA[7]
O&M Jobs/MW	0.33	EWEA[7]

Biomass parameters

Biomass plant construction requires adding biomass firing facilities to selected CST plants. The biomass construction timeline begins in January 2015 and continues through to the end of 2020. Construction activity for each plant is assumed to take 1 year.

Biomass jobs are considered in two components - those associated with co-firing the CST plants (biomass backup), and those associated with supplying the biomass fuel. Two modifiers are used:

Construction — Since the biomass here will use most of the same facilities as the CST plant, the jobs factor for biomass construction is reduced to 0.5 of the normal factor. The factor used is based on the analysis of thermal plants from Atherton et al[8].

O&M — The O&M jobs specifically for biomass backup are considered negligible compared with CST because the normal jobs factor used for biomass electricity generation is quite high, reflecting the relatively small size of plant usually involved. Since the biomass here is associated with relatively large CST plants, and the biomass will only be brought online occasionally (when the sun is not shining, the salt storage is exhausted and the wind cannot cover the demand), so that the O&M staff at the CST plants will be able to manage the O&M requirements for the biomass.

For jobs in the supply of biomass fuel, the normal jobs factor is applied.

The following parameters were used in the modelling of ZCA2020 biomass system:

Parameter	Value	Reference
Construction time	1 year	
Installation Job-years/MW	4.3 x 0.5 = 2.15	Atherton et al[8]
O&M Jobs/MW	0	Discussion in text
Jobs collecting biomass fuel Jobs/GWh	0.22	Atherton et al[8]

Results of detailed timeline modelling. 'Under construction' is the amount of capacity under construction at the beginning of each 6-month time period. 'Operational (Cumulative) is the total amount of operational capacity at the beginning of the time period.

Construction Task		Jan 2011	Jul 2011	Jan 2012	Jul 2012	Jan 2013	Jul 2013	Jan 2014	Jul 2014	Jan 2015
CST (On-grid)	Under Construction	250	1,000	2,000	3,500	5,000	5,750	6,700	8,060	9,860
(MW)	Operational (Cumulative)	0	0	0	0	0	250	2,000	3,500	5,000
CST (Off-grid)	Under Construction	0	0	0	0	0	0	0	0	0
(MW)	Operational (Cumulative)	0	0	0	0	0	0	0	0	0
Wind	Under Construction	500	1,250	2,000	3,250	4,500	5,500	6,000	6,000	6,000
(MW)	Operational (Cumulative)	2,000	2,000	2,500	3,250	4,500	6,500	9,000	12,000	15,000
Biomass	Under Construction	0	0	0	0	0	0	0	0	500
(MW)	Operational (Cumulative)	0	0	0	0	0	0	0	0	0
Transmission	Under Construction	500	1,500	3,000	4,000	4,500	4,500	4,500	4,500	4,500
(km)	Operational (Cumulative)	0	0	0	500	1,500	3,000	4,500	6,000	7,500
Jobs										
CST (On-grid)	Construction	933	3,703	8,266	15,032	21,689	25,101	33,791	43,723	56,060
Jobs	O&M	0	0	0	0	0	168	1,334	2,316	3,281
	Heliostat Manufacturing	0	0	172	1,366	2,371	3,191	4,465	5,329	6,466
CST (Off-grid)	Construction	0	0	0	0	0	0	0	0	0
Jobs	O&M	0	0	0	0	0	0	0	0	0
Wind	Construction	600	1,490	2,367	3,819	5,250	6,372	6,903	6,855	6,807
Jobs	O&M	800	794	986	1,273	1,750	2,510	3,451	4,570	5,672
	Manufacturing	0	0	7,395	11,933	16,407	19,913	21,571	21,742	21,913
Biomass	Construction	0	0	0	0	0	0	0	0	1,033
Jobs	O&M	0	0	0	0	0	0	0	0	0
	Collecting Biomass	0	0	0	0	0	0	0	0	0
Transmission	Construction	700	2,100	4,200	5,600	6,300	6,300	6,300	6,300	6,300
Jobs										
Total Jobs	Construction	2,233	7,293	14,832	24,451	33,239	37,773	46,994	56,877	70,199
Total Jobs	O&M	800	794	986	1,273	1,750	2,678	4,785	6,885	8,953
Total Jobs	Manufacturing	0	0	7,567	13,299	18,778	23,105	26,037	27,070	28,380

