

The science behind the energy debate: talking points

PM's Science Prize after party breakfast forum

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Organised by the Australian Institute of Physics, sponsored by CSIRO Industrial Physics and hosted by Questacon, the National Science and Technology Centre.

Speakers were invited to address the following four questions about coal, solar, fission and fusion:

- 1) How is energy obtained from this method?
- 2) How much energy can we get from this method?
- 3) What is the usage of this energy method in Australia?
- 4) What is the potential future for this technology?

Energy versus Power: a definition: David Jamieson

President of the Australian Institute of Physics, and Director, University of Melbourne Centre of Excellence for Quantum Computer Technology, Microanalytical Research Centre

Ladies and Gentlemen, welcome to the AIP breakfast on hot issues involving physics in our society.

There is a rising level of debate in our community about Australia's energy consumption both now and in the future.

But in this debate it is important to understand the difference between energy and power. These words are not interchangeable and I would like to open the presentations today with some words about the difference between energy and power. All the difficulties Australia faces today arise from problems associated with power, not energy.

Let me explain.

Australia and the world have an abundance of energy. It has a terrible shortage of power. Energy is measured in Joules. Joules are to energy like litres are to water or dollars are to bank accounts. There are lots of Joules lying around. In sunlight, coal, uranium, hot water, mobile phone batteries. But power is the rate at which energy is delivered. Power is to energy like flow rate from a tap is to water or the weekly spending rate is to dollars. Power is measured in Joules per second. (In fact power has a special unit of its own call the Watt where 1 Watt is 1 Joule to second, but here I will continue to use Joules per second to make it clear what I am talking about.)

What we need to run our cities and our civilisation is power, not energy. To run the nation of Australia requires about 45 billion Joules of energy to be delivered every second of the day 7 days a week. This is an astonishing amount of power.

It is also a bit technical. Let me put it another way. Instead of Joules, let me consider dollars instead. Easier to visualise aren't they? Imagine I tell you that you have won the lottery. The prize is 7,682,300 dollars. I give you a cheque. You put it in the bank right away and shortly afterwards pay off your house, buy a car, whatever. You can spend the dollars at whatever rate you want. All at once (on your house) or gradually (several cars over the next few weeks). A pile of dollars in the bank is powerful.

What instead if I said, "congratulations, you have won the lottery". "But the dollars are distributed 1 km apart over the surface of Australia. All 7,682,300 square kilometres of this nation of ours." Same number of dollars as before, but not nearly so powerful. Going to be a problem to spend. Going to cost heaps to collect into a concentrated form so you can pay off your house. Do you see now the difference between energy and power?

Another example. Your mobile phone battery stores about 10 thousand Joules in a fully charged battery. Useful. Your bathtub full of water at a temperature of 60 degrees Celsius will release about 80 million Joules of energy when it cools down to room temperature. Useless. There is no

way, even in principle, to collect that energy and put it into your phone battery (or indeed a thousand phone batteries) so it can be tapped to provide useful power. It is too dilute.

Indeed the second law of thermodynamics says that you cannot obtain more than about one eighth of this energy no matter how clever you are. Roughly speaking the second law accounts for the energy wasted collecting the energy.

How about solar energy? There is plenty of solar energy, but very little power. Just for reference, to power Melbourne (7 billion Joules per second) would take a solar collector more than 100 by 100 km square. Very expensive. Need a lot of energy to make. Useless at night!

So you might ask, let us conserve! Cut back! Energy efficient light bulbs! Well, we know that the equilibrium population of Australia, before electricity and modern technology, sustained a population of around 300,000 first Australians living without electricity for more than 50 thousand years. A rich and cultural life with more leisure time than we have now. But not for us I suspect.

Now we have twenty million people and counting. This land cannot sustain that number without electricity. Even if we cut back our power consumption by 50% (which seems unlikely – no more iPods, internet, air conditioners, lifts, cars...just the bare essentials) we will still need to find around 22 billion Joules per second (half today's rate) to run our newly austere lives. To say nothing of the fact that in the future, environmental catastrophe may mean we will need to take in millions of refugees from places that have become uninhabitable due to climate change.

