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The Power Makers’ Challenge

And the Need for Fission Energy
The modern world is caught in an energy resource and climate change pincer. As the growing mega-economies of China and India strive to build the prosperity and quality of life enjoyed by citizens of the developed world, the global demand for cheap, convenient energy grows rapidly. If this demand is met by fossil fuels, we are headed for an energy supply and climate disaster.

The development of an eighteenth century technology that could turn the energy of coal into mechanical work—James Watt’s steam engine—heralded the dawn of the Industrial Age. Our use of fossil fuels—coal, oil, and natural gas—has subsequently allowed our modern civilization to flourish. It is now increasingly apparent, however, that our almost total reliance on these forms of ancient stored sunlight to meet our energy needs has some severe drawbacks, and cannot continue much longer.

For one thing, fossil fuels are a limited resource. Most of the readily available oil, used for transportation, is concentrated in a few, geographically favored hotspots, such as the Middle East. Most credible analysts agree that we are close to, or have passed, the point of maximum oil extraction (often termed “peak oil”), thanks to a century of rising demand. We have tapped less of the available natural gas (methane), used mostly for heating and electricity production, but globally, it too has no more than a few more decades of significant production left before supplies really start to tighten and prices skyrocket, especially if we “dash for gas” as the oil wells run dry. Coal is more abundant than oil or gas, but even this has only a few centuries of economically extractable supplies.

Then there is climate change and air pollution. The mainstream scientific consensus is that emissions caused by the burning of fossil fuels, primarily carbon dioxide (CO₂), are the primary cause of recent global warming. We also know that coal soot causes chronic respiratory problems, sulfur causes acid rain, and heavy metals (like mercury) induce birth defects and damage ecological food chains. These environmental health issues compound the problem of dwindling fossil fuel reserves.

Clearly, we must unhitch ourselves from the fossil fuel-based energy bandwagon—and fast.
In the developed world (US, Europe, Japan, Australia, and so on), we have enjoyed a high standard of living, linked to a readily available supply of cheap energy, based mostly on fossil fuels. Indeed, it can be argued that this has encouraged energy profligacy, and we really could be more efficient in the mileage we get out of our transport fleet, the power usage of our fridges, lights and electrical appliances, and in the design of our buildings to reduce demands for heating and cooling. There is clearly room for improvement, and sensible energy efficiency measures should be actively pursued.

In the bigger, global picture, however, there is no realistic prospect that we can use less energy in the future. More than a third of all humanity, some 2.5 billion people, have no access to electricity whatsoever. For those who do, their long-term aspirations for energy growth, to achieve something equating that used today by the developed world, is a powerful motivation for development. As oil supplies dwindle, it must be substituted (or the technology changed) if we are to keep our vehicles going. Oil is both a convenient energy carrier, and an energy source (we “mine” it). In the future, we will have to create our new energy carriers, be they chemical batteries or oil-substitutes like methanol or hydrogen. On a grand scale, that is going to take a lot of extra electrical energy!

Then there is the growing human population (which we hope will stabilize by mid-century at less than 10 billion) and the burgeoning impacts of climate change and other forms of environmental damage, there will be escalating future demands for clean water (at least in part supplied artificially, through desalination and wastewater treatment), more intensive agriculture which is not based on ongoing displacement of natural landscapes like rainforests, and perhaps, direct geo-engineering to cool the planet, which might be needed if global warming proceeds at the upper end of current forecasts.

In short, the energy problem is going to get larger, not smaller, at least for the foreseeable future.

Let us say we aim to have largely replaced fossil fuels with low-carbon substitutes by around the middle of this century. How can we meet this enormous challenge? Nuclear power based on atomic fission is one possibility. Renewable energy sources which harness solar energy and its derivatives are another. Improved efficiency in the way we use energy may also offer a partial fix, at least in the short term. In the broader context, however, to imagine that the global human enterprise will somehow manage to get by with less and accept an unreliable supply, just does not stack up with the reality of a fast-developing, energy-starved world. Put simply, citizens in Western democracies are simply not going to vote for governments dedicated to lower growth and some concomitant critique of consumerism, and nor is an authoritarian regime such as in China going to risk social unrest, probably of a profound order, by any embrace of a low growth economic strategy. As such, reality is demanding, and we must carefully scrutinize the case for all of the alternative energy technologies available to us.