Jul 2015	Jan 2016	Jul 2016	Jan 2017	Jul 2017	Jan 2018	Jul 2018	Jan 2019	Jul 2019	Jan 2020	Jul 2020	Jan 2021
9,680	10,120	10,120	9,900	9,680	9,460	9,240	9,020	8,580	5,500	2,640	0
8,700	11,560	14,860	18,380	21,680	24,980	28,280	31,360	34,440	37,520	40,380	43,020
400	850	1,350	1,475	1,550	1,575	1,575	1,575	1,550	1,025	500	0
0	0	0	400	850	1,350	1,875	2,400	2,925	3,450	3,975	4,475
6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	5,000	2,000	0
18,000	21,000	24,000	27,000	30,000	33,000	36,000	39,000	42,000	45,000	48,000	50,000
1,000	1,500	2,000	3,000	4,000	4,000	4,000	4,000	3,000	2,000	1,000	0
0	500	1,000	2,000	3,000	5,000	7,000	9,000	11,000	13,000	14,000	15,000
4,500	4,500	4,500	4,500	4,500	4,250	3,750	3,250	2,750	1,750	750	0
9,000	10,500	12,000	13,500	15,000	16,500	18,000	19,500	20,750	21,750	22,750	23,500
56,014	58,090	57,623	55,918	54,236	52,578	50,943	49,330	46,547	29,598	14,093	0
5,664	7,465	9,519	11,679	13,665	15,619	17,540	19,295	21,019	22,715	24,250	25,628
6,558	7,079	7,342	7,223	7,237	7,250	7,264	7,278	7,292	7,305	7,319	7,333
2,315	4,879	7,687	8,331	8,685	8,754	8,683	8,614	8,409	5,516	2,669	0
0	0	0	254	536	844	1,163	1,477	1,785	2,089	2,387	2,666
6,759	6,712	6,665	6,618	6,572	6,526	6,480	6,435	6,390	5,287	2,100	0
6,759	7,830	8,886	9,927	10,953	11,964	12,960	13,942	14,909	15,862	16,801	17,379
22,086	22,261	22,436	22,614	22,792	22,972	23,153	23,336	23,520	23,706	23,893	24,082
2,055	3,067	4,069	6,073	8,057	8,017	7,977	7,937	5,923	3,929	1,955	0
0	0	0	0	0	0	0	0	0	0	0	0
0	38	76	152	227	376	524	670	815	958	1,027	1,095
6,300	6,300	6,300	6,300	6,300	5,950	5,250	4,550	3,850	2,450	1,050	0
73,443	79,048	82,344	83,241	83,850	81,824	79,333	76,866	71,118	46,780	21,867	0
12,423	15,295	18,405	21,860	25,154	28,427	31,663	34,713	37,713	40,666	43,439	45,673
28,644	29,340	29,779	29,837	30,029	30,222	30,418	30,614	30,812	31,011	31,212	31,415

Transmission parameters

New transmission line capacity is required early in the project, to connect new generating plant into the grid. The transmission installation timeline begins in 2011, and continues steadily throughout the project. The parameters for construction rate and employment are derived from National Environmental Policy Act (NEPA) documents on 500kV transmission lines projects in the USA. Construction jobs are based on an employment level of 2.1 job-yrs/km at an installation rate of 1.5 years/km of line. This is equivalent to 1.4 jobs/yr/km.

The following parameters were used for installation of new transmission lines:

Parameter	Value	Reference
Construction time	1.5 years	NEPA[9,10]
Installation Job-years/km	2.1	See text and NEPA[9,10]
Jobs/yr/MW	1.4	

Direct Displacement of Fossil Fuel Employment

The assessment of fossil fuel jobs displaced by the ZCA2020 Stationary Energy System is based on the following:

- Jobs created by coal and gas exports are not counted in this study.
  The most recent employment data that details coal mining and gas extraction jobs as opposed to overall mining industry employment is 2007. This has been scaled up at a factor of 2% growth per year to 2010. This is considered reasonable for domestic fossil fuel production, which has not seen the fast rate of growth that the export fossil fuel industry has in the years to 2010.
- The proportion of coal mined in Australia that is used in domestic electricity production is 28%[12]. As at June 2007, a total of 26,491 Australians were employed in coal mining[11], leading to an estimated 28,100 for 2010 and so approximately 7,900 of these are counted as directly employed in the generation of electricity from coal.
- The proportion of gas and LPG extracted (or refined) in Australia that is used in domestic electricity production and end-use heat is 55%[12]. As at June 2007, a total of 10,240 Australians were employed in Oil and Gas Extraction[11], with an estimated 11,100 in 2010, and so approximately 6,100 of these are counted as directly employed in the generation of electricity and end-use heat.
- There were 5,914 existing (2006) direct jobs in electricity production from fossil fuels (excluding extraction of fuels as above)[13]. Scaled up to 2010, this is approximately 6,300 electricity generation jobs.