However we can set an example to the world and attempt to arrest that climate change without hideous thinning of our population. It is clear to everyone that human generated CO₂ is linked to climate change. But don't worry! It won't have much effect on you or your children. We are a rich and powerful nation. We can cope. There will be no Australian children dying from famines due to crop failures. That will happen in the third world. Our power stations mostly use coal to make electric power. Surely one of the highest rates of CO₂ emission in proportion to the amount of power generated, especially in Victoria and South Australia which use brown coal. At the moment it is people living by subsistence agriculture who are paying the price for this.

There are very few alternatives that can give us the power we need to run our civilisation without the greenhouse emissions. Especially as this is an emergency! The climate is changing. We must do something about it now! We need an alternative power source right now! There is a very short list of alternatives.

We must be sure that the alternatives can provide us with the power we need to run our civilisation. We must look at the numbers. We must judge the down sides of the alternatives against the down sides of our present practices. And we must do that judgment on a global scale. We must take responsibility for the disposal of our own wastes. We must take responsibility for the downsides of our own lifestyle. It is the only ethical thing to do.

Appendix to speech

- 5) Drop a 1 litre milk carton through a height of 1 m.
- 6) $E = mgh = (1 \text{ kg})(10 \text{ N/kg})(1 \text{ m}) = 10 \text{ Joules}$
- 7) To get 9 GJ/s, need to drop 1 billion milk cartons every second!
- 8) Survey of people who drive Japanese cars. Subarus are produced by Japan's 30% nuclear produced electricity.
- 9) Fraction of nuclear power production: Japan 30% nuclear, France 77%
- 10) Geosequestration with gas fired power established, but not for coal. Decades away for coal.
- 11) Nuclear 40 times lower CO₂ than coal. Mainly from mining and enrichment.
- 12) CANDU needs more frequent refuelling for from 0.7% ²³⁵U to 0.5%. Enriched run longer without refuelling.
- 13) 1 GW coal is 2.5 Mtonnes, 1 GW nuclear is 25 tonnes of U.
- 14) Coal emits 10 times more radioactivity per unit of energy generated than nuclear

- 15) Three mile island was contained. No one killed. There was no containment building in Chernobyl.
- 16) Modern Nuclear Reactors of the sort we'd be likely to deploy in Australia have an expected core-meltdown frequency on one per 2 million reactor years.
- 17) The human body contains 7 grams of potassium. The radioactive isotope ^{40}K inside the human body is responsible for about 3500 becquerels of activity. Sleeping next to one's spouse gives you a radiation dose of 5 microseiverts per year.
- 18) You might also want to say that we (and the world) has an abundance of Uranium which we will not exhaust any time soon. We've mined less than one ten millionth of the world's Uranium and our (nuclearinfo.net) study which shows we have at least 8000 times minable Uranium than we've used already.

Fission: John Howard

Senior Fellow, Plasma Research Laboratory, Research School of Physical Sciences and Engineering, Australian National University

How is energy obtained from fusion?

Fusion is the ultimate renewable.

It is the process that power is the sun.

Isotopes of hydrogen – most abundant element in the universe – fused under enormous pressure.

The sun uses gravitational confinement

Terrestrial – needs magnets – 10 times hotter than the centre of the sun.

Inject radio waves, microwaves and particle beams to heat plasma

Extract energy through neutrons – absorbed by lithium blanket – breeds tritium (“self fuel”)

Alpha particles born from the reaction keep the plasma hot (“self-sustain”)

Confinement properties deteriorate with injected power (no chain reactions – “self-limit”)

Fusion reactors “self-heat”, “self-fuel” and are “self-limiting”

Cool the lithium blanket, boil water, steam turbines or take advantage of high heat differential directly.