Martin Nicholson, in *The Power Makers*, does this admirably—in a lucid and engaging way.
Technically, economically, socially, and politically—we face many challenges in trying to harness non-fossil fuel energy on a large scale. This is a complex topic—indeed; it requires a book like this to explain properly! How do we match supply to demand? What are the implications of harnessing diffuse energy sources? How do we manage energy flows that are variable and intermittent—sometimes delivering a lot of power, sometimes a little, and at other times none at all? What are the methods we can use to store large amounts of energy, to cover the non-generating periods? Is nuclear fission a clean and sustainable energy source? What are the costs and timescales required for a major energy transition?

Read on, and you will find the answers to these questions, and much more besides. It is a wonderful book.

Adelaide, 2 Dec 2010

Prof. Barry W. Brook
School of Earth and Environmental Sciences and Centre for Energy Technology The Environment Institute, The University of Adelaide
Preface

Modern society needs reliable electricity at an affordable cost.

I am in my sixties now and I have enjoyed reliable electricity for most of my life. Sure, there was the occasional brown-out or black-out, particularly in my youth. They were kind of fun. We could light candles or sit by the light of the open fire when the power went off. They were no fun for commerce and industry that had to close their doors. No fun for their workers who could not work and were sent home.

If you live in a western city today, you hardly ever see an interruption to your power supply. I would like to see it stay that way.

As a child, I never wondered where the power came from that worked the lights, the refrigerator, and the radio. When you flicked the switch it was just always there.

I am sure there are many people today who still do not know where their electricity comes from. They have not needed to know. It is just there!

Well, I hate to worry you, but that may be about to change.

All my life, nearly all my electricity has come from burning coal. That would be true for many of us all over the world. It is the cheapest source of electricity. Problem is, burning this coal produces air pollution and greenhouse gases (GHG) like carbon dioxide which is causing changes to the climate. Stop burning this coal and you stop producing the carbon dioxide but the lights go out unless you make the electricity some other way.

How easy is it to change the way we make electricity? Will we still have power to our homes and workplaces whenever we want it? Will we still be able to afford to pay the electricity bill? Well maybe, but maybe not—depending on how we finish up making the electricity. These are the questions we will explore in this book.

Low-carbon and affordable electricity are going to be key planks of any politician’s agenda over the next few years. Renewable energy sources are widely seen as a key part of replacing dirty coal. We already have a pledge from the US President for 10% of their electricity to come from renewable sources by 2012, and
25% by 2025. The European Union (EU) has a target of 20% by 2020 as do China and my home country, Australia.

Decarbonizing electricity is going to happen, eventually, but which solutions make sense today and which do not?

One of the most significant barriers to replacing coal with most renewable energy sources is that renewable energy is relatively dilute and variable in supply. It took immense pressure over millions of years to create those energy-rich fossil fuels like coal from plant matter. Extracting the equivalent energy from “new” energy sources is proving to be difficult and expensive.

Renewable energy is becoming a bit like a religion with its own high priests who usually head up renewable energy companies or conservation organizations. Renewable energy is seen by some as the solution to replacing dirty coal and delivering low-carbon electricity. The savior from the ravages of climate change. Along with religion often comes zealotry claims supported by misinformation.

Many still see the problem as more political than technical. “We just need to fix government policy decisions”, they say, blaming the coal, oil, and nuclear power lobby groups while ignoring the significant limitations of current generation renewable energy solutions. Not the least of which is cost.

Both sides of the debate (traditional sources vs. renewables) are at fault—each by over-stating their own case. The aim of this book is to inject some realism into the debate about making our electricity low-carbon while keeping the lights on and the electricity bills manageable.