Replacement of coal and gas as fuel sources in the domestic market, and conversion of existing fossil fuel electricity generation to renewable energy would therefore directly affect approximately 20,300 jobs.

This displacement of 20,300 jobs over 10 years can be compared with the monthly average fluctuations in national employment of 19,480 for January 2010[14], or the 77,000 ongoing jobs created in O&M and manufacturing by the ZCA2020 Plan.

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Appendix 8
Resource Requirements

Resource requirements calculated for major components of CST, Wind and transmission systems.

CST

There are six main types of resources required for a CST Tower system as proposed in the ZCA2020 project. The resources are steel, concrete, glass, silver, aluminium and nitrate salt (or fertiliser).

Steel, Glass and Concrete

TABLE A8.1
Summary of ATS-148 resource requirements, calculated using data from Sandia Labs' heliostat study[1]. Steel and glass from Table 3-4, pg 44; Concrete from Table 3-10, pg 49, and concrete data[6].

ATS-148 Heliostat Requirements				
Material Breakdown	**lb**	**kg**		
Structural Steel	8709	3950		
Gear Drives (steel and cast iron)	1500	675		
Steel Fasteners and Misc.	104	47		
Motors & Controls (Steel, Copper, etc.)	120	54		
Glass Mirrors	3300	1485		
Adhesives	160	72		
	13893	6283		
			148	m^2 heliostat
Total Steel		4726	31.9	kg/m^2
Total Glass		1485	10.0	kg/m^2
Total Adhesive		72		

ATS Concrete Requirements			
Concrete Foundation	2.5	yards (cubic) per heliostat	
	0.914	yards/metre	
m3 per heliostat	1.91	m^3 per heliostat	
kg/m3 concrete	2400		
kg per heliostat	4587		
		31.0	kg/m^2

For the CST component of the ZCA2020 project the requirements of steel, glass and concrete is as follows.

This calculation is based on data from eSolar and the ATS-148 heliostat.

TABLE A8.2
Summary of eSolar resource requirements, calculated from information from eSolar product information[2] and communication from eSolar CEO Bill Gross[4]. Additional concrete information from [5].

	eSolar Steel
46	MWe on-sun power tower module [1]
16	towers and receivers [1]
192000	heliostats [1]
1.14	m^2/mirror [3]
218880	m^2 mirrors
4758	m^2 mirror/MWe
4.76	m^2/kWe
75	kg steel/kWe [3]
15.8	kg/m^2 mirror field
	eSolar concrete
60	lbs/mirror [3]
27.2	kg/mirror
23.9	kg concrete/m^2 mirror
	eSolar glass
3	mm thick glass [3]
0.0030	m^3 glass/m^2 mirror
2600	kg/m^3 glass density [4]
7.8	kg glass/m^2 mirror

Mirrors and Heliostats

Mirrors are constructed of a substrate, a reflective material and a protective coating for the reflective material. Typically mirrors has glass as the substrate and silver as the reflective material, with copper and paint applied as protection. In the ZCA2020 project, standard mirrors are used for the CST systems. There are other alternatives such as polymer based mirrors or polished steel or aluminum mirrors. But standard mirrors are ideal due to their availability, cost effectiveness and efficiency.

The total mirror required for heliostats in the ZCA2020 project. This is based on Solar 220 requirements of 2,650,000 m^2 of mirrors per 217 MWe (spread out over 13.9 km^2 of land) [7].

Summary of silver requirements for ZCA2020 and Australian silver production.[9]

TABLE A8.3
Total Mirror Field Requirements

Value	Units
217	MWe – Solar 220
2.65	km2 – mirror aperture area for Solar 2207
0.012	km2 mirror/MWe
47000	MWe Total CST capacity for Australia
572	km2 mirror surface

TABLE A8.4
Mirror Silver Requirements (both mirror types)

Silver film backing on high peformance glass	
75	mg per ft^2, source [8]
0.09	m^2 per ft^2
833	mg per m^2
0.83	g per m^2
572	km^2 mirror surface for ZCA2020
572,098,864	m^2 mirror surface
ZCA2020 Requirements	
476,749	kg of silver needed
0.48	thousand tonnes of silver total
Australian silver production	
61.9	millions of ounces per year (2008)[9]
28.35	grams per ounce
2	thousand tonnes/yr of silver
Australian 10 year silver production	
18	thousand tonnes of silver