ITER next step device

How much energy can we get from fusion?

Fusion will provide centralized base-load supply.

D-T can supply earth for a million or more years based on known readily available D and Li reserves.

No greenhouse emissions

Unlimited fuel

Limited radioactive byproducts

No proliferation

No runaway reaction

1GW = >2000 wind turbines

23 km² solar panels

2.5M tonnes of coal

35 tonnes of Uranium oxide

250kg of T + D

What is the usage of this energy method in Australia

No-one uses fusion energy yet.

Australian discovered fusion reaction.

First tokamak in western world was in Australia.

Australia has made seminal contributions for the past 50 years.

Australia is still involved in fusion research.

What is the potential future for this technology?

ITER is next step fusion reactor

Consortium of nations

US\$10B over 10 years

Superconducting, burning fusion reactor

35 year lifetime.

Precursor to DEMO (demonstration fusion power plant)

Australia is exploring a role with ITER

In the longer term, it is a necessary part of the future energy mix.

Coal: Mark O'Neill**Executive Director, Australian Coal Association**

(Notes taken during the session)

Coal is very concentrated. Historically its very useful. It is possible to say that coal fuelled the industrial revolution. Coal and oil in particular has fuelled our prosperity over the last century.

There is a great deal of confidence that certainly a lot can be done about fossil fuels. However, it is wrong to say we can simply continue with the same energy use as we have now. If we are going to deal with climate change, we are going to have to change.

How do you get energy from coal?

Put the coal into a boiler and burn the coal – it is pulverised coal. From this you heat water, create steam and the high pressure drives a turbine which drives a generator.

An alternative method, and an older method, is coal acidification. Instead of burning coal, you react the coal with steam and oxygen in the air. This gives off a gas. The gas is called 'sim gas' which can be used to drive a modified turbine. This is considered the future for coal generator. Rather than burning the coal itself. You can also capture the carbon dioxide released.

What's the potential future for this technology?

Increased efficiency. If you use the best available conventional pulverised coal burner then 40-45% of the energy can be extracted from the coal. This is the best we can do at the moment. There is continual work to increase this efficiency and continual improvement. We can get to 50%.

Coal acidification. This is where you use a gas turbine to drive a steam turbine. Combine this with out current methods and you get higher efficiency.

How much do we currently use?

27% of our coal-based electricity is from brown coal, 56% from black coal.

Lignite presents 60% moisture, so you have to burn off a lot of water before you generate electricity. We get over 80% of our electricity in Australia from coal. That is why we have high per-capita carbon dioxide emissions.

Use of coal globally is about 24% of our primary energy.

Projections are that we will be using at least twice as much coal as we are today. In the last 9 months alone China replicated Australia's usage.

The key is carbon capture and storage. Technology exists to do this. Key questions – carbon storage needs to be co-located at the emission point. Also, we need to capture CO₂ at the power station. All of this can be done at a reasonably modest scale. The biggest challenge is the 'cost challenge' for the next decade.

Most of Australia's power stations are 30 years plus. They are terribly inefficient. By increasing their efficiency we will improve their output.

Baseload energy supply is important. It is a fact that our society demands electricity at night, 24 hours. Air conditioners and i-pods. One of the real challenges for alternatives is delivering power on a costly basis. Coal does it cheaper and better than anything else.

Cheaper, not environmentally, but economically.

Fusion: Kath Smith

Research Scientist, Principal Research Scientist and Research and Section Leader with ANSTO (Australian Nuclear Science and Technology Organisation)

I thought it would be festive to show this cartoon of nuclear fission. As you can see fission occurs when a neutron of appropriate energy impacts a radioactive atom such as uranium-235. This produces fission fragments, neutrons and heat.

As the other speakers have done I will now address the 4 common questions put by the convenors of this breakfast.

How is energy obtained from fission.