Looking to a future where computers and other electric appliances dominate nearly every aspect of economic life, electricity is likely to be even more essential. Even with transport, where oil has enjoyed a near monopoly for over a century, electricity is making tentative inroads with electric cars and improved batteries. The future is electric.

We cannot indefinitely keep using up the Earth's stored energy resources like coal and oil faster than the Earth can replace them. Eventually they will run out and there will be no more concentrated stored energy left. Sustainable energy is a must. The real question is: how quickly can we transition from the stored energy sources of coal, oil, and gas to truly sustainable energy resources? And what resources are sustainable anyway?

Fission is the richest source of energy readily available on the Earth today. Natural radioactive decay takes place deep in the earth producing hot aquifers that we use to produce electricity and heat buildings in some places. But this natural radioactive decay only supplies a small fraction of the energy we need.

For over 50 years, man-made fission energy has made a significant contribution to meeting our electricity needs. It has turned out to be the safest and cleanest way to produce vast quantities of cheap electricity. Much safer than coal, gas, oil, or renewable hydro and even safer than many of the other renewable sources. Much cleaner than coal, gas, and oil, producing no carbon dioxide in operation. Fission can also be made to be sustainable, unlike fossil fuel stored energy sources. So why do we not just use more man-made fission energy? Unfortunately, there are influential lobby groups who do not see it this way.
Let us come clean right up front. Fission energy is just another name for nuclear energy. So why rename it? For many, nuclear power has bad vibes. Some will go to any lengths to stop its use. Nuclear power reminds them of nuclear bombs and nuclear wars. Nuclear bombs mean millions of innocent people dying from radiation sickness. Some think that because nuclear energy involves radiation so nuclear energy must be dangerous too. This is not so. The time has come to decouple this (often unconscious) association; hence the name change. Call it marketing spin if you like.

Man-made fission energy is the best option to address climate change. Not only is it the best option—it is the only option if we are to avoid expensive changes that disrupt our electricity supply. Fission is clean, green, and affordable.

All bold statements you might think, so they need to be defended. For those that doubt this can all be true, it is fine to be sceptical. Why not check these statements again after you have finished reading this book? If I have done my job properly, you should be nodding your head next time around.

I have titled this book *The Power Makers’ Challenge* so I had better tell you who the Power Makers are. These are the people we trust to build, run, and control our electricity system and ensure the electricity gets safely and reliably to our homes and workplaces—the generator operators, the system operators and the network operators. For many years in most countries the Power Makers all worked for governments. Now many work for private businesses but the governments maintain a regulatory role—as they should; electricity is an essential service that we mess with at our peril.

The challenge facing our Power Makers is reliable, clean electricity. With over 65% of our electricity currently coming from fossil fuels (coal, gas, and oil) that produce 44% of the world’s greenhouse gas emissions, this is no small challenge.

The Power Makers have no choice but to either clean up the fossil fuel power plants or replace them. As we will see in the book, they will probably do a bit of both. Neither is straightforward. Both are likely to be more expensive. And some of the replacement solutions are much better than others.

The Power Makers face this challenge at a time of ever increasing demand for electricity. The continuously rising world population; the moves by third and second world countries to become first world countries; the unsustainable reliance on oil for transport all guarantee a greater need for electricity everywhere for the foreseeable future.

This means alternative fuels need to reliably replace the fossil fuels and be sufficiently scalable to meet this future demand.

As we work through this challenge, we will see that many of the popular alternatives proposed are either not up to the task or will be so expensive when deployed on the scale needed that they will prove to be unattractive replacements. Hopefully, we can dismiss some of the popular myths about alternative energy sources for generating electricity as well as some of the popular myths about fission energy.
I have structured the book into five parts:

Part I Expects what electricity is and how we make it.

Part II Looks at the pluses and minuses of renewable energy technologies.

Part III Does the same for clean coal technologies.

Part IV Covers fission energy, how it works and answers the tricky questions.

Part V Looks at the likely future of electricity production.