TABLE A8.5
Nitrate Salt Requirements for thermocline vs two-tank

Component	Two-Tank Molten Salt	Thermocline with Quartzite
Nitrate Solar Salt $	11,800,000	3,800,000
Filler Material	0	2,200,000
Tanks(s)	3,800,000	2,400,000
Salt-to-Oil Heat Exchanger	5,500,000	5,500,000
Total	21,100,000	13,900,000
Specific Cost,$/kWh	31	20
MWh storage	688	
per tonne salt	$450.00	
per tonne quartzite filler	$72.00	
	Two tank	Thermocline
	$11,800,000	$3,800,000
tonnes salt	26222	8444
tonnes/MWh	38	12
	difference:	32%
Filler		$2,200,000
tonnes filler		30556
Power Tower system		
(uses less salt than trough due to higher operating temperature)		
tonnes salt per MWh	14.3	
tonnes if thermocline used	4.61	
MWe installed	46,878	
hours storage each	17	
MWh storage	796,919	
	Two-tank	Thermocline
tonnes salt	11,395,936	3,669,878
MT salt	11.40	3.67

CST Energy Storage

The ZCA2020 proposes a molten salt storage systems to be integrated to provide energy storage for the CST system. Molten salt utilises common nitrate salts, such as fertiliser, to store energy as heat in a insulated environment. Table A8.5 and Table A8.6 compare salt requirements for various systems, based on data from Sandia studies[10,11].

TABLE A8.6
Comparison of amount of salt required for higher temperature (650˚C) storage and lower temperature storage.[11]

Molten salt storage		Binary salt	Binary salt	Binary salt with oxygen blanket	Ternary salt with oxygen blanket	Quaternary salt with oxygen blanket
	MWh	1	1	1	1	1
Specific heat capacity (c) of molten salt	kJ/kg.K	1.52	1.52	1.52	1.35	1.35
Hot tank temperature	ºC	500	565	650	650	650
Cold tank temperature	ºC	290	290	290	190	170
Rankine (steam) cycle efficiency - supercritical double reheat	%	46	46	46	46	46
Electrical energy required	kJ	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000
Thermal energy storage requirement	kJ	7,826,087	7,826,087	7,826,087	7,826,087	7,826,087
Q= mc(T2-T1)						
m = Q/(c(T2-T1)) mass of salt	kg	24,518	18,723	14,302	12,602	12,077
	m^3	14	10	8	7	7
Mass of salt with 2/3 quartzite filler	kg	8,173	6,241	4,767	4,201	4,026
Density	kg/m^3	1800	1800	1800	1800	1800

TABLE A8.7
Resources Required for ZCA2020 Electrical Transmission

HVDC Equivalent to single circuit HVAC (single tower)	Resources Required
Length of 500kV HVDC line	13,673 km
Steel	379,210 tonnes
Aluminium	73,823 tonnes
Concrete	1,063,604 tonnes
HVAC **Equivalent of two single circuit HVAC (double circuit, single tower)**	**Resources Required**
Length of 500kV HVAC line	9,631 km
Steel	290,631 tonnes
Aluminium	103,999 tonnes
Concrete	749,181 tonnes

Total Resources Required	
Steel	669,841 tonnes
Aluminium	177,822 tonnes
Concrete	1,812,785 tonnes

Transmission

The ZCA2020 project will require a total of 23,304 km of transmission lines, 13,673 km of HVDC and 9,613 km of HVAC of transmission lines. A total of 39067 transmission towers are required at 350 m intervals. The HVDC transmission lines are estimated to be equivalant to a single circuit HVAC requirements. The HVAC transmission lines are estimated to be equivalant to two single circuit HVAC requirements.

The estimation of transmission system resources is based on the summaries for outlined in the tables in this section. This includes both resources requirements per transmission tower and resources requirement per unit length of transmission lines. The 500 kV transmission lines requirements are based two Orange/Zebra 1 conducter per unit length, and 2 OPGW Earth wire per unit length. Data from [12,13,14].

