SACE Stage 2: Earth and Environmental Science

Topic 4: Earth's sustainable future

Backdrop: Wattle Point wind farm, York Peninsular, South Australia; photo by David Cook (http://reneweconomy.com.au/biggest-battery-storage-array-mooted-for-south-australia-wind-farm-15699/)

Foreground: A derelict 19th farm cottage in sheep grazing country is a stark reminder of past unsustainable practices.

"The most sustainable way is to not make things. The second most sustainable way is to make something very useful, to solve a problem that hasn't been solved" – Thomas Sigsgaard

Version 1 notes by Peter Reeve, Bernd Michaelsen, Howard Fallowfield

Monday_11_December_2017

Topic 4: Earth's sustainable future

In this topic, students explore how increases in human life span and greater use of scientific and technological knowledge have increased the global demand for energy, water, and soil resources. They recognise why provision of good-quality fresh water and groundwater at local and global levels will continue to be of high importance into the future.

Students investigate how effective use of resources is constrained by factors such as waste disposal, and the efficiency of energy technologies. They consider how the desire to use more renewable sources to increase supply has generated discussion about the advantages and disadvantages of renewable and non-renewable resources, and changes in practice that might lead to a more sustainable future.

Students explore the consequences of using various types of renewable energy resources, and factors affecting the sustainability of soil, water, and energy resources. They investigate a range of aspects of soil, water, and energy use, and use critical-thinking skills to evaluate data and develop logical solutions

NOTE TO TEACHERS:

*These notes have been designed to elaborate on the **Possible Contexts** provided in the Earth and Environmental Science subject outline. They are intended to provide further ideas and links to teaching and learning resources that address the **Science Understanding.** It is important to remember that you are not expected to cover all of the material included. Rather, these notes should be regarded as a 'smorgasbord' from which individual teachers might pick and choose, according to the needs and abilities of their students and according to the context of their externally assessed 'Earth Systems Study'.*

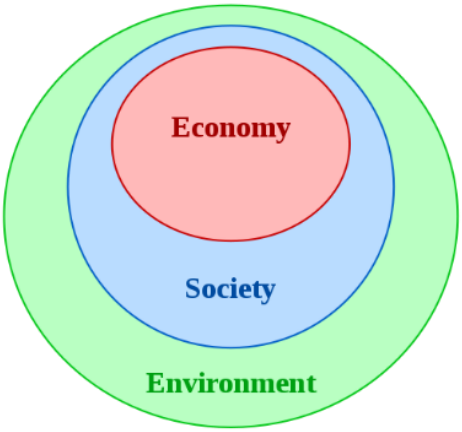
Science Understanding	Possible Contexts	
Renewable resources include some that are available regularly and others that are replenished at time scales from years to millennia. • Discuss the need for, and limitations of, renewable sources of energy, including biofuels, solar, wind, and geothermal energy. • Determine whether a renewable resource is either diminished or sustained over time, given the abundance of the resource and how readily it can be replenished. • Investigate how the timescale required to replenish a large groundwater system, such as the Great Artesian Basin, is influenced by the rate of depletion of the system. • Discuss the sustainability of soil and water at local, regional, and global scales.	Research the development of wind farms in a chosen location (region, state, or territory) and/or arrange a local visit to report on current and proposed electricity generation, costs of construction, and ongoing maintenance needs. www.earthsciencewa.com.au/mod/resource/view.php?id=1104 Sketch or photograph examples of dryland salinity or erosion to illustrate a negative impact of human activity on sustainability of resources. Investigate how stormwater run-off affects the sand budget at the coast.	
	Investigate the drains and bores in use in areas that recycle stormwater run-off. www.salisbury.sa.gov.au/Live/Environment_and_Sustainability/Wetlands_and_Water/Wetlands http://bhkcstormwater.com.au/ Collect, sieve, and microscopically view soil samples to compare and report on two or more soil types in a local district.	
	Evaluate the economic, social, and environmental impacts of the use of geothermal energy in energy production. www.earthsciencewa.com.au/mod/resource/view.php?id=1103	
The availability and quality of fresh water can be influenced by human activities, and natural processes at local and regional scales. • Discuss how stormwater run-off in urban areas may be recycled for community use so that it is not wasted and does not pollute waterways. • Explain how overextraction of groundwater from near-coastal aquifers may cause inflow of sea water. • Explain how pollution of groundwater can result from a variety of rural, urban, and industrial activities.	Discuss how urbanisation, overextraction, pollution, siltation, drought, and algal blooms affect the availability and quality of fresh water. www.mdba.gov.au/managing-water/water-quality/blue-green-algae www.water.nsw.gov.au/__data/assets/pdf_file/0008/548621/algal_murray_stage_1_final_report.pdf	

Science Understanding	Possible Contexts	
	Visit, or investigate online, a water desalination plant, to research and report on aspects of production, including the energy used and cost. Undertake research to design a comparative table of soil types found across a local district or region, to compare soil fertilities, mineral source rock types, and past and current land use. Investigate and report on the sources and costs of water for domestic use at students' own locality, and how these may have changed over time. Obtain data to calculate and report on the volume of rainwater that falls annually on a typical house roof in a local district	
	Evaluate the benefits and limitations of using desalination of sea water to provide a viable water resource.	
The effective use of energy resources is constrained by factors including waste disposal, and the efficiency of available technologies to collect, store, and transfer the energy. • Compare the advantages and disadvantages of using renewable and non-renewable energy resources.	Use different carbon calculators to estimate individual carbon footprints and investigate why different calculators give different results.	
	Investigate how using the same scientific knowledge in different scenarios can have unexpected consequences by comparing the operations at the hydroelectricity plant in the Italian Alps, which is well-managed, with those at the plant in São Paulo, which has developed a black foam issue. Investigate the cost and efficiency of solar panels over the past decade.	

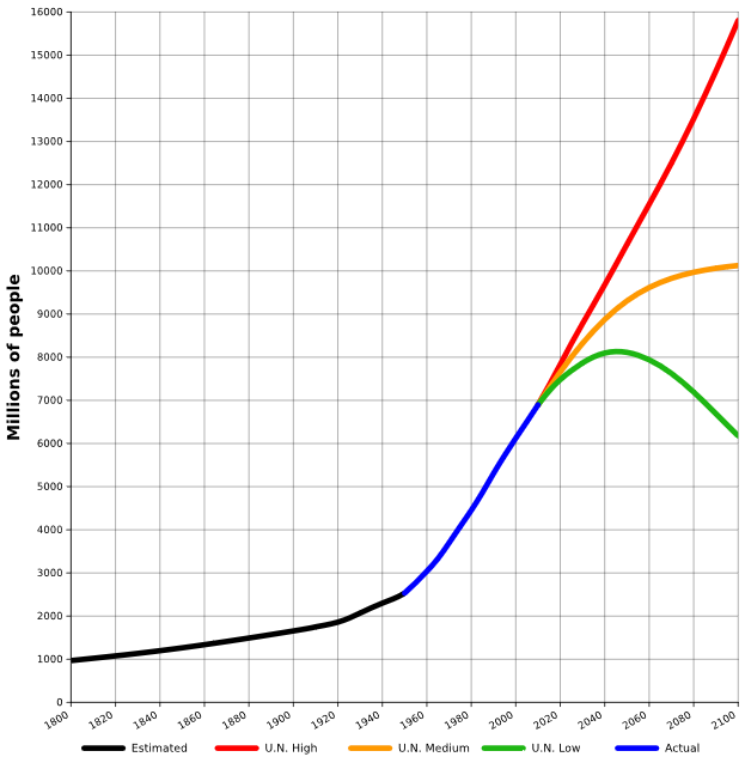
Definitions of "sustainability"

https://en.wikiquote.org/wiki/Sustainability: "**Sustainability** in ecology is how biological systems remain diverse and productive. Long-lived and healthy wetlands and forests are examples of sustainable biological systems. In more general terms, sustainability is the endurance of systems and processes"

https://en.wikipedia.org/wiki/Sustainability: "In ecology, **sustainability** (from *sustain* and *ability*) is the property of biological systems to remain diverse and productive indefinitely"

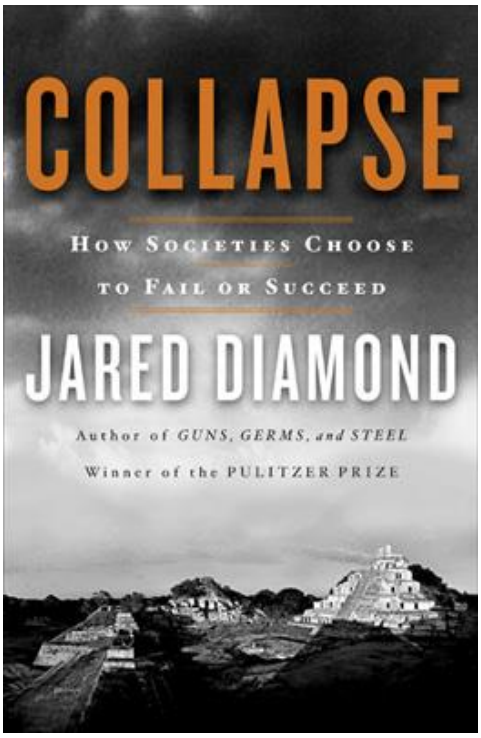


Schematic representation of the "three pillars of sustainability", whereby the economy and society are constrained by environment limits (https://en.wikiquote.org/wiki/Sustainability)



World population growth between 1800 and 2100. The United Nations envisage three population growth scenarios beyond the present: Low , medium or high projections towards the year 2100 (https://courses.lumenlearning.com/boundless-biology/chapter/human-population-growth/)

"Collapse: How Societies Choose to Fail or Succeed" a 2005 book by Jared Diamond.



Collapse: How Societies Choose to Fail or Succeed (https://en.wikipedia.org/w/index.php?curid=1451552)

Jared Diamond lists twelve (12) environmental problems currently facing humanity. In his assessment, historical problems that have afflicted past societies include:

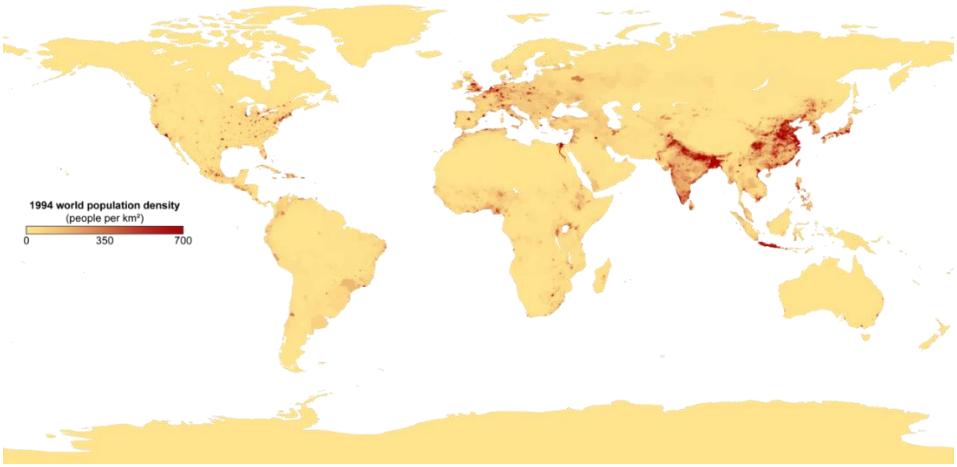
1. **Deforestation** and **habitat destruction**
2. **Soil problems** (erosion, salinisation, reduced fertility)
3. **Water management problems**
4. **Overhunting**
5. **Overfishing**
6. **Exotic species**' effects upon **native species**
7. **Overpopulation**
8. Increased **per-capita impact** of people

And he perceives additional present and future problems to be:

9. Anthropogenic **climate change**
10. Build-up of **toxins** in the environment
11. **Energy** shortages
12. Full human use of Earth's **photosynthetic capacity**

In this topic (Earth's Sustainable Future) we shall explore some of these notions.

Mankind's ecological footprint extends beyond where he lives



1994 world population map by NASA, originally uploaded by Keenan Pepper, legend added by SG (en.wiki). - Image:Population density.png from NASA.gov, Public Domain, (https://commons.wikimedia.org/w/index.php?curid=2871394https://en.wikipedia.org/wiki/Population_density#/media/File:Population_density_with_key.png)

Earth's human (over) population

Earth's population and population distribution is pertinent to understanding its sustainable future. That is because population size determines the magnitude of resource use.

Population clock

Visit the population clock at http://www.worldometers.info/world-population/

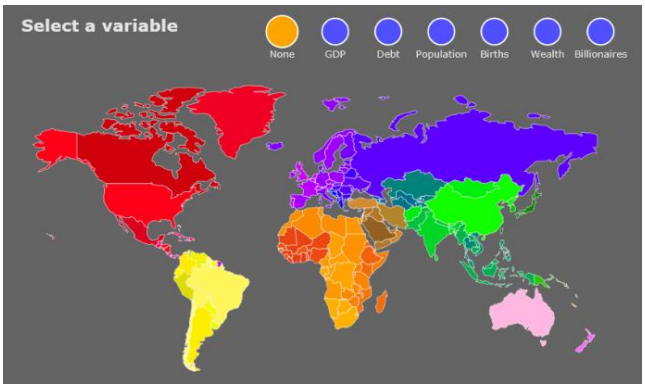
TOP 20 LARGEST COUNTRIES BY POPULATION (LIVE)

1	China	1,389,223,050	11	Japan	125,998,712
2	India	1,345,157,305	12	Ethiopia	104,767,346
3	U.S.A.	326,869,413	13	Philippines	104,057,674
4	Indonesia	264,003,010	14	Vietnam	95,577,843
5	Brazil	211,524,591	15	Egypt	95,524,773
6	Pakistan	197,407,068	16	D.R. Congo	82,671,680
7	Nigeria	192,658,640	17	Iran	81,097,595
8	Bangladesh	165,150,361	18	Germany	80,628,398
9	Russia	143,364,171	19	Turkey	80,551,281
10	Mexico	130,490,671	20	Thailand	68,322,813

Population of the world's 20 most populous countries according to "Population clock" at 4:40 PM, 31 August 2017 (http://www.worldometers.info/world-population/).

The population statistics in the above figure were calculated on 31 August 2017. How have they changed between then and your visit to the "Population clock"?

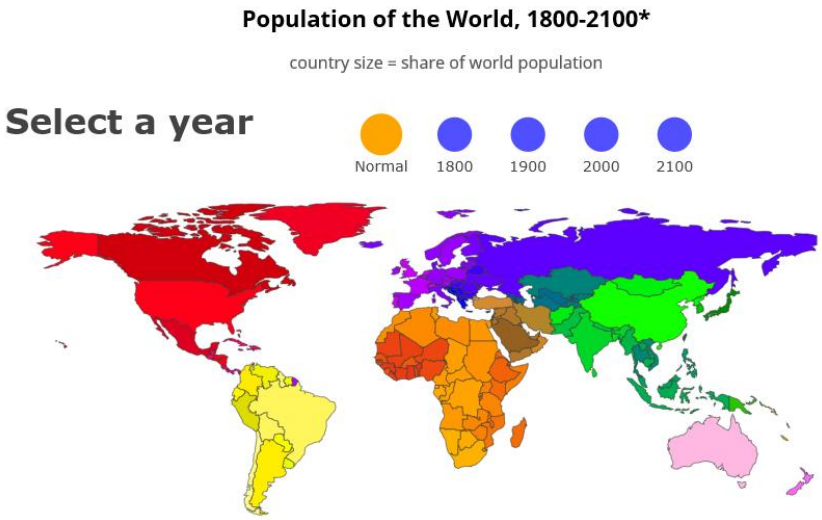
How we share the world



Cartograms versus conventional maps of the world (http://metrocosm.com/how-we-share-the-world/)

How is the world divided according to six (GDP, debt, population, births, wealth, billionaires) socioeconomic variables?

World population – past and future



World's population between 1800 and 2100 CE (http://metrocosm.com/world-population-history-map/)

In relative terms, which continent will see the largest increase in human population? And which countries in that continent will have populations exceeding 100 and 200 million people? Do these countries presently have the economic capacity to absorb their respective population increases?

Where on Earth would it seem there will be zero or near zero population growth, between now and 2100?

Renewable resources include some that are available regularly and others that are replenished at time scales from years to millennia.