There are a number of technical appendices and literature references for further reading for those who want a more in-depth understanding of the technologies. It is not necessary to read these to understand the book but they provide some useful reference material for those that have an interest. They might also answer many of those nagging questions you may have about the material.

Martin Nicholson
Acknowledgments

After writing my last book, *Energy in a Changing Climate*, it became clear to me that the energy carrier we call “electricity” was critical to establishing and maintaining our standard of living. Electrification of our homes and workplaces has seen changes to our world that would have been inconceivable in the nineteenth century, but generating electricity has also been a major contributor to man-made greenhouse gas emissions.

Two special fellow Australians have offered invaluable support to me while writing this book about the challenges faced by our electricity providers. Dr. Tom Biegler, who has many years’ experience with energy systems and Professor Barry Brook who is Director of Climate Science at The Environment Institute, University of Adelaide have both extensively edited the book. Barry also has a strong interest in energy systems, particularly as they relate to the environment. I thank them both for their invaluable contribution to this book.

I also thank Dr. Gene Preston who works in the power industry in Texas for his first-hand experience with electricity generation and distribution in the US. Gene has provided many valuable suggestions for this book.
## Contents

### Part I About Electricity

1 **What is Electricity?** .................................. 3  
   1.1 Electricity: Simply Expressed .......................... 3  
   1.2 How Do We Measure Electricity? ..................... 4  
   1.3 The Big Differences Between Electricity and Water .... 5  
   1.4 The Power Makers’ Challenge ........................ 6  

2 **Faraday’s Miracle** ................................... 9  
   2.1 Faraday’s Contribution .................................. 9  
   2.2 Generators Explained .................................. 10  
   2.3 What Drives the Generator? ............................ 10  
   2.4 What Powers the Engines? ............................. 11  
   2.5 Power Generator Types ................................ 12  
   2.6 Comparing Generators ................................. 12  
   2.7 Capacity Factor ....................................... 13  

3 **Poles and Wires** ..................................... 15  
   3.1 Electricity Networks .................................... 15  
   3.2 Transmission Losses .................................... 16  
   3.3 Controlling the Network ............................... 17  
   3.4 Advantages of Transmission Networks ................. 18  

4 **The Balancing Act** ................................... 19  
   4.1 Demand and Supply .................................... 19  
   4.2 Network Reliability .................................... 21  
   4.3 Reserve Capacity ....................................... 21  

5 **Dollars and Cents** ................................. 23  
   5.1 Calculating Generating Costs .......................... 23  
   5.2 Typical Generating Costs .............................. 24
5.3 Baseload, Intermediate, and Peak Load \hspace{5mm} 24
5.4 Getting the Mix Right \hspace{5mm} 25
5.5 Transmission Costs \hspace{5mm} 26
5.6 Energy Efficiency \hspace{5mm} 26
5.7 Energy Conservation \hspace{5mm} 27
5.8 Energy Reduction Targets \hspace{5mm} 28
References \hspace{5mm} 28

6 The Carbon Challenge \hspace{5mm} 29
6.1 Climate Change Summary \hspace{5mm} 29
6.2 Reducing Emissions \hspace{5mm} 30
6.3 A Price on Carbon \hspace{5mm} 30
6.4 Emission Intensity \hspace{5mm} 30
6.5 The Power Makers’ Response \hspace{5mm} 31
References \hspace{5mm} 32

Part II Renewable Energy

7 Many Options \hspace{5mm} 35
7.1 Wind \hspace{5mm} 35
7.2 Solar \hspace{5mm} 36
7.3 Hydro \hspace{5mm} 36
7.4 Biomass \hspace{5mm} 37
7.5 Geothermal \hspace{5mm} 38
7.6 Tidal \hspace{5mm} 39
7.7 Waves \hspace{5mm} 39
7.8 Dilute Resources \hspace{5mm} 39
7.9 Variability \hspace{5mm} 40