TABLE A8.8
Conductor Resource Requirements

Conductor	Material	Ton/km
Orange / Zebra x1	Steel	0.44
	Aluminium	1.19
Earth Wire (OPGW)	Steel	0.35
	Aluminium	0.33

TABLE A8.9
Tower and Conductor Totals

Individual Tower Weights (kg)				
Voltage (kV)	Steel	Aluminium	Concrete	Circuits
500	8,851.86	0	27,225.13	1
Conductor (kg/km)				
Voltage (kV)	Steel	Aluminium	Rating Amps	MVA
500	2,442.4	5,399.2	3,484	3,017.23

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Appendix 9 Economic Comparison Assumptions and References

This appendix provides the basis for "Business-As-Usual" (BAU) Stationary and Transport energy supply and demand, the resulting greenhouse gas emissions, and the discounted present-value costs, for the period 2010 to 2040. In addition, it provide back-up information regarding comparisons of the Plan to other economic activity.

ZCA2020 Plan vs Business As Usual

The assumptions on which the BAU scenario was modelled include the following:

The BAU scenario models how much conventional fossil fuel generation will be required to meet a projected electricity demand of 325TWh/yr by 2020. Capital expenditure is made until 2020 to meet growing demand, and in the same fashion as the ZCA2020 case, any new capacity required beyond 2020 is not in the scope of this analysis. This 325 TWh/yr would be enough to meet BAU demand growth if no efficiency measures are implemented, or the full heating & transport load if efficiency and fuel swtiching occurs. Capital and operating costs are based on data from ACIL Tasman[2] and other industry sources.

Capital expenditure

New black coal power stations are built to replace old coal generation as it is retired, the equivalent of 1/30th of total MW capacity per year amortised over the time period. This is priced at $1,900/kW.

New capacity which is added to meet growing peak and average demand is a mixture of open-cycle (OCGT) and combined-cycle gas turbines (CCGT), at $850/kW. Based on industry sources, BAU peak electricity demand is assumed to continue to grow faster than GDP at 3.15%/yr[3].

New transmission expenditure is $2 billion/yr[4].

Operating expenditures

Electricity generation grows to supply 325TWh/yr in 2020. Mix continues to be 25% brown coal, 55% black coal and 20% gas[5].

Brown coal fuel cost is $5/MWh (electrical), based on current industry prices, and is assumed to remain constant.

Black coal is $85/tonne in 2011, $100/tonne in 2012 and rises in line with GDP growth (2.1%/yr) thereafter, reflecting parity with international markets. Average black coal fleet efficiency is 35% sent-out, reflecting a mix of older, low-efficiency plants and newer, higher-efficiency plants.

Natural gas is priced based on ACIL Tasman forecasts. $3.9/GJ in 2010, to $4.5/GJ in 2020, $5.2 in 2030 and $6.1 in 2040. Thermal efficiency is 40%, reflecting the mix of OCGT and CCGT.

For fossil fuels, variable O&M Costs are $1.50/MWh. Fixed O&M costs are $40,000/MW/yr (coal) and $10,500/MW/yr (gas). Solar fixed O&M is $60,000/MW/yr[21], wind is $40,000/MW/yr[22].

Non-electrical fuels

BAU oil and gas demand for transport and heating, respectively, are also modelled. This is the 'bill' that would occur if no efforts are made (under either BAU or ZCA2020) to fuel-switch to supply these service with electricity, and the extra electricity supply is used to meet a growing demand for current services with no efficiency measures. It is recognised that extra capital investment would be needed to supply the electrified transport and heating infrastructure to make this change. However, the fossil fuel 'bill' that will otherwise be incurred can be considered a fund from which the fuel switch and efficiency expenditure can be sourced, to avoid future fossil fuel costs.

It is assumed that without efficiency or fuel switching, demand for oil and gas continue to rise from current rates of consumption in line with GDP growth of 2.1%/yr[1].

Gas price is the same as above.

Crude Oil Price: The present crude oil price is used as a 2010 starting point (US$80/bbl). Given that the world is now broadly at the peak of oil production, an escalation rate of 5% on top of normal CPI is assumed, but capped at $US 130 / barrel (2010 real dollar terms). This cap represents a view that under Business As Usual, alternative (and environmentally damaging) oil sources such as tar sands and shale oil will set a limit to which the price of oil can rise in real dollar terms. This price projection is informed by CSIRO research[8].

Other modelling assumptions

Foreign Exchange Rate: An exchange rate of 0.85 $US/$A is assumed as representing a long term historical average.