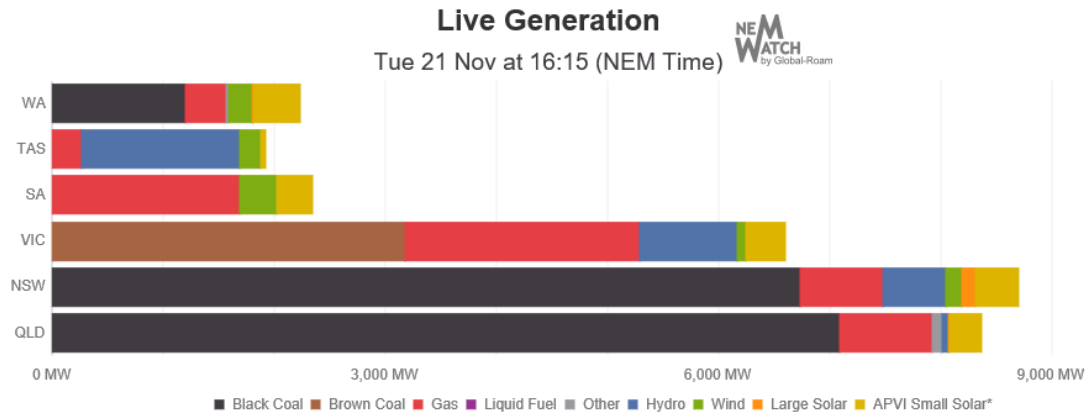
- **Discuss the need for, and limitations of, renewable sources of energy, including biofuels, solar, wind, and geothermal energy.**

Australia's electrical power generation and power network

The cost of electricity prices in South Australia is possibly the highest in the world (http://www.abc.net.au/news/2017-06-28/sa-has-most-expensive-power-prices-in-the-world/8658434). This cannot have happened by chance. There must be fundamental reasons causing this, yet politicians, consumers and environmentalists are arguing why.

GLOBAL-ROAM Pty Ltd in conjunction with RenewEconomy have developed an **internet widget** that allows for the direct monitoring of electricity generation across the nation (http://reneweconomy.com.au/nem-watch/).

The figure below is a screen-capture taken at in the afternoon of 21 November 2017. It provides a breakdown of how each state (excluding NT and ACT) was generating electricity.



Region	Black Coal (MW)	Brown Coal (MW)	Gas (MW)	Liquid Fuel (MW)	Other (MW)	Hydro (MW)	Wind (MW)	Large Solar (MW)	APVI Small Solar* (MW)	Region Total (MW)
WA	1,197	0	373	0	17	0	211	10	422	2,230
TAS	0	0	262	0	0	1,431	187	0	41	1,921
SA	0	0	1,685	0	0	0	338	0	318	2,341
VIC	0	3,179	2,108	0	0	878	82	0	357	6,604
NSW	6,740	0	743	0	0	570	141	118	390	8,702
QLD	7,096	0	829	0	86	62	0	6	294	8,373
Total	**15,033**	**3,179**	**6,000**	**0**	**103**	**2,941**	**959**	**134**	**1,822**	**30,171**

Summary of electricity generation for the Australian states at 4:15 PM on Tuesday 21 November 2017 (http://reneweconomy.com.au/nem-watch/). In Adelaide and local regions the day had a maximum temperature of 35 °C, mostly clear skies and little wind.

Based on data in the above figure, some pertinent observations include:

- Only SA and Tasmania do not generate electricity from burning coal (either lignite or black coal).
- Both NSW and Queensland rely on black coal-fired power stations for more than 75% of their electricity.
- Queensland has the greatest reliance with 84% of its electricity derived from black coal.
- The only states without hydro-electrical generation are SA and WA.
- States with the highest proportion of renewable energy were Tasmania (~86%) due mainly to its extensive hydro resources, WA (~29%) and SA (~28%).
- SA's energy mix is mostly gas with important contributions from home-owners' solar panels (~14%) and wind turbine facilities (~14%).

At the time that the data in the above figure above were downloaded (4:15 pm 21 Nov 2017), temperatures (°C) in the main capital cities were: Adelaide 34°, Brisbane 21°, Melbourne 32°, Sydney 23°, Perth 25°, Hobart 27°. In other words, it was a fairly normal Spring day with capital city temperatures ranging between 21° and 34° C in the late afternoon.

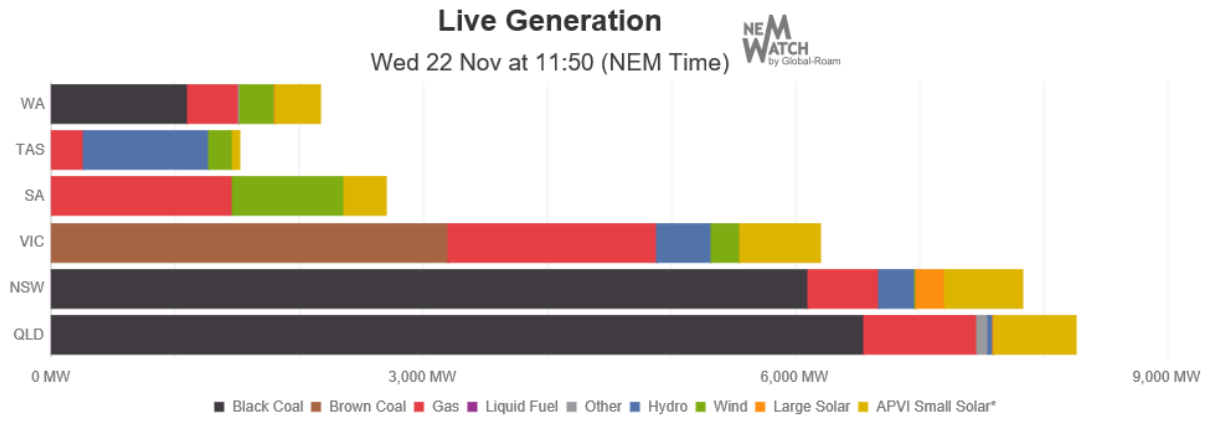
By nightfall, the solar power component across the country will of course be zero. The amount of (potential) solar power also varies by season – as indicated by mapped irradiance data in the figure below, solar irradiance in the populated areas of the state is in winter, 40–50% of what it is in summer.

In South Australia, the generation of mains electricity is dominated by gas-fired turbines on Torrens Island in Adelaide's metropolitan area, and in the state's south-east.

Data in the above figure indicate that, in Queensland, "other" sources accounted for 86 MW; and in WA "other" sources of power produced 17 MW. What are the "other" sources and are they "renewable"?

Twenty (20) hours later the "energy mix" has changed for all the states but in particular for South Australia.

Compare the data in the figure above with similar data in the figure below that summarises electricity generation ~ 20 hours later, i.e. the next day. What proportion of South Australia's energy mix were renewables on 22 November 2017?

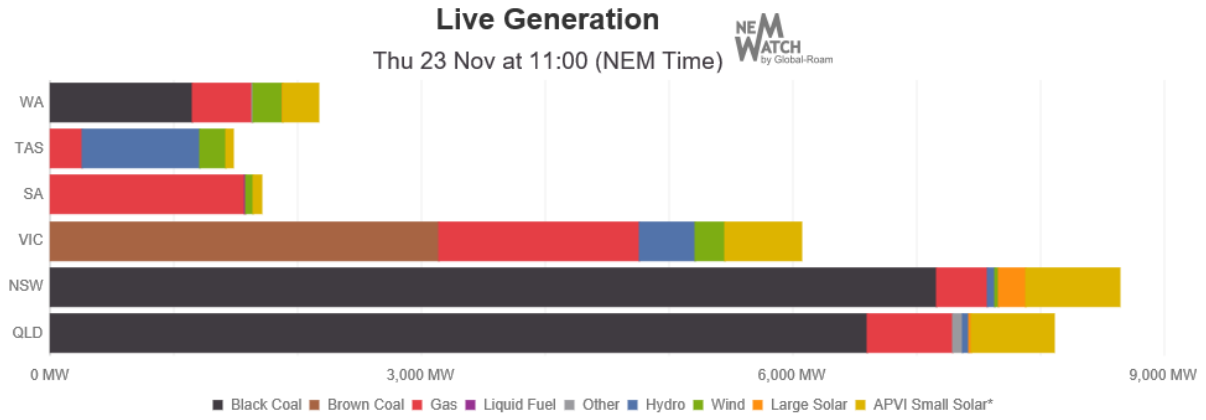


Region	Black Coal (MW)	Brown Coal (MW)	Gas (MW)	Liquid Fuel (MW)	Other (MW)	Hydro (MW)	Wind (MW)	Large Solar (MW)	APVI Small Solar* (MW)	Region Total (MW)
WA	1,100	0	407	0	13	0	280	7	368	2,175
TAS	0	0	262	0	0	1,011	190	0	62	1,525
SA	0	0	1,464	0	0	0	897	0	337	2,698
VIC	0	3,200	1,681	0	0	438	233	0	650	6,202
NSW	6,102	0	575	0	0	283	10	232	628	7,830
QLD	6,552	0	910	0	90	43	0	10	656	8,261
Total	**13,754**	**3,200**	**5,299**	**0**	**103**	**1,775**	**1,610**	**249**	**2,701**	**28,691**

Summary of electricity generation for the Australian states at 11:50 AM on Wednesday 22 November 2017 (http://reneweconomy.com.au/nem-watch/). In Adelaide and regions, the day had clear skies and a steady breeze.

Based on the above figure, data for South Australia indicate that on the day in question, only 54% of the state's locally generated power derived from so-called **baseline power**.

*Research the term **baseline power**. What is baseline electricity generation and why is it so-often mentioned in debates about energy security and sustainable industries? When thinking about this, refer to the figure below that shows a summary of SA electricity generation on Thursday 23 Nov 2017, i.e. the next day.*



Region	Black Coal (MW)	Brown Coal (MW)	Gas (MW)	Liquid Fuel (MW)	Other (MW)	Hydro (MW)	Wind (MW)	Large Solar (MW)	APVI Small Solar* (MW)	Region Total (MW)
WA	1,155	0	474	0	14	0	237	6	282	2,168
TAS	0	0	257	0	0	955	209	0	62	1,483
SA	0	0	1,574	10	0	0	59	0	69	1,712
VIC	0	3,141	1,623	0	0	448	245	0	617	6,074
NSW	7,168	0	406	0	0	57	33	219	762	8,645
QLD	6,606	0	692	0	77	54	0	20	665	8,114
Total	**14,929**	**3,141**	**5,026**	**10**	**91**	**1,514**	**783**	**245**	**2,457**	**28,196**

Summary of electricity generation for the Australian states at 11:00 AM on Thursday 23 November 2017 (http://reneweconomy.com.au/nem-watch/). In Adelaide and nearby regions, the day was overcast and wind-still.

Tasmania generates most of its electricity from hydro-electric facilities, but these have been constructed at a considerable cost to the environment.

Research the pros and cons of hydroelectricity, in the context of the Tasmanian and Snowy Mountains hydroelectric schemes. How does the environment continue to degrade as a consequence of these schemes even 50 years after their completion?

Has the extensive use of hydro-electricity in Tasmania benefited or diminished the economy and/or prosperity of Tasmania?

The population of Western Australia (2.58 million) is significantly greater than South Australia (1.72 million), yet according to the "live" data from reneweconomy.com.au generates less electricity that passes into its grid. How can that be? To answer this question, think about, and if necessary research the demographic and industrial differences between the two states.

Similarly, Queensland (4.9 million persons) with a smaller population than Victoria (6.3 million) generates more electricity. Why might that be?

The future of Australia's energy mix

Please watch the 2012 video (3:05) from the **Climate Council** of Australia at https://www.climatecouncil.org.au/australia-s-electricity-sector-ageing-inefficient-and-unprepared

Wind energy

Wind energy is an important form of so-called "green" energy. However, wind turbine farms are controversial because they are a form of "visual pollution" and have been dubiously linked with negative health outcomes for local communities. Having said that, some land-holders are keen to have them on their land because they earn significant royalties from energy companies.

The 420 MW Macarthur Wind Farm in south-western Victoria. The facility can power ~173,000 average Australian homes, and it is claimed save ~ 1.7 million tonnes of greenhouse gases per year. (https://www.agl.com.au/about-agl/how-we-source-energy/renewable-energy/macarthur-wind-farm)

AGL recently sold its share of the Macarthur Wind Farm (above figure). This 429 MW power facility comprises 140 individual 3 MW turbines and is the largest wind-energised power plant in the Southern Hemisphere. South Australia has similar but smaller facilities.

Earlier in this course on Earth and Environmental Science, we discovered how different greenhouse gases have varying "greenhouse" affects. When AGL claim that the Macarthur Wind Farm saves 1.7 million tonnes of greenhouse gases, which greenhouse gases are they referring to?

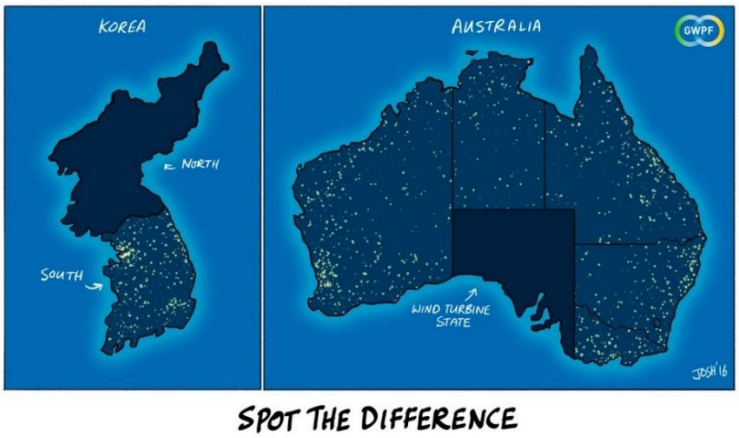
It is likely that the cheapest (? easiest) alternative to the Macarthur Wind Farm is to burn lignite (brown coal) in the Latrobe Valley. Other than CO_2, what other greenhouse gases pollutants are produced in the Latrobe Valley coal-fired power stations?

It is not strictly true to say that wind turbines (or for that matter other forms of "green energy") have zero carbon emissions. That is because large quantities of energy and resources are required to build a facility like Macarthur. Moreover, wind turbines require considerable maintenance due to the spinning action of the blades and generators, and the physical wear of all moving parts.

Is it possible to calculate a "break-even" point in time; i.e. the number of operating years that wind turbines need to produce electricity before they break-even and produce more energy than it took to make them?

The "Great South Australian Blackout"

Mid-afternoon on 28 September 2016, South Australia experienced a dramatic electrical power outage. With the exception of Kangaroo Island, the entire state was without mains electricity from ~ 4 pm onwards. Power was progressively restored across the Adelaide metropolitan area and other districts progressively over several days – however most of Adelaide had mains power restored by 6 am the following morning.



Politically inspired cartoon suggesting that the 28 September 2016 blackout in SA was largely due to an over-reliance on wind-turbine generated electricity (https://energy-investments.com/green-disaster-south-australian-blackout-due-to-loss-of-wind-power/)

The immediate cause of this unprecedented blackout was a freak storm with at least 80,000 lightning strikes that destroyed more than 20 high voltage transmission towers (see figure below) and other infrastructure, especially in the Mid-North.

High voltage transmission towers destroyed by storms on 28 September 2016 (http://tasmaniantimes.com/index.php?/weblog/article/how-not-to-run-a-modern-society-on-renewable-energy-/show_comments)

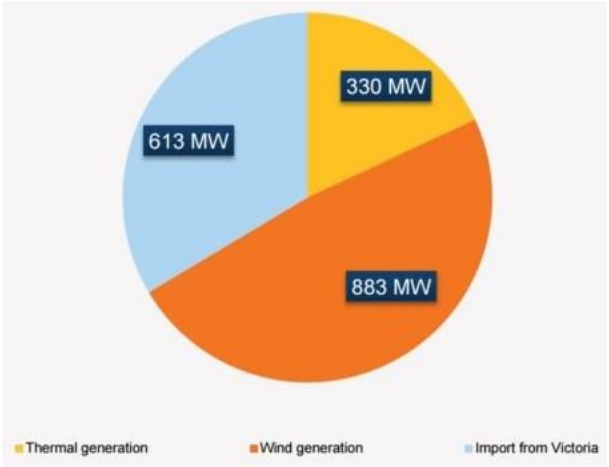
At around the time that Adelaide was blacked-out, there was an "uncontrolled reduction" of ~315 MW of wind generated power in the region north of Adelaide. Consequently, there was an additional demand placed on the main interconnector that feeds electricity from Victoria to South Australia. Unable to handle the unprecedented demand for additional power in South Australia, the interconnector shut-down (to safeguard itself), leaving mainland South Australia without electricity. At the time of the incident, the second

interconnector between Victoria and South Australia was shut-down due to maintenance and was therefore unable to take-up some of the extra South Australian power demands.