Splitting the atom by neutron bombardment (fission) releases energy, which heats the coolant (usually water) and this heat can be used

- to drive turbines to generate electricity
- to drive reversed thermocouples and so directly generate a potential (this technology is used in space vehicles)
- to crack water into hydrogen and oxygen (the hydrogen can then be used as fuel to produce heat and electricity – hence the term “hydrogen economy”)
- to directly provide heat for chemical or industrial processes

How much energy can we get from this method

This is a bit of a “how long is a piece of string” question. But it may be relevant to say that one nuclear fuel pellet the size of your thumb can generate as much electricity as a railway car of coal.

What is the usage of this energy method in Australia

None. However, there is currently a Federal Government Inquiry in progress on all aspects to do with uranium mining and its usage.

For reference it is noteworthy that

- there are currently about 440 nuclear power plants world wide which generate ~17% of the world's electricity
- usage varies from country to country: the French generate 78% of their electricity from nuclear; China generates about 2% but has plans to build 2 more plants immediately and 50 more in the next decade. Asia is the fastest growing region for nuclear power.

What is the potential future for this technology?

Firstly a few facts

- The world energy demand is likely to double by ~2040, mostly in developing countries. Most of these countries have few indigenous energy sources and are seeking security of supply.
- Global warming is occurring and will have all sorts of negative consequences on climate, water supplies and crops.
- Global warming has been linked to atmospheric CO₂ content.
- So the choice for many countries is either introduce nuclear or continue to burn fossil fuels.
- Per kilowatt of electricity, nuclear produces only less than 2% of the CO₂ emissions produced by coal.
- Nuclear power is broadly competitive in cost terms with other energy sources.
- Australia's per capita carbon emissions are the highest in the world.
- Australia has 40% of the world's known uranium reserves.
- If Australia built 5 power reactors by 2020, ~17% of Australia's energy demand would be met and 50 million tonnes of CO₂ emissions could be avoided.

So perhaps it is timely to consider nuclear power for Australia.

It is also worth mentioning that there is currently a lot of international interest in nuclear power and that various programs and initiatives have been begun.

The Generation IV International Forum (GIF) is an international project to develop a number of advanced reactors that take revolutionary (rather than evolutionary) steps forward. The aims are to improve sustainability, safety, proliferation resistance and economic performance.

Members: Argentina, Euratom, Brazil, Canada, France, Japan, South Korea, Switzerland, South Africa, USA and UK

The US concept of a Global Nuclear Energy Partnership (GNEP) proposes a new framework of business and political relationships to establish reliable supply of nuclear technology while avoiding proliferation. Basically countries would be divided into supplier and user nations and only some nations would be allowed to make or reprocess fuel.

The US also has begun 4 domestic initiatives

1) Nuclear Power 2010

- Explore new sites
- Develop business case
- Develop Generation III+ technologies
- Demonstrate new licencing process

2) Advance Fuel Cycle Initiative

- Recovery of energy value from Spent Nuclear Fuel
- Reduce the inventory of civilian Pu
- Reduce the toxicity & heat of waste
- More effective use of the repository

3) Nuclear Hydrogen Initiative

- Develop technologies for economic, commercial scale generation of hydrogen

4) Generation IV

- Better safer more economic nuclear power plants with improvements in
 - safety and reliability,
 - proliferation resistance and physical protection,
 - economic competitiveness and sustainability.

Solar: Andrew Blakers

Foundation Director, Centre for Sustainable Energy Systems at the Australian National University

- 1) To tackle greenhouse, we need a diverse range of energy sources, including energy efficiency and renewables
- 2) Key renewable technologies for Australia include photovoltaics, solar heat and wind
- 3) The solar industry is doubling in size every 18 months; currently worth \$20 billion per year
- 4) Australia has a strong but declining foothold in the solar energy industry
- 5) Attractive long-term integrated incentives are available in Europe, Japan and parts of the US, including R&D funding for Universities and companies, commercialisation funding and market support.
- 6) Australia will need to match these incentives if it is to remain a global player.