8 Nature’s Curse \hspace{5mm} 41
8.1 Natural Variability of RE Resources \hspace{5mm} 41
8.2 Why RE Variability is a Problem \hspace{5mm} 42
8.3 Negative Load \hspace{5mm} 42
8.4 Forecasting \hspace{5mm} 43
8.5 Measuring Variability \hspace{5mm} 43
8.6 Variability Across Generators \hspace{5mm} 45
8.7 Managing Variability \hspace{5mm} 45
References \hspace{5mm} 45

9 Nature’s Saviors \hspace{5mm} 47
9.1 Reliable and Proven \hspace{5mm} 47
9.2 More Hydropower \hspace{5mm} 47
9.3 More Conventional Geothermal \hspace{5mm} 48
13.3 Can Gas Deliver Us From Coal? ......................... 78
13.4 But Isn’t Nuclear Dangerous? ......................... 79
Reference .................................................. 79

Part IV Fission Energy

14 Fission, Not Combustion ................................. 83
14.1 How Do Coal and Fission Energy Produce Electricity? ... 83
14.2 Fission Reactors ..................................... 83
14.3 Fuel and Waste ..................................... 84
14.4 Carbon Dioxide Emissions ......................... 85
14.5 Cost .................................................. 85
14.6 What’s the Drama? .................................. 85
Reference .................................................. 85

15 Safety First ........................................... 87
15.1 Reactor Safety ..................................... 87
15.2 Nuclear Waste ..................................... 90
15.3 Proliferation of Nuclear Weapons .................. 91
15.4 Safety Summary ................................... 91
References .................................................. 91

16 More Smoke and Mirrors ............................... 93
16.1 Myth 1: Renewables Make Nuclear Unnecessary ... 93
16.2 Myth 2: Nuclear Energy is Too Expensive .......... 94
16.3 Myth 3: Nuclear Plants Could Not be Built in Time ... 94
16.4 Myth 4: Uranium Supplies are Not Sustainable ... 95
16.5 Myth 5: All Radiation is Dangerous ................ 95
16.6 Myth 6: Nuclear GHG Emissions are Huge .......... 96
16.7 Myth 7: Gas is Less Risky for Investors .......... 96
References .................................................. 96

17 Is Fission Really Necessary? .......................... 97
17.1 Challenging Times .................................. 97
17.2 Renewable Energy ................................ 98
17.3 Clean Coal ......................................... 98
17.4 Fission Energy .................................... 98

18 The Next Generation of Fission ....................... 101
18.1 Fuel Recycling .................................... 101
18.2 Generation III Reactors ......................... 101
18.3 Modular Construction ................................................. 102
18.4 Fast Reactors ....................................................... 102
References ............................................................... 103

Part V The Melting Pot

19 Variable Loads are Here to Stay .......................... 107
19.1 Intermediate and Peak Loads .............................. 107
19.2 Variability Won’t Go Away ................................. 108
Reference ............................................................... 109

20 Cost Matters ....................................................... 111
20.1 Comparing Generator Costs ................................. 111
20.2 The Generator Mix ............................................... 112
20.3 The Impact of a Rising Carbon Price ................. 113
Reference ............................................................... 113

21 Distributed Generation and Storage ..................... 115
21.1 Distributed Generation .......................................... 115
21.2 Decentralized Energy ........................................... 116
21.3 Community Energy Storage ............................... 117
21.4 Reducing Demand Variability ............................ 117
21.5 Distributed Generation Future ......................... 117

22 Smart Grids .......................................................... 119
22.1 The Vision ........................................................ 119
22.2 What Would be Needed for a Smart Grid? ............ 120
22.3 What are the Benefits? ....................................... 120
22.4 What are the Risks? ............................................ 121
References ............................................................... 121

23 Electric Transport ................................................ 123
23.1 The Demise of Oil ................................................. 123
23.2 The Rise of the Electric Car ............................... 123
23.3 How Will We Refuel Our Electric Vehicles? ............ 124
23.4 How Much Electricity Would Transport Need? ....... 124
23.5 What Will be the Impact on the Electricity Network? 125