As a consequence of the September 2016 blackout, a **South Australian Power Crisis** has ensued, with the SA State Government and the Federal Government exchanging much criticism, especially with regard to the state's **energy mix** how SA's high reliance on non-baseline power (i.e. renewables) contributed to the crisis.

The SA Government's explanation for the September 2016 power blackout can be found at https://statedevelopment.sa.gov.au/upload/energy/facts/energy-in-south-australia.pdf?t=1481241303925.

The figure below depicts SA's energy mix prior to the September 2016 state-wide blackout. Excluding roof-top solar panels, South Australia imported ~34% of its mains power from Victoria.



South Australia's electricity generation-mix (excluding home-owner solar panels) prior to the 28 September 2016 state-wide blackout (https://cleantechnica.com/2016/10/05/accusations-continue-fly-south-australian-blackout/). Thermal generation refers to gas-fired power generation.

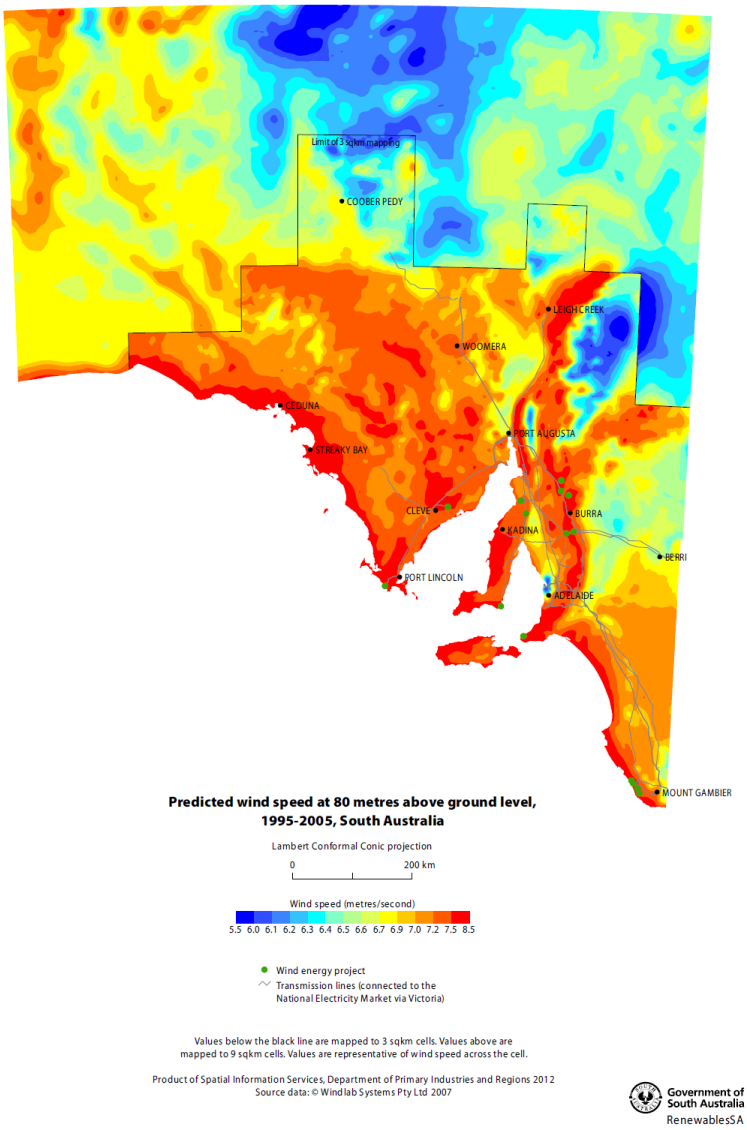
Given that a large proportion of Victoria's electricity is generated from "dirty" lignite, how much of South Australia's electricity is currently being generated from Victoria's lignite? Has the amount of electricity imported from Victoria changed since the September 2016 blackout?

Investigate how the present Government of South Australia and the state opposition propose to deal with the so-called South Australian Energy Crisis in terms of:

- *Electrical energy generation*
- *Electrical energy storage.*

*What novel approaches to the **South Australian Energy Crisis** are being proposed by entrepreneurs and industry?*

When addressing these questions bear in mind the scale in megawatts (MW) and the proportion of South Australia's total electricity budget.

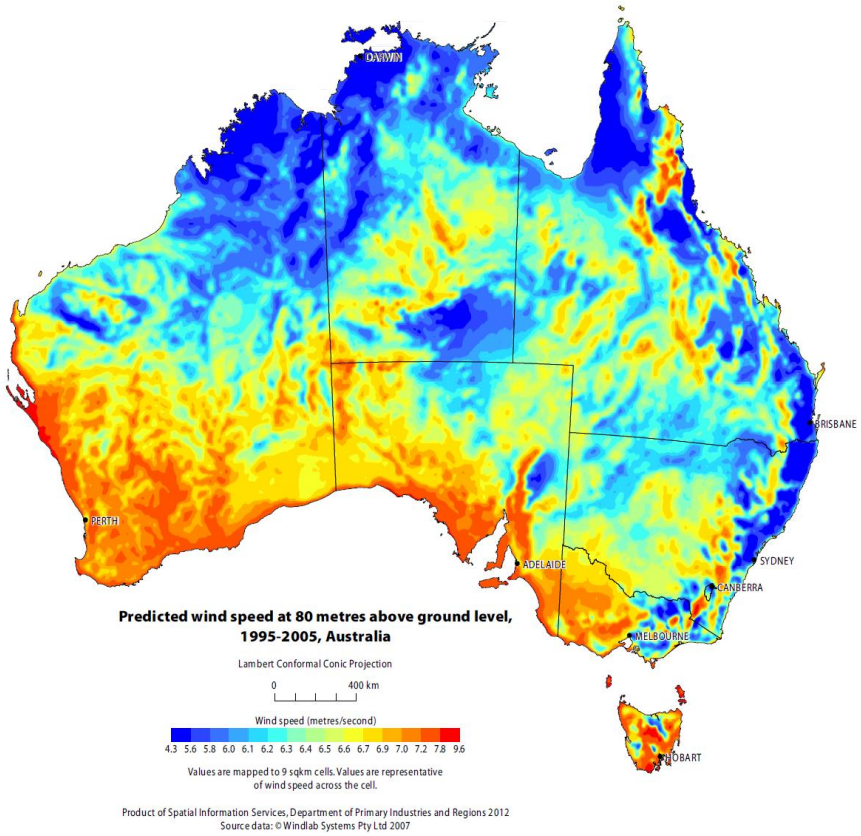


Predicted wind speed at 80 metres above ground level in South Australia (http://www.renewablessa.sa.gov.au/investor-information/resources)

The figure above shows a map of "windiness" in South Australia. Evident from the data is that populated areas around the state's coast are also some of the windiest. This means that wind turbine facilities can be built relatively close to populated areas that need the power. However, the same cannot be said for much of eastern Australia, except for western Victoria and the vicinity of Canberra where large wind farms have already been built.

Windfarms need to be located relatively close to population centres because of the high inefficiency in transmitting electricity long distances via high-voltage power lines.

Use the internet to research the quantity of electrical energy that is lost in transmission in Australia. In general terms, how might these inefficiencies be overcome?



Predicted wind speed at 80 m above ground surface, Australia (http://www.renewablessa.sa.gov.au/investor-information/resources)

Solar power

The Government of South Australia has an excellent website (http://www.renewablessa.sa.gov.au/investor-information/resources) dedicated to renewable energy, including renewable resource maps, infrastructure maps, and a "bioenergy roadmap".

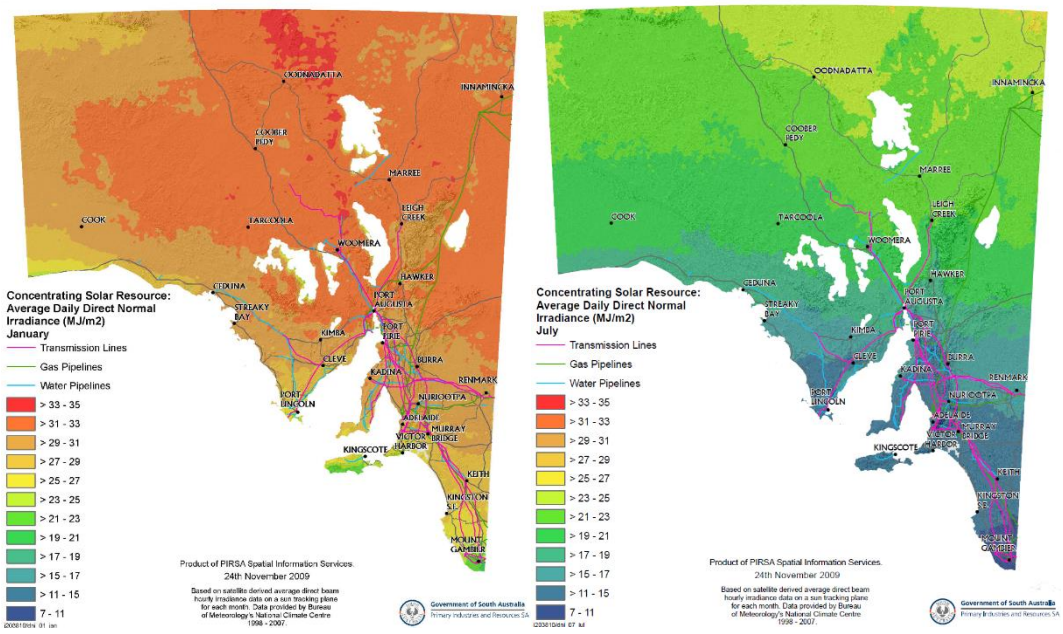
The site also provides "Energy Fact Sheets" on SA's power security, the national electricity market, on the new South Australian Grid-connected Battery Storage Project, and the state government's energy plans for South Australia's future energy security.

Some statistics from ARENA (Australian Renewable Energy Agency) at https://arena.gov.au/blog/rooftopsolar/ include:

- In late 2017, solar rooftop panels in Australia surpassed the 6000 MW capacity.
- 6000 MW is sufficient to power at least 1.8 million homes (the entire Sydney metropolis).

- There are now ~2.8 million small-scale installations in Australia.
- Queensland (34% of households) has the largest uptake of roof-top solar panel systems, followed by South Australia (32%) and Western Australia (27%).

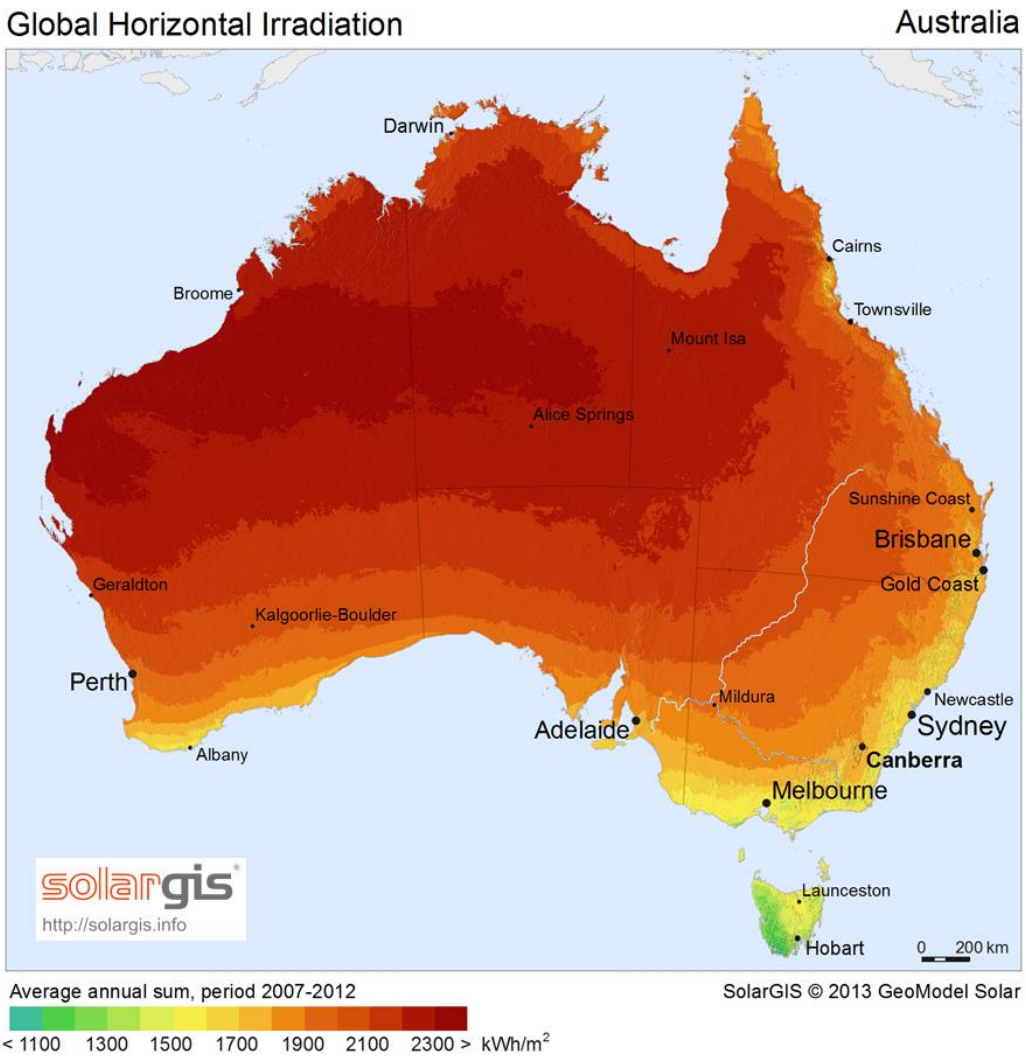
Infographic on Australia's uptake of solar rooftop panels, current on 1 September 2017 (https://arena.gov.au/blog/rooftopsolar/)



Average daily direct solar irradiance in South Australia. Left: January Right: July (http://www.renewablessa.sa.gov.au/investor-information/resources/direct-normal-irradiance)

Direct **solar irradiance** is a measure of how much sunlight hits Earth's surface, either within any typical day or averaged over a longer period like a year. The figure above compares the average daily direct solar irradiance in South Australia between a typical January and a typical July.

Data in the figure below is different – it refers to the <u>average annual</u> irradiance across Australia. One interesting observation is that the average annual irradiance for Mt Gambier region, in SA's southeast is similar to Melbourne's and much of coastal NSW. Indeed, all of Australia with the exception of the (unpopulated) western wilderness areas of Tasmania are very suited to solar energy. The main problem with solar energy is the capacity to store and use that energy during overcast days and during the night. We shall revisit this subject later.