Carbon Price: Another possible scenario is that a carbon price is established in Australia. A 2011 starting price of $A10/tonne is assumed, rising within two years to $A20/tonne, and then escalating at 5% per year on top of normal CPI. This reflects the view that there is already too much carbon in the atmosphere and that the world will move to stabilise and then reduce carbon in the atmosphere over the period 2010—2040. The BAU case therefore represents the situation where Australia is exposed to an initially moderate carbon cost but nevertheless chooses not to take action to reduce carbon emissions.

Discount Rate: A discount rate of 1.4% is assumed. This is the same as used by the Stern Review[6,7]. It is made up of two components: a pure time preference rate of 0.1% and an allowance for the marginal utility of consumption of 1.3%.

The pure time preference rate is an allowance only for extinction and reflects the utilitarian view that a unit of consumption to someone now should be valued equally to a unit of consumption by someone else in the future.

1.3% is the assumed rate of real income growth. Discounting with this implements an assumption that the marginal utility of consumption is constant as a proportion of total consumption. That is, a marginal dollar of consumption when total consumption is $100 has the same utility as two marginal dollars of consumption when total consumption is $200.

They key results of the model are shown in Table A9.1.

For comparison, the model has also been run at discount rates of 6% (Table A9.2) and 8% (Table A9.3).

TABLE A9.1
Summary of Economic Model results

	BAU	ZCA2020	BAU-ZCA
Capital Investments	$135	$337	-$203
BAU electricity ramp down - operating & fuel costs (2011 - 2020, ZCA case only)		$77	
Coal and Gas for electricity	$300		
Operations and Maintenance Costs	$55	$90	
Emissions (Stationary Energy)	$424	$42	
Oil – BAU or ZCA2020 ramp-down	$1,297	$236	
Heating Gas – BAU or ZCA2020 ramp-down	$143	$24	
Summary Results			
Sum	$2,354	$806	$1,548
Sum Excl Oil & Gas	$914	$546	$368
Sum Excl Emissions	$1,930	$765	$1,165
Sum Excl Oil, Gas & Emissions	$490	$504	-$15

TABLE A9.2
Summary of results using 6% discount rate

	BAU	ZCA	Diff
Sum	$1,153	$598	$554
Sum Excl Oil & Gas	$436	$388	$49
Sum Excl Emissions	$974	$565	$409
Sum Excl Oil, Gas & Emissions	$257	$354	-$97

TABLE A9.3
Summary of results using 8% discount rate

	BAU	ZCA	Diff
Sum	$881	$530	$351
Sum Excl Fuel	$331	$337	-$7
Sum Excl Emissions	$752	$500	$253
Sum Excl Fuel and Emissions	$202	$307	-$105

Parameters for electricity price modelling

TABLE A9.4
Parameters used for AER Electricity Model[9]

Modelling Parameters	
Nominal Risk Free Rate	5.65%
Expected Inflation rate	2.57%
Debt Risk Premium	3.25%
Market Risk Premium	6.5%
Utilisation of Imputation (Franking) Credits	60%
Gearing (Debt/Equity)	60%
Equity Beta	0.8
Debt raising cost benchmark	0.08%
Nominal Vanilla WACC	9.68%
Economic lifetime	30 years

Comparable Expenditures Elsewhere in the Economy

Comparison Figures Item	$A Billion	Reference
Nation Building Program	6.0	10
Alcohol 2003—04	9.3	11
Gross Value Added (GVA) 2009—Arts & Recreation	10.1	12
Gambling 2005-06	17.0	13
Domestic Appliances 2009	18.4	14
Federal Defence 2008—09	19.2	15
Federal Education 2008—09	22.6	15
Banking & Mining Industry Tax 2009	29.0	16
GVA 2009—IT & Telecoms	34.2	12
GVA 2009—Rental/ Hiring/ Real Estate	36.0	12
Gas, Coal & Uranium investments per year until 2016	36.5	17
ZCA Plan	37.0	
Insurance 2009	37.8	18
Recreation 2003-2004	45.0	11
GVA 2009—Education	48.7	12
Federal Health 2008—09	49.1	15
Car Retailing 2009	54.7	19
GVA 2009—Transport, Postal & Warehousing	59.5	12
GVA 2009—Healthcare & Social Assistance	66.6	12
GVA 2009—Mining	80.8	12
GVA 2009—Construction	81.6	12
GVA 2009—Manufacturing	103.1	12
GVA 2009—Finance & Insurance	118.0	12
Federal Social Security & Welfare 2008—09	124.6	15
Federal Expenditure 2009	324.6	15
Australia Gross Domestic Product (GDP)	1,197.0	20

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