24 Summing It All Up ................................................ 127
24.1 Carbon Challenge ............................................... 127
24.2 Reducing Emissions ............................................. 127
24.3 An All-Renewable Future .................................... 128
24.4 Clean Coal and Gas ............................................ 129
24.5 Fission Energy ................................................. 130
24.6 Melting Pot .................................................... 131
24.7 Future Technologies ......................................... 131
24.8 Conclusion ..................................................... 132
Reference ......................................................... 132

Author Biography ................................................ 133

Appendix A: Definition of Terms ................................. 135

Appendix B: Power Generation and Network Control ............ 139

Appendix C: Wind Power .......................................... 147

Appendix D: Solar Power .......................................... 155

Appendix E: Energy Storage ...................................... 165

Appendix F: Carbon Capture and Storage ......................... 173

Appendix G: Nuclear Power ...................................... 177

Appendix H: Electricity Costs and Markets ....................... 187

Index .............................................................. 195
Abbreviations

ABWR  Advanced boiling water reactor
AC    Alternating current
AEMO  Australian energy market operator
BEV   Battery electric vehicle
BWR   Boiling water reactor
CAES  Compressed air energy storage
CCGT  Combined cycle gas turbine
CC    Combined cycle
CCS   Carbon capture and storage
CFL   Compact fluorescent lamp
CHP   Combined heat and power
CO₂   Carbon dioxide
CO₂-e Carbon dioxide equivalent
CSP   Concentrated solar power
DC    Direct current
DG    Distributed or decentralized generation
DOE   US Department of Energy
EGS   Enhanced or engineered geothermal system
EIA   Energy information administration
EOR   Enhanced oil and gas recovery
EPBT  Energy payback time
EPR   European pressurized reactor
EU    European Union
EWEA  European Wind Energy Association
FBR   Fast breeder reactor
GDP   Gross domestic product
GHG   Greenhouse gas
GW    Gigawatt (power)
GWh   Gigawatt-hour (energy)
ha    Hectare
HEV   Hybrid electric vehicle
HVDC  High voltage direct current
IAEA  International Atomic Energy Agency
ICE  Internal combustion engine
IEA  International Energy Agency
IFR  Integral fast reactor
IGCC  Integrated gasification combined cycle
IPCC  Intergovernmental Panel on Climate Change
ISA  Integrated sustainability analysis, University of Sydney
ISCC  Integrated solar combined cycle turbine
ITER  International thermonuclear experimental reactor
km  Kilometer
kV  Kilovolt
kW  Kilowatt (power)
kWh  Kilowatt hour (energy)
LCOE  Levelized cost of electricity
LOLE  Loss-of-load event
LOLP  Loss-of-load probability
LRMC  Long-run marginal cost
LWR  Light water reactor
MIT  Massachusetts Institute of Technology
MJ  Megajoule
MSW  Municipal solid waste
MW  Megawatt
MWe  Megawatt electrical (power)
MWh  Megawatt hour (energy)
NEEDS  New Energy Externalities Developments for Sustainability
NG  Natural gas
NREL  National Renewable Energy Laboratory (US)
OC  Open cycle
OECD  Organisation for Economic Co-operation and Development
OCGT  Open cycle gas turbine
PBMR  Pebble bed modular reactor
PEV  Plug-in electric vehicle
PHEV  Plug-in hybrid electric vehicle
PHS  Pumped hydro storage
PHWR  Pressurized heavy water reactor
Pu-239  A fissile isotope of plutonium
PV  Photovoltaic
PWR  Pressurized water reactor
RE  Renewable energy
SCADA  Supervisory control and data acquisition
SFR  Sodium-cooled fast reactor
SMR  Small modular reactor
SRMC  Short-run marginal cost
STE  Solar thermal electric
<table>
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<tr>
<th>Abbreviation</th>
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<tr>
<td>Th-232</td>
<td>A fertile isotope of thorium</td>
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<tr>
<td>U-235</td>
<td>A fissile isotope of uranium</td>
</tr>
<tr>
<td>U-238</td>
<td>A non-fissile (fertile) isotope of uranium</td>
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<td>United Kingdom</td>
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