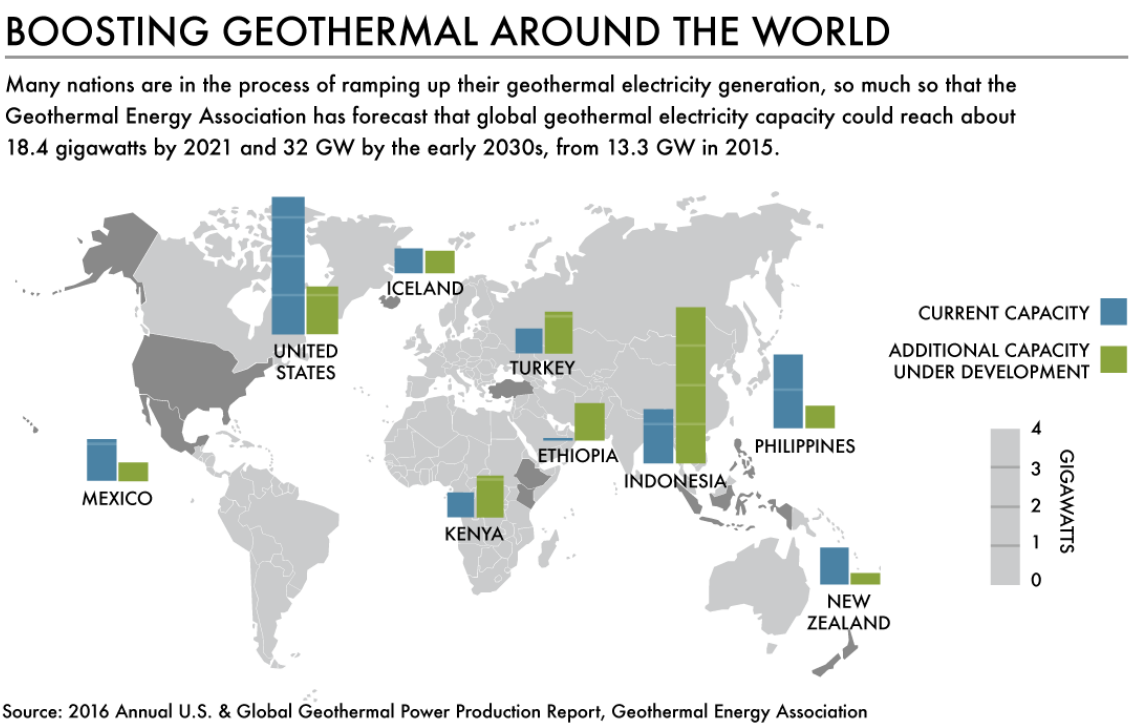
Global horizontal irradiance for Australia (https://solargis.com/products/maps-and-gis-data/free/download/australiaSolar irradiance in)

Across the nation, during the month of October 2017, solar roof-top installations exceeded a cumulative capacity of 100 MW. This amounted to 15,736 new solar systems. The scale of this installation boom can be explained by the continued rapidly increasing electricity prices. The last calendar month that installations exceeded 100 MW was in June 2012 when significantly higher (? excessively generous) subsidies were available to homeowners

Information source: http://www.news.com.au/finance/money/costs/report-shows-boom-in-solar-as-electricity-price-rises-start-to-bite/news-story/1f1397de9a5e35f4c960c0ba88e433c2.

Please watch the short video (1:19) at the above website showing the demolition of the Port Augusta Power Station and SA's politicians blaming each other for the energy crisis. In the video, the SA Government claims that SA has the lowest wholesale electricity prices in Australia and is now a net exporter of power into the eastern electricity grid.

Geothermal energy



2015 global geothermal generation capacity (https://ensia.com/features/geothermal-energy/)

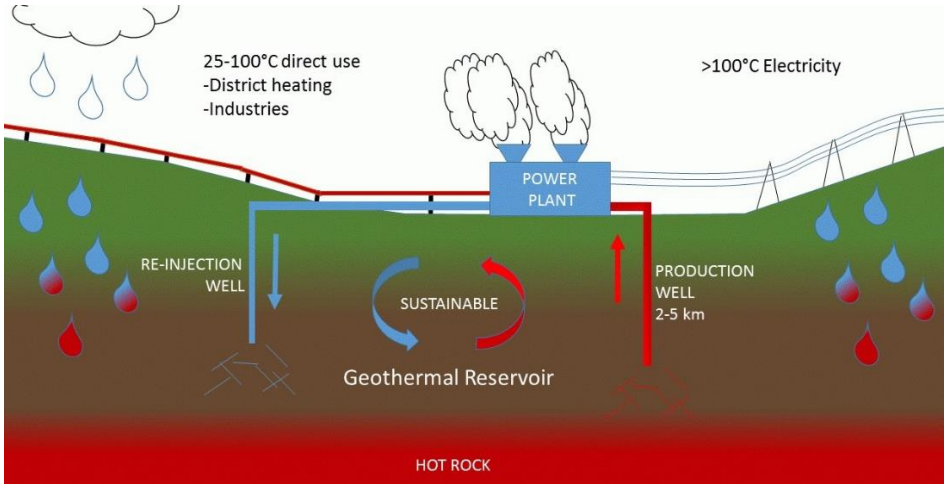
Geothermal energy is heat energy within Earth. This heat is ultimately sourced as **radiogenic heat** produced as a consequence of the **radiogenic decay** of uranium, specifically the **isotopes** ^{238}**U** and ^{235}**U**.

Presently, there is only one geothermal energy plant in Australia, located in Birdsville, Queensland. Here the energy source is from hot (98 °C) bore water from a depth of 1,230 metres in the **Eromanga Basin** (**Great Artesian Basin**).

Please watch the video (10:16) on geothermal energy in Iceland at https://www.youtube.com/watch?v=Rs6n0baLQ6w.

Another short video (3:37; https://www.youtube.com/watch?v=mCRDf7QxjDk) by the US Department of Energy, suggests that up to 10% of US energy requirements could be met by geothermal energy. The video describes three types of geothermal plant:

- dry steam geothermal (most common technology),
- flash-steam geothermal,
- binary-cycle geothermal (uses a heat-exchange).



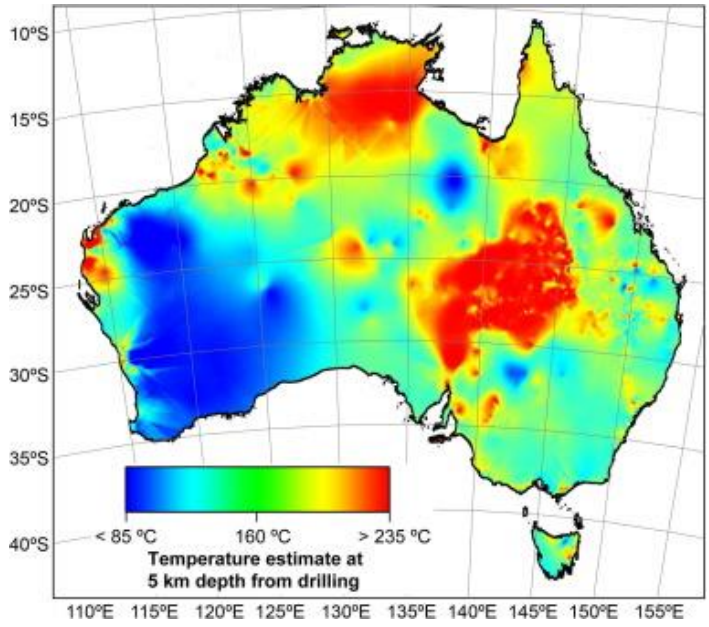
Schematic representation of the energy cycle of a geothermal power plant (http://arcticgreencorp.com/geothermal-energy/)

The geology of Australia and Iceland are very different – there are very few geothermal springs on the entire continent of Australia. However, one such examples is in the **Arkaroola Wilderness Sanctuary**, of the northern Flinders ranges – the **Paralana Hot Springs** with a water surface temperature of ~ 62 °C.

Paralana Hot Springs, northern Flinders Ranges (http://heysentrail.asn.au/wp-content/uploads/2015/02/12.Paralana-Hot-Springs.jpg)

Despite the lack of geothermal springs at the surface, there are huge geothermal heat resources in Australia – they comprise heated granite and related crystalline rock, typically at depths of around 4 to 5 km, buried beneath **Phanerozoic** sedimentary basins. The figure below summarises where Australia's major geothermal resources are located.

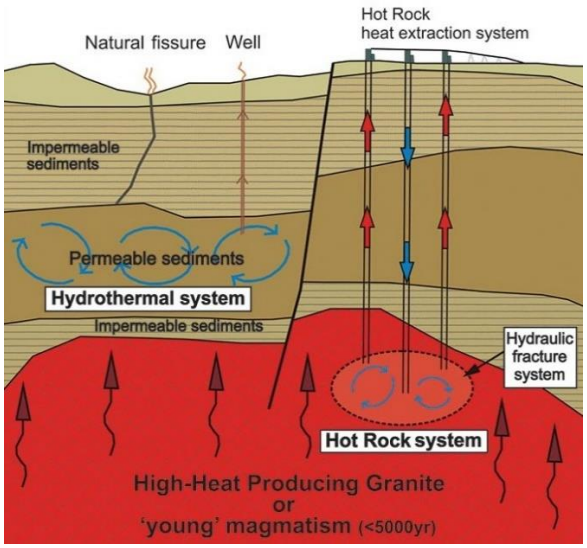
Hot fractured rock systems



Temperature estimate at 5 km depth from data taken from 1500 drillholes. Figure from a 2015 paper in GeoResJ on "Maximum depth of magnetisation of Australia, its uncertainty and implications for Curie depth" by Richard Chopping and Brian Kennett (http://www.sciencedirect.com/science/article/pii/S2214242815000376)

Locate the Birdsville power plant on this above map

Unfortunately, it is very expensive (tens of millions of dollars) and technically risky to drill to depths of ~4 km to reach rocks of suitable temperatures for the harnessing of geothermal energy.



Geological setting of hydrothermal systems, and hot fractured-rock geothermal systems, by Geoscience Australia (http://www.futuredirections.org.au/publication/geothermal-industry-future-australia/). Hot water that drives Birdsville's power generation comes from a relatively shallow "hydrothermal system" scenario on the left. Petratherm was exploring for deeper hot dry rocks, the scenario on the right.

During the last minerals and energy boom (2005–2011) several companies were actively exploring for geothermal energy in South Australia. Perhaps the best known of these is Petratherm Ltd that commissioned the Paralana-1A and Paralana-2 drillholes (located between the northern Flinders Ranges and the SA-NSW border) which reached depths of ~4 km.

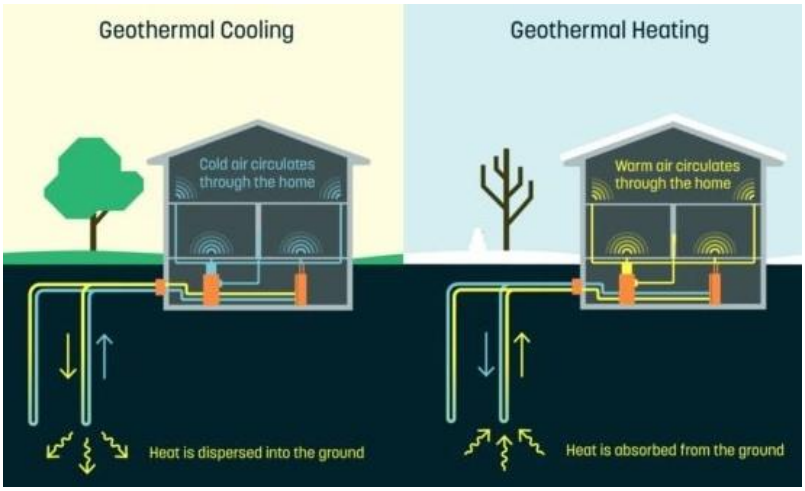
To date, despite being significantly innovative and "taking risks" the geothermal energy industry in Australia has been unable to demonstrate economic large-scale power generation. To find-out why, visit http://www.futuredirections.org.au/publication/geothermal-industry-future-australia/.

Why has the geothermal industry not been able to demonstrate technical and economic feasibility of large-scale power generation?

Geothermal heat pumps

The video by the US Department of Energy discussed, amongst other things, **geothermal heat pumps** (GHPs) otherwise known as **ground-sourced heat pumps**. Geothermal heat pumps are not futuristic technology. There are businesses in Australia that will install GHP systems in public buildings and private homes – GeoExchange Australia Pty Ltd (GXA) is one such company (https://www.geoexchange.com.au/about-geoexchange-australia/).

Please watch the video on **ground-source heat pump** systems, designed for private homes at https://www.geoexchange.com.au/home-residential/.



How heating and cooling are achieved using a ground-source heat pump (http://reneweconomy.com.au/google-creates-dandelion-promote-geothermal-energy-69981/)

What is the typical cost of establishing a ground-source heat pump for an Australian home? When you Googled for the answer to this question, you probably came across a lot of information relevant to the UK – why?

Biofuels?

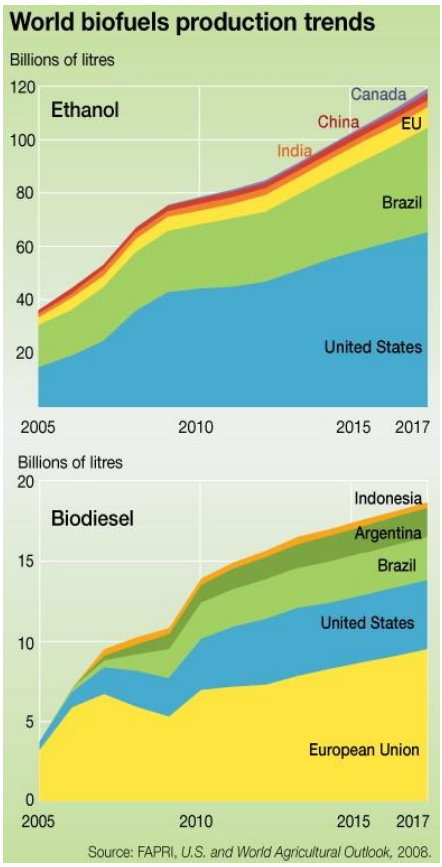
What are **biofuels**? To find-out, please watch an introductory video (2:56) at https://www.youtube.com/watch?v=-ck3FYVNl6s.

Theoretically, biofuels are **carbon neutral**, since crops used to make biofuels remove carbon dioxide (CO_2) from the atmosphere as they grow, and release the same quantity of CO_2 back into the atmosphere when they are burnt. Thus, biofuels are considered a source **renewable energy**.

Are there any factors that could impact the carbon neutrality of biofuels? Consider agricultural production. If fossil fuels are used in other parts of the production cycle, how could this impact upon "sustainability"?

Bioethanol and **biodiesel** are liquid biofuels, used as a substitute for petrol and diesel respectively. These types of biofuels are referred to as **first generation** because they are produced from agricultural food crops, such as maize, sugarcane, soybean and rapeseed. Production of these liquid biofuels is increasing.

Maize (background) and soybean (foreground) grown for biofuel production (http://www.mxdsystems.com/wp-content/uploads/2015/06/iStock_000043447164_Medium.jpg)



Biofuel production trends (http://theconversation.com/explainer-what-are-biofuels-12907)

Sustainability of biofuels

First generation biofuels are often seen as competing with crops used for food production. Is it sustainable and ethical to replace crops used for food production with crops used for fuel production? If increasing biofuel production reduces the land available for food production, how could this impact food production?

Please watch the video "Biofuels – the answer or the problem?" (6:04) at https://www.youtube.com/watch?v=t_Fw6y4T3Po

The following table considers the global potential for ethanol production.

Table 1. Global potential for ethanol from principal grain and sugar crops.

Crop	Global acreage (million hectares)[a]	Global average yield (tons/hectare)[a]	Global production (million tonnes)	Conversion efficiency (litres/tonne)[b]	Land intensity (litres/hectare)	Maximum ethanol (billion litres)	Gasoline equivalent (billion litres)	Supply as % of 2003 global gasoline use[c] (%)
Wheat	215	2.8	602	340	952	205	137	12
Rice	150	4.2	630	430	1806	271	182	16
Corn	145	4.9	711	400	1960	284	190	17
Sorghum	45	1.3	59	380	494	22	15	1
Sugarcane	20	65	1300	70	4550	91	61	6
Cassava	19	12	219	180	2070	39	26	2
Sugarbeet	5.4	46	248	110	5060	27	18	2
Total	599					940	630	57

[a] Data from FAO online statistical database.
[b] Data from various sources.
[c] Global gasoline use in 2003 = 1100 billion litres (Kim and Dale 2004).

Taken from Rajagopal et al. 2007
(https://are.berkeley.edu/~dwrh/CERES_Web/Docs/BioFuel_Challenge_ERL.pdf)

From data in the above table, it is apparent that even if all of the land currently used for production of the listed crops were to be used solely for the production of ethanol, this would only satisfy an estimated 57% of global demand for petrol (gasoline).

Thus, given the amount of land available globally for production of first generation biofuels, increased production of these biofuels is likely to have a greater impact on food availability and price, rather than fuel prices.

The effect of increasing the costs of e.g. grain (wheat, barley etc.), is likely to be felt most in developing countries, where grain comprises a large proportion of the diet.

Furthermore, if more land is to be made available for production of first generation biofuels, large-scale clearing of existing vegetation would be required. Obviously this would have significant environmental consequences.

Second generation biofuels

Second generation biofuels utilise biomass that has little or no nutritional value, such as agricultural and slurry wastes, or is derived by planting specialised crops on degraded land that is not suited to agricultural production. By producing biofuels from second generation sources, it is hoped that some of the economic, logistical, social and ethical issues identified with first generation biofuels can be overcome.

Algal biofuels

As an introduction to **algal biofuels**, please watch the short videos:

"Energy 101 – Biofuels" by the US Dept. of Energy (2:55):
https://www.youtube.com/watch?v=-ck3FYVNl6s

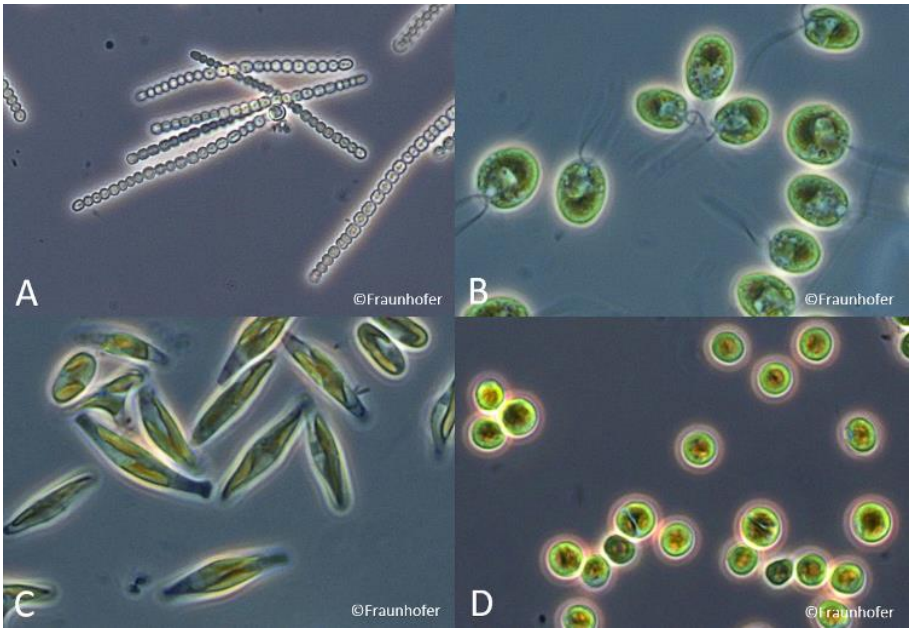
"Algal fuels could change the world" (3:17) at
https://www.youtube.com/watch?v=kQFKYp0p8po

"Algal farm" a detailed overview of algae production for energy (8:15) at
https://www.youtube.com/watch?v=pA4a_I-rb3Q

Algal biofuels are a type of second generation biofuel that show great potential for overcoming some of the issues identified with first generation biofuels.

'Algae' refers to a large group of simple plant-like organisms. Algae are usually divided into two groups, microalgae and macro-algae, based on their size. Microalgae are defined as microscopic, photosynthetic, free-living organisms that can survive and thrive in a wide range of aquatic habitats of varying salinity (including freshwater and seawater), temperature and pH. Macro-algae, the seaweeds, have their cells organised into plant-like structures resembling leaves, stems and roots. Microalgae were among the

first lifeforms on Earth, responsible for fixing massive amounts of CO_2 from the atmosphere while producing life-sustaining oxygen.



Photomicrographs of different microalgae species viewed under a microscope (http://www.chemistryviews.org/SpringboardWebApp/userfiles/chem/image/2015/2015_12/Microalgae/microalgae_figure_1.jpg)

There are several advantages of using algal biomass for biofuel production. These advantages include:

- Unlike other oil crops, algae grow rapidly and are rich in lipid oil.
- The production of algae does not compete or conflict with the production of food and other products derived from land-based agriculture.
- Water used to grow algae can include wastewater and waters of high salinity that cannot be utilised by conventional agriculture.
- Algae can be grown on CO_2 captured from the burning of coal and gas for electricity generation.

Algae, like any plant, require nutrients. Nitrogen, phosphorus, iron and silicon are the major nutrient requirements. Carefully controlling the concentrations of these nutrients is vital to maintaining productivity. Too little of any nutrient can impact the growth rate of the algae while too much could prove toxic.

? *Consider the nutrient requirements described above. If any one of these nutrients were in short supply, how would this impact on the sustainability and cost of production? Which of these nutrients are required for the production of food or other industrial use(s)?*

A report by the US National Academy of Sciences considered the amount of nitrogen and phosphorus required to produce 10 billion gallons of algal

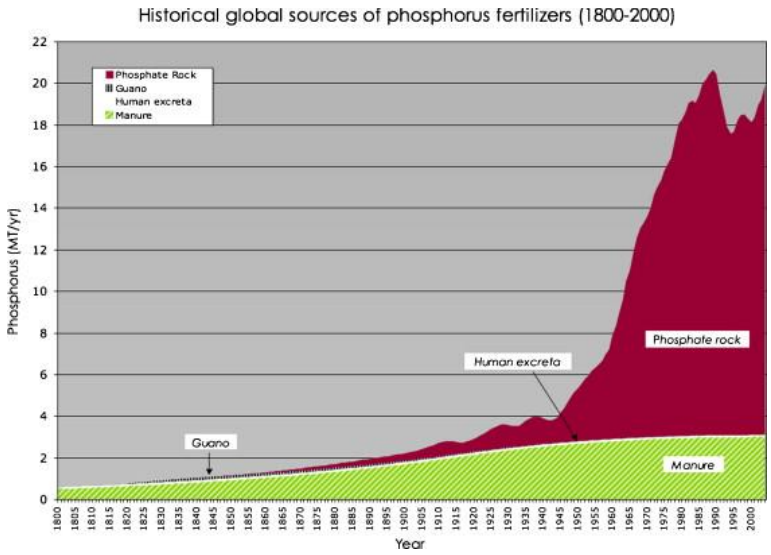
biodiesel per year. Based on 2006 data, it was calculated that, if the algae grown had a 20% oil content, it would require 107% of the nitrogen (ammonia) and 51% of the phosphorus consumed in the US. For context, the US used an estimated 300 billion gallons of liquid fuels in 2008. Thus, finding a sustainable supply of nutrients to support the expansion of algal biofuel production is the key, and clearly such a large supply would not be inexpensive.

The importance of phosphorous to the biosphere

Please watch the video "Peak Phosphorus" (6:08) at
http://www.abc.net.au/catalyst/stories/3166841.htm

Globally, phosphorus is a key agricultural fertiliser. Since the mid-19th Century, phosphorus fertilisers have been pivotal in increasing yields from agricultural crops, ensuring there is enough food for increasing populations. Rock phosphate, a non-detrital sedimentary rock is mined to meet the demand for phosphorous fertiliser.

The following graph shows how phosphate fertiliser consumption has increased over time.



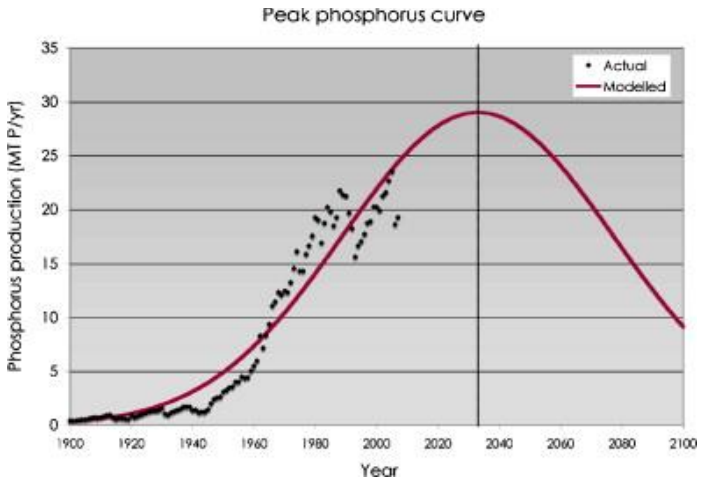
The historical sources of phosphate for use as fertilisers, including manure, human excreta, guano (bird poo) and phosphate rock (http://www.sciencedirect.com/science/article/pii/S095937800800099X)

Rock phosphate used to make phosphorus fertilisers, is a finite resource. Consider the implications for the sustainability of global agriculture, and algal production, if the supply of this commodity were to diminish. What alternatives are there to rock phosphate?

What countries or regions on Earth supply the world with rock phosphate? What are the HDI (human development indices) for the rock phosphate "suppliers" versus the rock phosphate "consumers"?

Phosphorous from rock phosphate is a non-renewable finite resource. As global population has increased, so too has the demand for phosphate. It is

anticipated that the production of phosphate will reach a 'peak', after which production will decrease, as the figure below illustrates.



Cordell et al. (2009) estimates that peak phosphorus production could be reached by 2033 (http://www.sciencedirect.com/science/article/pii/S095937800800099X#aep-section-id23)

Estimates of when "peak phosphorus" will be reached vary considerably, between 30–400 years. What kinds of factors and variables may cause these estimates to vary so greatly?

A reduction in the availability of phosphorus would likely cause prices for the raw material to increase. This would have a direct impact on the viability of biofuel production, including algal biofuels.

A free downloadable PDF by the US National Academies of Sciences, Engineering and Medicine on the "Sustainable Development of Algal Biofuels in the United States" (2012) is available at https://www.nap.edu/catalog/13437/sustainable-development-of-algal-biofuels-in-the-united-states

Sustainable algae production

One method to improve the sustainability of nutrients and reduce the global reliance on manufactured nutrient sources is to *integrate algal production with wastewater treatment*.

Wastewater, produced by humans and animals, contains naturally high levels of the nutrients that could be cycled to support algal growth. By integrating algal production with wastewater treatment, the nutrients present in the wastewater can be utilised for algae production, meaning they are not discharged into aquatic environments, which in itself causes major ecological problems.

Flinders University researchers taking measurements from a High Rate Algal Pond (HRAP) at Kingston on Murray in the Riverland region of South Australia. HRAPs use algae to treat wastewater. Microalgae, produced as a by-product of the treatment process, can be utilised for biofuel production, as well as for animal feed and compost.

Biogas

Biogas is another type of biofuel, produced as a result of **anaerobic fermentation** or digestion of biomass. Biogas is produced naturally in anaerobic environments such as swamps. Anthropogenic biogas production takes place in an **anaerobic digester**. In this process, anaerobic bacteria biochemically digest organic matter such as glucose and convert it to methane (CH_4) and carbon dioxide (CO_2), via the following chemical reaction:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

? *Anaerobic digestion takes place in four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Research what these are and briefly summarise them.*

Biogas can be produced from a number of sources, for example sewerage sludge (**biosolids**), animal manure, landfill, energy crops and various waste streams such as the organic fraction of municipal wastewater and food processing residues.

It is estimated that if all the waste generated by Australian domestic, industrial and agricultural industries were treated in biogas plants, up to 650 megawatts of electricity could be produced, enough to power around 1 million homes. This is easy to say, but there are of course many limiting factors.

Please watch the video (8:11) on "Aerobic digestion" and how in Wales (UK) **biodigesters** are using food waste to produce heat and electricity at https://www.youtube.com/watch?v=HW4SXfy1Kko.

Please read the excellent report on "Biogas: smells like a solution to our energy and waste problems" at (https://theconversation.com/biogas-smells-like-a-solution-to-our-energy-and-waste-problems-36136).

Systems for biogas production

Intensive agriculture, where livestock are raised in large sheds or feedlots, results in a large amount of concentrated effluent – primarily faeces and urine. In the pork industry, large quantities of effluent are often captured and treated in **anaerobic lagoons**.

An anaerobic lagoon is a basic type of **anaerobic digester**, designed to promote oxygen free conditions. These lagoons are not aerated, heated or mixed and are typically at least 2.4 m deep; however, oxygen can diffuse into the water as air blows over the pond surface – therefore to minimise this effect, the deeper the pond relative to its surface area, the better.

Provided sufficient land is available, anaerobic treatment in lagoons is a cost-effective solution for dealing with effluent streams. Initial setup costs can be high, but ongoing costs are very low, given there is no need for additional energy intensive inputs such as mixing or aeration.

The treated effluent from anaerobic lagoons still contains nutrients such as nitrogen and phosphorus and, as such, is often used as a fertiliser to irrigate surrounding cropland. Alternatively, the effluent may be further treated in **facultative** or anaerobic lagoons, making it suitable for discharge to the environment or for reuse on the farm.

Criteria	Range
Optimum water temperature (C):	30 - 35 degrees (Essentially unattainable in municipal systems)
pH	6.6 to 7.6
Organic loading:	0.04-0.30 kg/m^3/d (2.5 - 18.7 lbs/10^3 ft^3/d ((temperature dependent)
Detention Time:	1 to 50 days (temperature dependent)
Surface Area:	0.2 to 0.8 hectares (0.5 to 2 acres)
Depth	2.4 to 6.0 meters (8 to 20 feet) (depths approaching 6.0 meters [20 feet] preferred)

Source: Metcalf & Eddy, Inc., 1991.

*Ideal design criteria for an anaerobic lagoon (*https://www3.epa.gov/npdes/pubs/alagoons.pdf)

Note the optimum temperature requirement in the above table. Would this be achievable in a conventional anaerobic lagoon?

Anaerobic treatment produces large amounts of CH_4, a potent greenhouse gas which contributes to global warming. A cost effective way of capturing this

gas is to place a cover over the anaerobic lagoon, thereby trapping the methane produced. The captured gas can then be purified and burnt to produce energy in the form of heat and/or electricity.

Please watch the video entitled "Australian Biogas Benefits – Pork CRC": (5:50) at https://www.youtube.com/watch?v=4BASwiMclJE.

An interesting case-study of a piggery that produces biogas for electricity generation, and compressed natural gas to run vehicles is that of Bacon Hill, Nebraska. Please view the video (5:30) on this at https://www.youtube.com/watch?v=iwzUQ-DiPfY.

Melbourne Water's Western Treatment Plant at Werribee

Treating domestic wastewater requires a considerable amount of electricity. Melbourne Water's Western Treatment Plant at Werribee, uses a similar process to capture biogas from their primary wastewater treatment lagoons. Around 65,000 cubic metres of biogas are captured daily, producing around 7 MW of electricity, allowing the plant to be self-sufficient for electricity.

Covers over the primary treatment lagoon at Melbourne Water's Western Treatment Plant capture biogas to generate electricity. (http://www.gticovers.com/img/case-studies/_Big/Melbourne_Water_-_GTI_biogas_collection_cover_1.JPG)

Research undertaken by Flinders University is aiming to further enhance biogas production at the Western Treatment Plant by incorporating **high rate algal ponds** (HRAPs) in the treatment process. HRAPs utilise algae to treat wastewater. The microalgae produced in the system are harvested and used as an additional source of biomass to further increase biogas production.

Please watch a very short video (1:32) about Flinders University's "Algae for Energy" project at https://www.youtube.com/watch?v=FrupgbzpV-A.

Flinders University high rate algal ponds treat wastewater at Melbourne's Western Treatment Plant. Algal biomass is to be harvested and utilised to enhance biogas production (https://www.waterportal.com.au/swf/images/swf-files/2016_wastewater-treatment-and-biomass-production-in-high-rate-algal-ponds.pdf)

Considering the amount of energy that can be produced using covered anaerobic lagoon systems, are there any strategies that could be used to enhance biogas production? In what ways are these systems inefficient for biogas production? When answering this question, consider the optimum design criteria for an anaerobic lagoon.

Anaerobic digestion can be optimised to provide ideal conditions for biogas production by controlling factors such as temperature and the composition of feedstock within the digester. In some systems designed for electricity generation, excess heat is used to keep the digester at the optimum temperature. Systems such as these can have high setup and ongoing maintenance costs; however, they can enable self-sufficiency for heat and power generation, making them economically viable in the long-term.

The Berrybank Farm Piggery in Victoria has developed an integrated management system to generate heat and electricity from biogas, recycle water and collect waste for sale as fertiliser.

Please read http://www.sustainability.vic.gov.au/~/media/resources/documents/publications%20and%20research/knowledge%20archive/bioenergy%20resource%20in%20victoria/archive%20bio%20berrybank%20piggery%20case.pdf.

Please watch the video "Example of a biogas digester for electricity and heat production" (6:40) https://www.youtube.com/watch?v=UlImPgLbg0M.

Using the internet, find other examples of how and where biogas is produced for energy production. How are digesters optimised to increase biogas production?

Further resources

What are biofuels?: http://theconversation.com/explainer-what-are-biofuels-12907

Overview of biofuel technologies:
https://www.iea.org/publications/freepublications/publication/2nd_Biofuel_Gen.pdf

How the great phosphorus shortage could leave us all hungry:
https://theconversation.com/how-the-great-phosphorus-shortage-could-leave-us-all-hungry-54432

Integrating algal biomass production and wastewater treatment:
https://waterportal.com.au/swf/images/swf-files/2015_integrating-algal-biomass-production-and-wastewater-treatment.pdf

Algae for energy and feed: A wastewater solution: http://porkcrc.com.au/wp-content/uploads/2013/06/4A-101-Algae-for-energy-and-feed-A-review-130513.pdf

A detailed description of biogas production is found in the following factsheet:
www.wmaa.asn.au/lib/pdf/07_publications/1306_biogas_factsheet.pdf

Information on anaerobic lagoons: https://www3.epa.gov/npdes/pubs/alagoons.pdf

- **Determine whether a renewable resource is either diminished or sustained over time, given the abundance of the resource and how readily it can be replenished.**

"A **renewable resource** is a **natural resource** which replenishes to overcome **resource depletion** caused by usage and consumption, either through biological reproduction or other naturally recurring processes in a finite amount of time in a human time-scale" (https://en.wikipedia.org/wiki/Renewable_resource).

The key to this definition are the words "human time-scale", because even non-renewable resources such as petroleum and mineral deposits will continue to form but over time-scales of millions and tens of millions of years.

A short but thoughtful discussion on *"What is to be sustained?"* can be found at https://www.nap.edu/read/9077/chapter/5. Here the Nobel laureate Robert Solow is quoted as saying:

> *"a sustainable path is one that allows every future generation the option of being as well off as its predecessors"*

Natural resources that fully replenished over a human time-scale, and are therefore clearly renewable include:

- wind energy,
- wave and tidal energy,
- solar energy, and
- geothermal energy.

The natural resources listed above all derive their "energy" from external sources, e.g. the Sun's electromagnetic radiation, the Moon's gravitational pull on Earth's oceans.

Ocean water might be considered a renewable resource, simply because it is so vast that it is difficult to see how it might be diminished over a human lifetime – every day Earth's oceans are "topped-up" with rainfall and river discharge.

Renewable resources

Components within ecosystems are obviously renewable and include:

- wood from forests,
- fish from the oceans,
- mammals (i.e. whales etc.) from the oceans, and
- water from rivers.

Permaculture

Permaculture is the development of agricultural ecosystems intended to be sustainable and self-sufficient.

Find-out more on permaculture by watching the National Geographic video (40:08) "Life is Good: Sustainable Living" of permaculture in tropical Australia at https://www.youtube.com/watch?v=EpM_10cCQwY.

Another video (19:31) on permaculture in the South Island of New Zealand is accessible at https://www.youtube.com/watch?v=6GJFL0MD9fc.

*How realistic are these two videos? What proportion of humanity could realistically live in the manner depicted? If more and more people began to live the **low impact** lifestyle of the people in this video, would that ultimately benefit or degrade the environment?*

Sustainable living is a lifestyle that attempts to reduce an individual's or society's use of Earth's natural resources and personal resources.

What is the maximum human population that Earth could support if most people (say > 75%) of the human population lived like the people in the video?

Whether the renewable resources of wood, fish and mammals are also **sustainable resources** depends on the rate of exploitation by humans.

Pile of bison sculls to be used for fertiliser, 1870 (https://rarehistoricalphotos.com/bison-skulls-pile-used-fertilizer-1870/). An estimate of the number of sculls in this pile is ~ 180,000.

Bison (*Bison bison*), otherwise known as American buffalo is a species native to the United States and Canada. As suggested by the pile of bison skulls in the above figure, bison were exploited to the brink of extinction during the

19th Century. Bison were hunted for their skins to make leather, and bison bones were used in refining sugar and in the production of fine bone-china.

Tens of millions of bison, comprising several sub-species, roamed the Great Plains and Rocky Mountains prior to European colonisation. North American Indians were very dependent on bison. For example, Comanche Indians (using bow and arrow) were hunting ~ 280,000 bison per year in the 1830s – a figure considered to be sustainable (https://rarehistoricalphotos.com/bison-skulls-pile-used-fertilizer-1870/).

Using rifles, the US military purposefully decimated bison numbers to starve the Indian population. By 1884, only 325 bison remained and these were finally afforded protection. There are presently ~ 550,000 bison in North America, and hunting is restricted to one bison per licensed hunter per lifetime. With appropriate safeguards, such a rate of hunting is obviously sustainable since numbers of bison continue to grow.

In Australia, kangaroo culling (shooting) is also legal; however, landholders must obtain permits from the revenant government departments and a shooter must be accredited, licensed and operate closely with landholders . Since the early the 19th Century, European farming practices have substantially changed Australia's ecological balance.

? *How has European agriculture practices affected the numbers of large kangaroos across Australia? And how has it affected the very small kangaroos and related marsupials?*

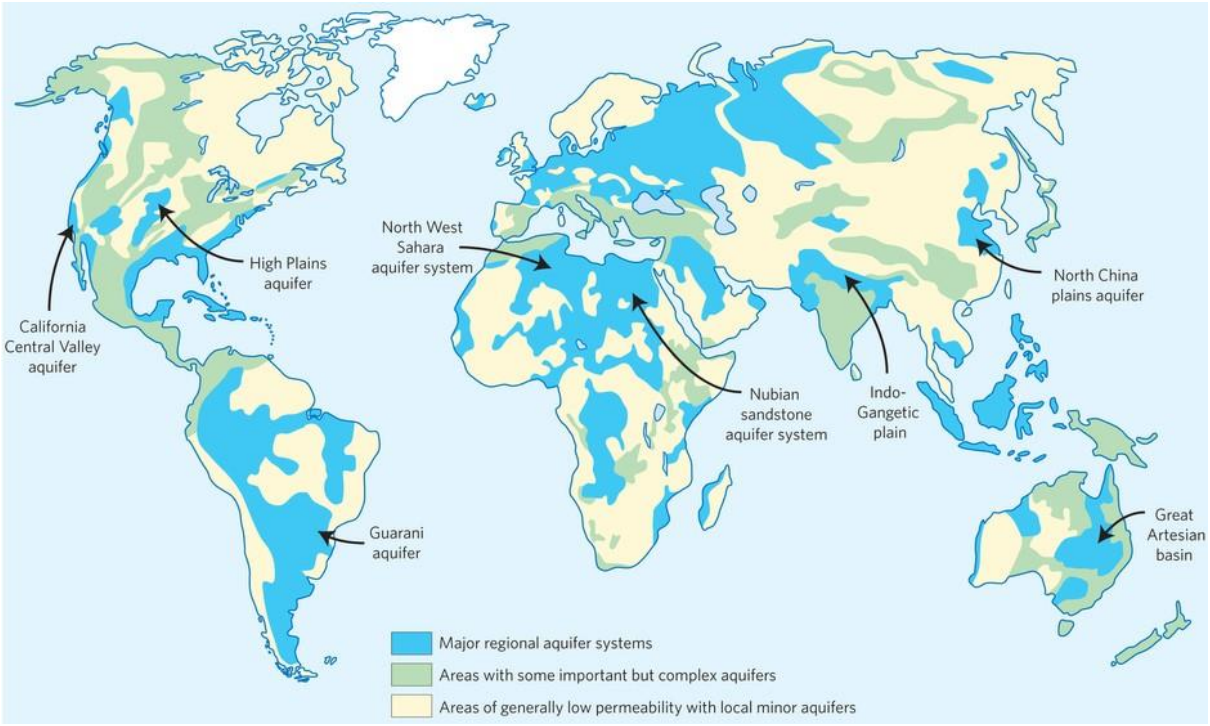
Should we be eating more of Australia's native animals to help create a more sustainable use of renewable resources? To provide an informed answer, consider factors such as erosion of the landscape by e.g. beef cattle versus kangaroos, and even wild (introduced) deer.

We often hear much about **sustainable agriculture**. Are we really talking about something that is truly sustainable, or are we reporting that the rate of degradation of the resource is slowing-down?

For agriculture to be truly sustainable it would be necessary to use either no conventional (non-renewable) fertiliser. Moreover, the renewable fertilisers would need to be spread onto the ground using 100% recycled vehicles running on renewable petrol (e.g. biofuels). Similarly, water used in sustainable agriculture would need to be sourced in such a way as to have no measurable impact on other parts of the ecosystem that require water.

? *Consider the production of bioethanol made from sugar cane, and biogas made via anaerobic digestion of human sewage, pig manure or municipal waste. Can bioethanol and biogas be considered a truly renewable resource?*

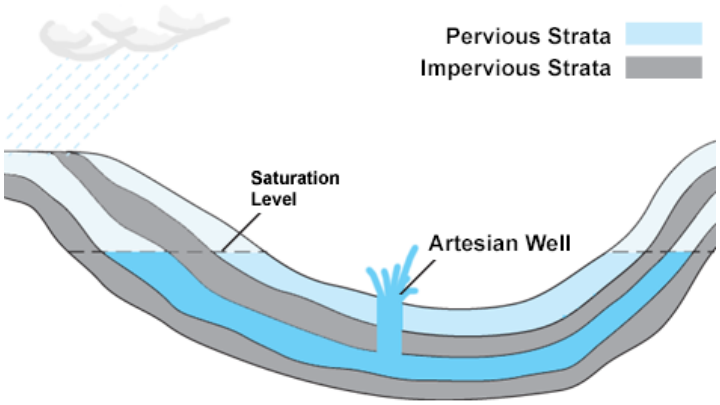
- **Investigate how the timescale required to replenish a large groundwater system, such as the Great Artesian Basin, is influenced by the rate of depletion of the system.**



Global groundwater resources (http://4.bp.blogspot.com/-i5Kg0_297bU/VkdjRB5zXaI/AAAAAAAABS0/PZwccVsViZc/s1600/global%2Bgroundwater%2Bresources.jpg)

Definitions:

- An **artesian basin** is a geological structure in which water is confined under pressure (https://en.oxforddictionaries.com/definition/artesian_basin).
- If a well-bore is drilled into a basin or other confining structure and water moves to the surface under its own hydrostatic pressure, the water is said to be **artesian**; an artesian aquifer is an aquifer whose potentiometric surface is above ground surface (i.e. water flows to the surface).



Schematic representation of the relationship between an artesian well and its relationship to water recharge areas in the highlands (https://simple.wikipedia.org/wiki/Great_Artesian_Basin)

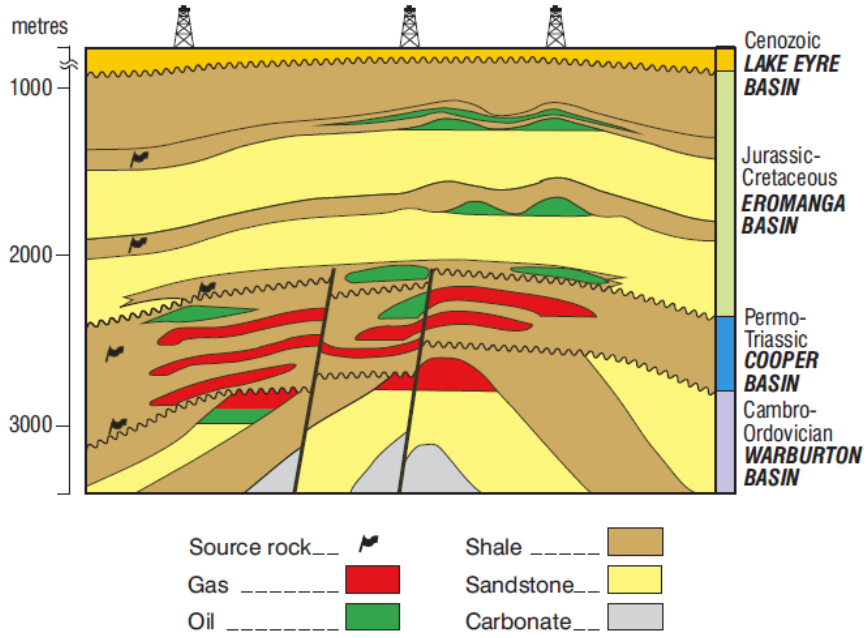
The Great Artesian Basin (GAB)

The **Great Artesian Basin** (GAB) covers 1.7 million km^2, 23% of mainland Australia. "Great Artesian Basin" is a hydrogeological term – geologists and in particular petroleum explorers use the term **Eromanga Basin**.

Some facts regarding the GAB:

- The total volume of water stored is ~65,000 million megalitres (6.5x10^{10} ML), sufficient to fill Sydney Harbour 130,000 times.
- Basin depth ranges up to 3000 metres.
- Maximum pressures in the deeper parts of the basin are ~1300 kPa.
- Average temperature of GAB water is around 30 – 60 °C, but can reach 100 °C in the deepest parts of the basin.

Sources: http://www.gabcc.gov.au/basin and https://theconversation.com/water-in-water-out-assessing-the-future-of-the-great-artesian-basin-13104

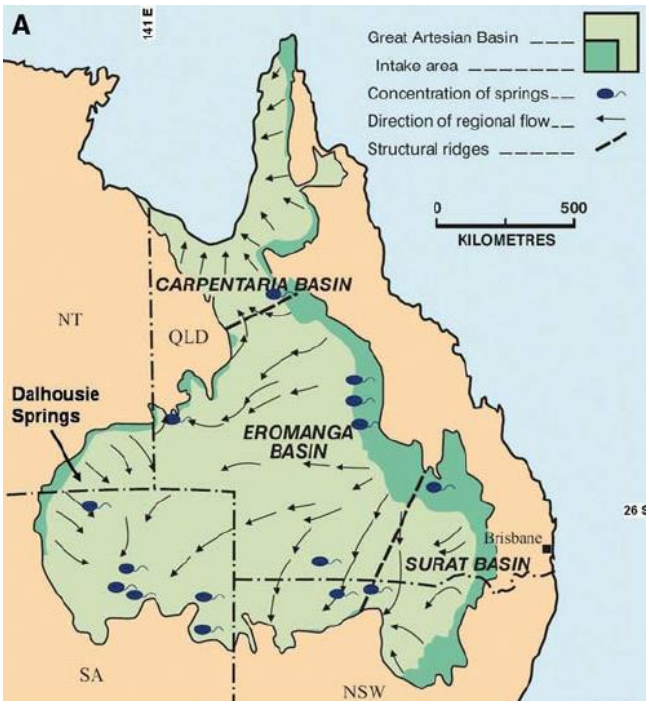


Schematic section showing typical petroleum (oil & gas) traps in the Cooper Basin (central Eromanga Basin) area. The Great Artesian Basin is equivalent to the two uppermost sandstone units coloured yellow (http://www.petroleum.statedevelopment.sa.gov.au/__data/assets/pdf_file/0009/257931/Eromanga_figures_6.pdf)

During the early 20th Century there was somewhat of a boom in water-bore drilling and production from the GAB. As early as 1912, there was an interstate conference to consider solutions to depleted flows from GAB water-bores – more than a century later over exploitation of the GAB continues.

Source: http://www.gabcc.gov.au/publications/pressure-heat-fact-sheet

Dalhousie Springs, is a natural artesian spring in northern South Australia (https://en.wikipedia.org/wiki/Dalhousie_Springs)



Extent of the GAB showing recharge areas in dark green and regional flow vectors as arrows. Many mound spring complexes such as Dalhousie Springs are sited on geological faults (https://www.researchgate.net/publication/235128597_Travertine_and_tufa_from_Dalhousie_Springs_Australia-_Implications_for_recognizing_Martian_springs/figures?lo=1)

Detailed studies have shown that some of the water in the GAB is as old as 2 million years. If this water was recharged in the uplands of Queensland (see figure above), and flowed SE to source the **mound springs** in South Australia, it would have travelled ~1200 km, meaning its flow rate is only about ~60 cm per year. It is difficult to know the precise rates of water inflow and outflow across the basin, which, for such a large system will vary considerably.

Many mound springs in South Australia, fed from the GAB, have stopped flowing, and the water-table has dropped. Therefore, out-flow since the early

20th Century must have been significantly greater than net inflow. It is likely to take many thousands, if not tens of thousands of years of natural recharge to repair over-exploited aquifers in the GAB.

As well as providing water for farming and pastoral leases the GAB suppliers water essential to exploration and mining activities.

Adani Australia, a subsidiary of the Adani Group based in India, plans to excavate a coal mine of unprecedented scale in central Queensland. Please view the info-graphic on this project at https://theconversation.com/infographic-heres-exactly-what-adanis-carmichael-mine-means-for-queensland-87684?utm_medium=email&utm_campaign=The%20Weekend%20Conversation%20-%2088727432%20copy&utm_content=The%20Weekend%20Conversation%20-%2088727432%20copy+CID_a7a904927b9bf88180d068f2819b1940&utm_source=campaign_monitor&utm_term=Infographic%20heres%20exactly%20what%20Adanis%20Carmichael%20mine%20means%20for%20Queensland.

If the project goes ahead, the Adani Carmichael mine complex will:

- stretch for 50 km in length,
- comprise 6 open-pits and 5 underground mines,
- incorporate an onsite processing plant and 189 km rail connection, and
- via a Queensland government license, be allowed to extract unlimited volumes of water from the Great Artesian Basin for at least 60 years.

It is forecast that the Carmichael project will use 12,000 ML of water each year from the GAB – the volume is even greater than the 10,000 ML of water currently extracted by BHP's Olympic Dam mine in South Australia.

Note: 12,000 ML per year is the equivalent of 13 Olympic swimming pools per day (https://theconversation.com/why-does-the-carmichael-coal-mine-need-to-use-so-much-water-75923)

As well as supplying potable water for human consumption, the Great Artesian Basin supports A$12.8 billion of economic activity. This will be jeopardized if the GAB continues to be overexploited.

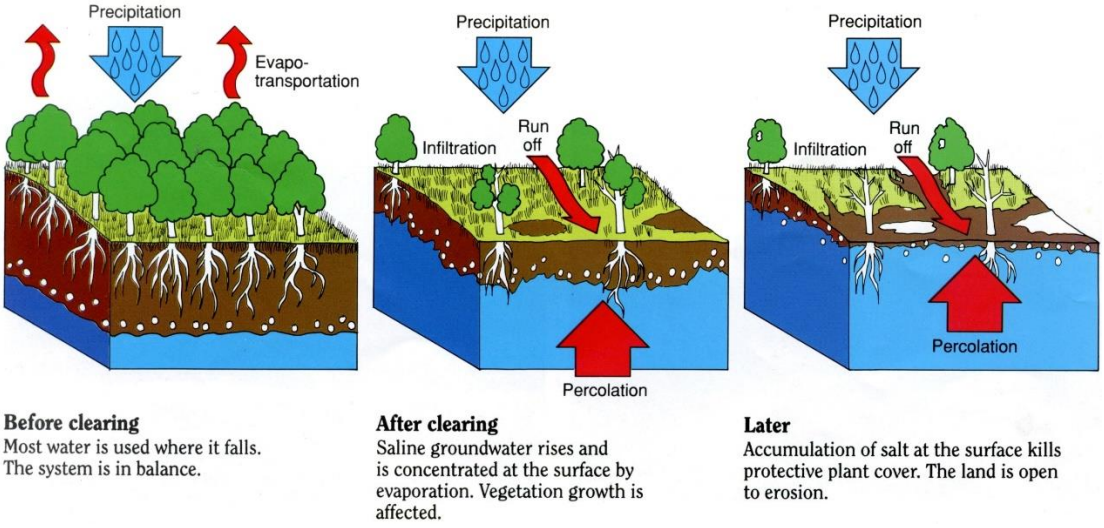
- **Discuss the sustainability of soil and water at local, regional, and global scales.**

As an introduction to this subtopic, please view the short video (3:25) on land and water management issues in Australia at
https://www.youtube.com/watch?v=QBCUazd5fe8

Dryland salinity is one of the major issues facing the sustainability of soil and water in Australia.

Salt affected valley floor near Ongerup in the SW of Western Australia (https://www.agric.wa.gov.au/soil-salinity/dryland-salinity-western-australia)

The main cause of dryland salinity in areas that were in the past agriculturally fertile is deforestation. Prior to land-clearing, there is a natural balance between precipitation and evapotranspiration; however, after the clearing of deep-rooted trees, saline groundwater rises to the surface due to upward percolation. Build-up of salt at the surface as in the figure above of a photo near Ongerup in Western Australia causes the demise of grasses and short-rooted vegetation, eventually leaving the land salt-encrusted with low fertility.



Schematic diagram of changes to the distribution of salt in the landscape due to changes in land-use (http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_salinity_management_dryland)

For a more detailed explanation of "Soil Salinity in Australia", please view the video (5:48) at https://www.youtube.com/watch?v=P4pX5W_WwU4

In the video on "Soil Salinity in Australia" it is mentioned that houses that have been built to last 25 years are only surviving for two due to salt damp. How long do houses in Europe typically last for? What needs to be done to make housing in Australia a more environmentally friendly and sustainable?

As South Australian, we are very dependent on the River Murray; water from the Murray is used in viticulture and agriculture from where it flows into South Australia, to its mouth where it enters the Southern Ocean. Upstream soil salinity of areas that drain into the river, and heavy usage by NSW and Victoria of impacted negatively on the water quality in South Australia. The quality of the water available to Adelaide and SA's agricultural areas is much poorer than it was decades ago, and this has had significant social and economic ramifications, in addition to the obvious environmental problems.

Maintaining soil quality and the prevention of erosion is an especially difficult problem in South Australia. Learn more from the video (4:12) "The Story of Soil Conservation in SA" at https://www.youtube.com/watch?v=DsdpMCjCVSo

To learn more about the River Murray's salinity, please watch the short video on Salinity and the River Murray (2:32): https://www.youtube.com/watch?v=gi6r2lpGoBY

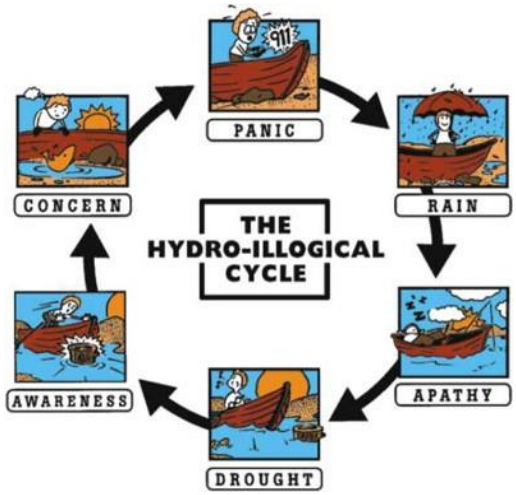
The following worksheet produced by the SA **Environmental Protection Authority** (EPA) provides an overview of dryland salinity in Australia and a number of research ideas that could be completed by students: www.epa.sa.gov.au/soe_2008/resources/education/dry_land_salinity.pdf

Water management: the hydro-illogical cycle

The **hydro-illogical cycle** is a useful concept in understanding how environmental management is often not a purely scientific issue. Rather, politics, people's perceptions and economic factors all have an important role to play in environmental management.

In Australia, our cycles of drought and flooding rains are a good illustration of the hydro-illogical cycle in action. Droughts typically take place over timescales of multiple years to decades, meaning the effects of drought are often not instant, but rather creep up over multiple years. Action to deal with the consequences of drought – for example cities running out of water and loss of agricultural production – tend to be reactionary as a result. While the times are good and water is plentiful, little action is taken to protect against the effects of drought, such as increasing water storage and managing water resources more effectively. This means that when the water begins to run out, panic sets in and rapid and drastic measures have to be taken to ensure there is enough water to go around, such as water restrictions. When the drought

breaks and water is again plentiful, people and politicians quickly forget about the effects of drought, meaning little action is taken to guard against the next drought and so the cycle begins again.



Hydro-illogical cycle (http://drought.unl.edu/portals/0/user_image/cycle.jpg)

The hydro-illogical cycle is especially prevalent in Australia, where we seem to be forever cycling between "drought and flooding rain". The hydro-illogical cycle is expensive – both ecologically and economically. Learn more on the hydro-illogical cycle at http://www.gbra.org/wheel8.swf.

Does the hydro-illogical cycle occur in Australia? Try to think of some examples. How can this cycle be broken? What are the usual political responses to the cycle?

Read: Breaking the Hydro-Illogical Cycle: Changing the Paradigm for Drought Management: http://www.agriskmanagementforum.org/content/drought-risk-reduction-changing-paradigm-drought-management.

The availability and quality of fresh water can be influenced by human activities, and natural processes at local and regional scales

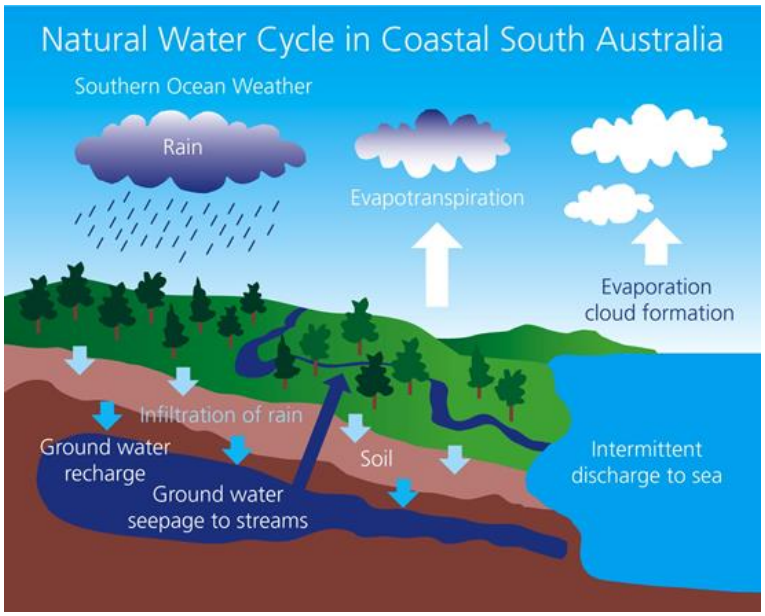
Earth's water cycle

For an introductory overview of Earth's water cycle view the video (6:47) at https://www.youtube.com/watch?v=al-do-HGuIk

The water cycle describes how water moves between the hydrosphere, the atmosphere, how it is used in the biosphere and moves into and out of the geosphere. This is an extremely complex process which needs to be very much simplified in these course notes.

In a natural system, water evaporates from the sea and land to enter the atmosphere as water vapour. Soon after, this vapour forms clouds. As the water vapour in clouds cools and condenses, precipitation (rain, snow, hail etc.) forms and falls onto the land. This precipitated water then either runs off the land as surface water via streams and rivers into the sea or infiltrates into the ground.

In a natural system, generally more water will infiltrate the ground than runs-off into the sea. Infiltrated water ends-up filling the pore spaces and fractures in soil and rock, becoming groundwater. Groundwater moves at a much slower rate than surface water but will, generally, make its way back to the sea over timescales that could range from decades to centuries or even millennia.



Natural water-cycle in South Australia (http://www.epa.sa.gov.au/files/7489_natural_water_cycle.jpg)

- **Discuss how storm-water run-off in urban areas may be recycled for community use so that it is not wasted and does not pollute waterways**

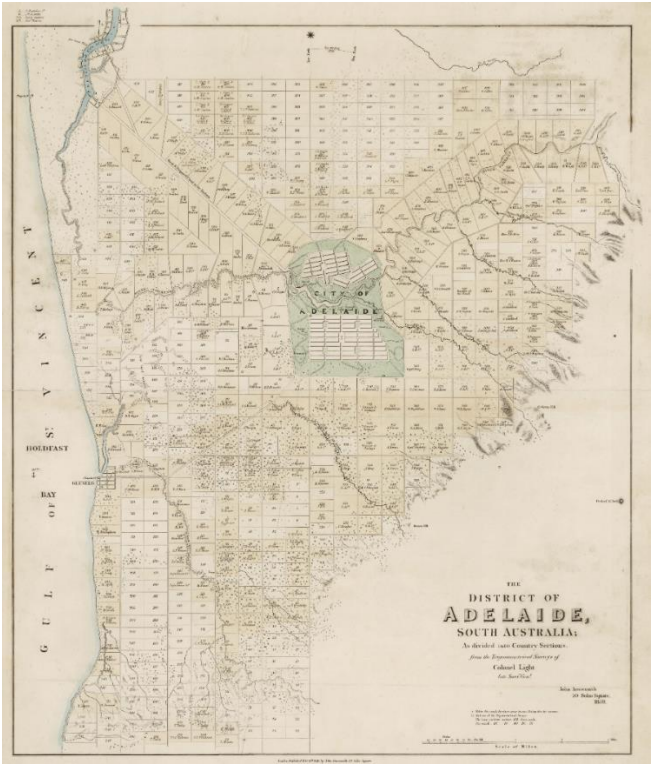
Urbanisation

Adelaide, the capital of South Australia has undergone significant changes since South Australia was proclaimed a British colony in 1836. Prior to settlement, the Adelaide Plains consisted of open, grassy areas, with a significant covering of trees.

View over the Glenelg Plains, looking approximately from present-day Glenelg towards Mount Lofty, South Australia by John M. Skipper 1837. http://nla.gov.au/nla.obj-135277269/view

Consider how the landscape of the Adelaide Plains has changed between 1837 and today. What changes have occurred that affect the natural water cycle?

Importantly, large areas of the plains were covered with wetlands, swamps and marshes. Consider the historic map of Adelaide in the figure below. It was, produced in 1837, only a few years after the colony of South Australia was proclaimed.



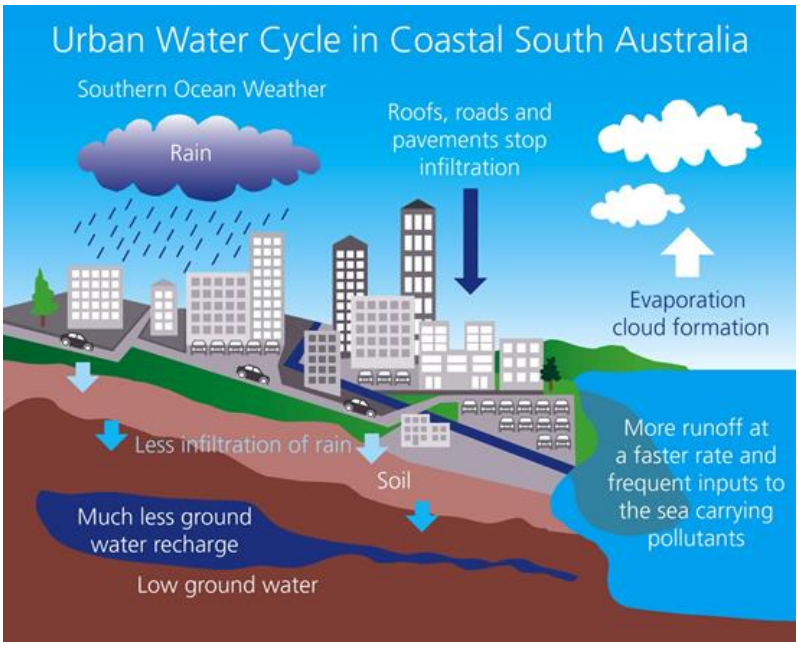
Cadastral map (1839) of the district of Adelaide produced by the late Surveyor-General John Arrowsmith. The map shows how the district was divided into county sections based on Colonel Light's trigonometrical surveys. It was produced only three years after European settlement and the proclamation of South Australia as a British province, well before major development on the plains beyond the City of Adelaide proper (http://nla.gov.au/nla.obj-231421265/view)

Critically study the creeks and rivers shown in the historic map – do they connect with the sea? If not, where did the water go after it rained?

In Adelaide prior to settlement, there was little direct connection between watercourses and Gulf St Vincent. *Most water was intercepted by extensive systems of wetlands, bogs and marshes*, allowing most of the water to infiltrate into the ground. Water that did escape to the sea would have been of a high quality (i.e. it was filtered of suspended solids) after passing through these wetlands the aforementioned wetlands.

There are very few pristine features that remain of pre-1837 Adelaide. What does remain is the odd large and gnarly eucalypt – but little else. This natural Adelaide Plains has been replaced by a city of 1.3 million people. Such **urbanisation** has drastically altered the local water cycle.

Urbanisation leads to an increase in surfaces such as rooves, driveways, roads, footpaths and carparks. These hard surfaces do not allow much water to seep into the ground. Consequently, large quantities of water flow directly into drains, which in turn flow into creeks and rivers, and eventually into the sea. This runoff is referred to as **storm-water**. The figure below highlight important elements of the **urban water cycle.**



The urban water-cycle (http://www.epa.sa.gov.au/files/7492_urban_water_cycle.jpg)

Compare this water cycle to the natural water-cycle. How long would it take water to drain back into the sea after falling on the land in an urban environment compared to a 'natural' or rural environment?

The image below is a recent oblique aerial photo of Adelaide, looking from the outlet of the River Torrens towards the Adelaide CBD, with the Mount Lofty Ranges in the background.

Major discharge of stormwater (dark water body of increased turbidity) from the River Torrens into Adelaide's coastal waters (Gulf St Vincent) on 25 October 2005. Photo by S. Bryars. (https://www.researchgate.net/profile/Jochen_Kaempf/publication/261174132/figure/fig7/AS:296908095541255@1447799814673/Fig-7-Major-discharge-of-stormwater-from-the-Torrens-River-into-Adelaide%27s-coastal.png)

Compare and contrast the historic map and painting from the 1830s with the above image. How has the landscape changed? How have these changes impacted the water cycle? Consider the amount of concrete and hard surfaces now present. This photo was taken after a heavy rainfall event and shows

River Torrens discharging highly turbid (dark and murky) stormwater into Gulf St Vincent.

Note the contrast in colour between the clear seawater in the foreground of the image, and the turbid river water closer to the beach. Prior to settlement, would it have been possible for this discharge to occur? What effects could this water have on photosynthetic organisms such as seagrass and coral which grow in relatively shallow water close to the shore?

Stormwater pollution

Please watch the video "An Introduction to Urban Stormwater Pollution" at https://www.youtube.com/watch?v=X5T1815YPG8

Stormwater catchments, the area of land over which stormwater is collected, is often very diverse, potentially covering both urban and rural areas. The type of catchment from which water is collected has a strong influence on the quality of that water. The **heterogeneous** nature of stormwater catchments means that the range of pollutants found in this water also tend to be highly diverse and change over time. Typical stormwater pollutants include:

- metals such as copper, zinc and lead, along with oil and grease from road surfaces,
- nutrients such as nitrate and phosphate from fertilisers and animal wastes,
- pathogens from animal faeces and sewer contamination (sometimes sewers that carry human waste leak),
- rubbish (bottles, cans plastics) and plant materials such as leaves, and
- sediments such as sand and silt.

Impact of stormwater pollution on seagrass communities, Gulf St Vincent

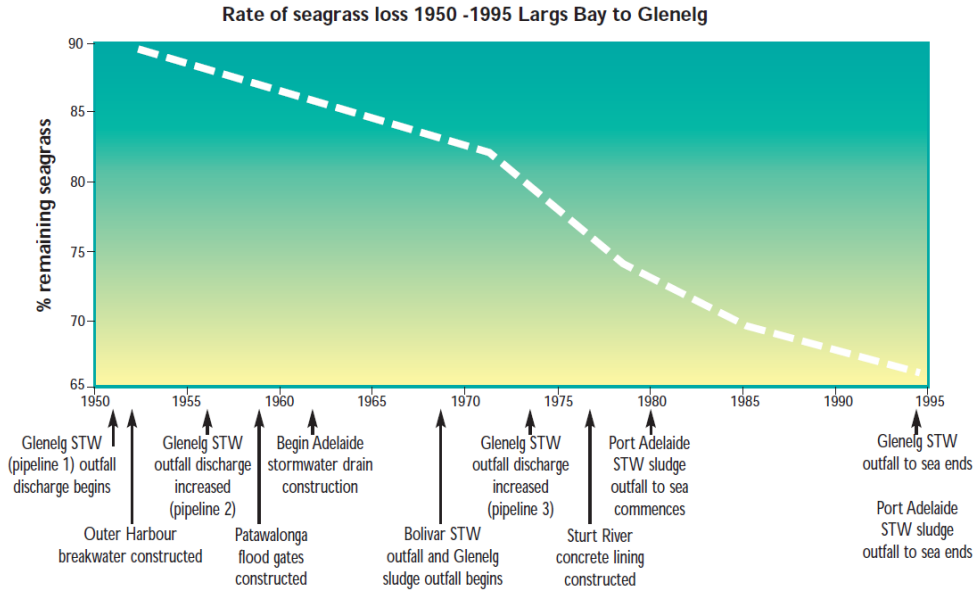
The **Adelaide Coastal Waters Study** (ACWS), spearheaded by the SA EPA and Flinders University, produced a coastal water quality improvement plan in 2013, after more than a decade of intensive research. One of the primary motivations for undertaking this major study was the significant loss of seagrass communities along the Adelaide coast.

Seagrasses are **angiosperms** (flowering plants) which form colonies referred to as **underwater meadows**, in both coastal and marine environments. Seagrasses baffle the energy of waves as they approach the coast, thereby helping to reduce beach erosion and also provide valuable, indeed essential habitat for a variety of marine animals.

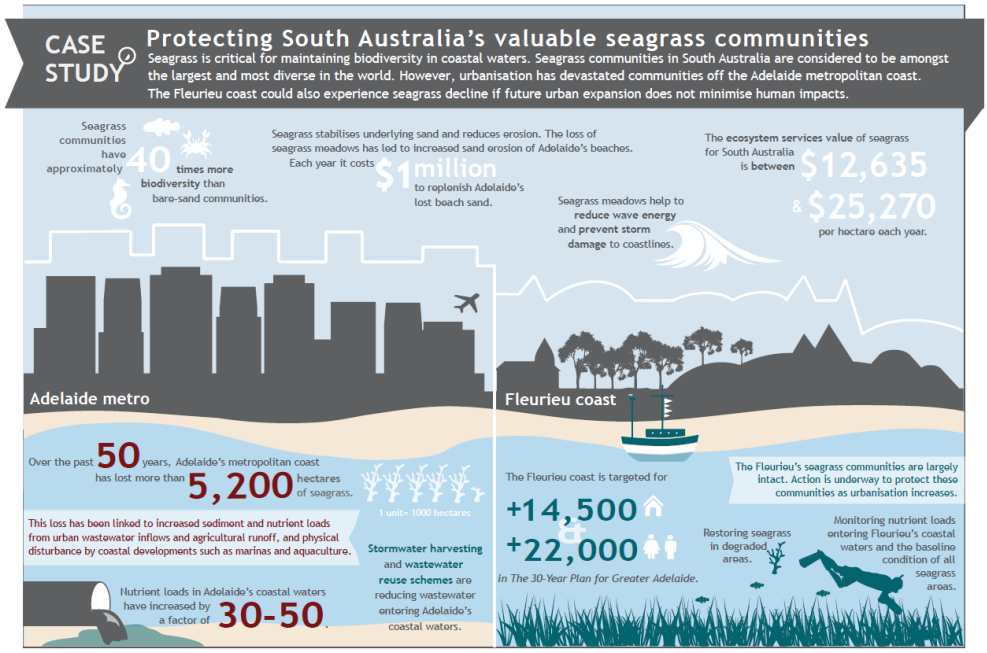
A seagrass meadow about to flower, offshore Adelaide
http://www.epa.sa.gov.au/files/11736_seagrass_mar_2016.medium.jpg

Since European settlement on the Adelaide Plains, more than ~5000 hectares of seagrass (the equivalent to the grassed area of ~3000 Adelaide Ovals) has been lost from the Adelaide coastal zone. The destruction of seagrass meadows and associated ecosystems can be directly attributed to the input of nutrient-rich, turbid and coloured water from stormwater and wastewater discharges.

The graph in the figure bellow shows how the reduction of seagrass meadows over time correlates with the introduction of various stormwater and wastewater discharges.



Timeline of seagrass loss from Largs Bay to Glenelg in Adelaide's coastal waters.
(https://www.environment.sa.gov.au/files/sharedassets/public/coasts/seagrasses.pdf)

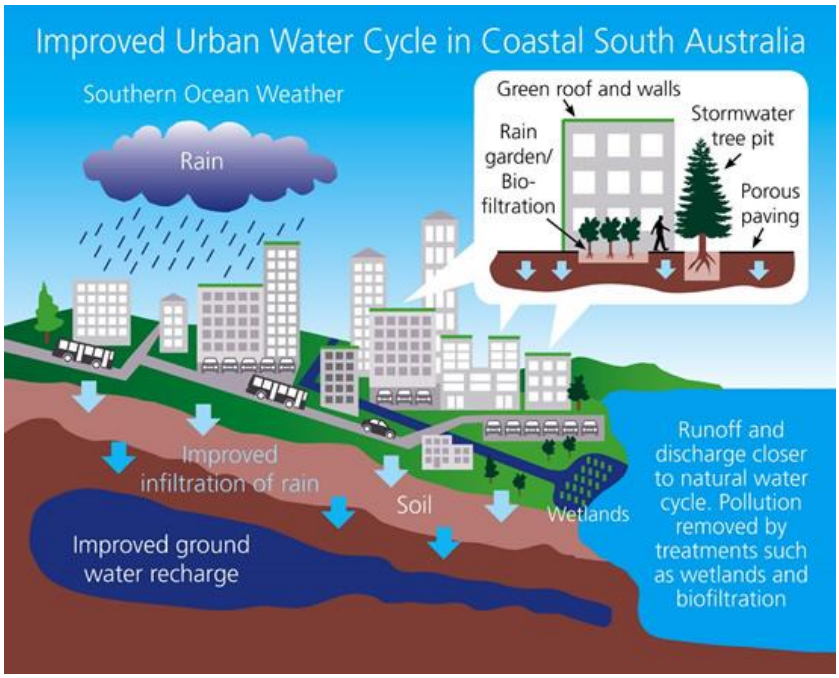


Schematic summary of the value of Adelaide's seagrass communities (http://www.naturalresources.sa.gov.au/adelaidemtloftyranges/about-us/our-regions-plan)

The ACWS delivered a number of important recommendations to help protect Adelaide's coast including action to reduce:

- stormwater and wastewater discharge into Gulf St Vincent,
- the amount of suspended solids within stormwater by 50%,
- inputs of nitrogen by 75%,
- the amount of coloured dissolved organic matter discharged from stormwater.

For these recommendations to become achievements, improvements to the urban water cycle are required. Consider the following figure that highlights elements of the improved urban water cycle in the Adelaide region.



Improved urban water-cycle in coastal South Australia
(http://www.epa.sa.gov.au/files/7484_improved_urban_water_cycle.jpg)

What changes to the way we plan cities and urban areas to restore the water cycle to a more natural state? Where in the world have such changes been implemented (successfully or otherwise)?

Stormwater capture and reuse

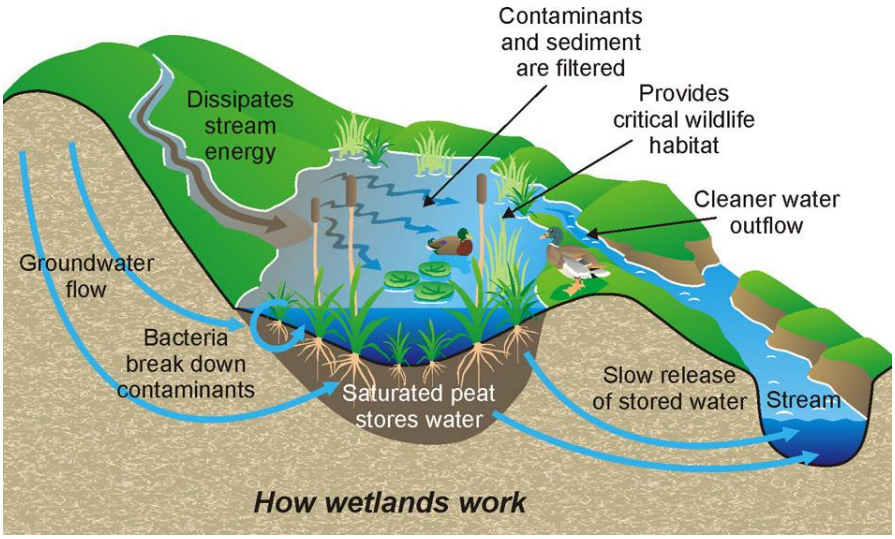
In the greater Adelaide region, an average of 86 GL (1 GL or gigalitre = 1 billion litres) per annum of stormwater discharges into the sea. The ACWS identified that up to 70% (60 GL) per annum of this discharge could be captured for reuse – that's equal to 150,000 Olympic-sized swimming pools worth of water per year!

Wetlands and water sensitive urban design

Urban wetlands and **water sensitive urban design** assist in improving the urban water cycle.

Please watch the extended video on the function of wetlands, water reuse and management in the City of Salisbury (15:06) at
https://www.youtube.com/watch?v=ToxhwoWEjjc

In Adelaide, e.g. the City of Salisbury, and many other cities around the globe, wetlands are being reinstated within urban environments. This enlightened urban planning policy recognises that wetlands filter water in a number of ways; through the physical trapping of debris, absorbing excess nutrients, reducing sediment discharge into creeks and rivers , and by assisting the purification of water with respect to some undesirable chemicals and microbes.



Schematic representation of natural water purification by wetlands (http://nmfarmgirl.umwblogs.org/files/2013/02/wetlands-purification-diagram.jpg)

Litter, especially plastics in waterways can be hazardous to wildlife and are foreign to the natural ecology. Wetlands can trap some, but not all of the unwanted debris within reed beds. The installation of rubbish traps (e.g. **trash racks**) to wetlands reduces the amount of physical debris moving through the waterway, thereby improving the water quality.

Trash racks capture rubbish transported in storm-water at the Urrbrae wetland in suburban Adelaide. http://www.mitchamcouncil.sa.gov.au/webdata/resources/images/DSCN2655.JPG

Excess nitrate and phosphates are a common pollution problem in South Australian waterways and are a major cause of often toxic, algal (**cyanobacterial**) blooms. The stormwater system and water runoff introduces pollutants such as leaves, debris, **fertilisers**, **herbicides**, **detergents** and animal faeces to the waterways, increasing the amount of nutrients in the water.

When wetlands are incorporated into the urban infrastructure, the chances of algal blooms are reduced because plants in and surrounding the waterbodies

absorb excess nutrients from the water and soil. Moreover, within wetlands, sediment particles are able to settle and accumulate as sedimentary substrate. When water flows are slowed within wetlands, sediments that accumulate help trap pollutants such as heavy metals and chemicals, that become part of the silty/clayey sediments.

The Sun's UV rays are effective in killing bacteria in waterways, but only where the water is clear and is less than one metre deep.

The following table lists typical removal efficiencies for various pollutants in artificial wetlands.

Table 13.1 Typical Annual Pollutant Load Removal Efficiencies for Constructed Wetlands

Pollutant	Expected Removal	Comments
Litter	> 95 %	Subject to appropriate hydrologic control
Total suspended solids	65-95 %	Depends on particle size distribution
Total nitrogen	40-80%	Depends on speciation and detention time
Total phosphorus	60-85 %	Depends on speciation and particle size distribution
Coarse sediment	> 95%	Subject to appropriate hydrologic control
Heavy metals	55-95%	Quite variable, dependent on particle size distribution, detention time etc

Source: Department of Environment WA (2004)

Source: https://www.sa.gov.au/topics/planning-and-property/land-and-property-development/planning-professionals/water-sensitive-urban-design

In addition to wetlands, **water sensitive urban design** and **rain gardens** have the potential to be integrated into urban water management strategies. Rain gardens are constructed gardens designed to capture and treat stormwater runoff from hard surfaces. The stormwater is diverted through the garden and pollutants are removed through sedimentation, binding to components in filter media and through the action of specially selected plants and their associated microbial communities. They can be scaled to match the catchment. After treatment by the raingarden, stormwater can be captured for reuse or allowed to re-enter the stormwater system.

Additional information on rain gardens is provided at http://www.epa.sa.gov.au/environmental_info/water_quality/programs/rain-garden-500.

Established bio-filtration rain garden beds at Linde Reserve, Stepney

Rain garden bio-filtration system, prior to planting, City Of West Torrens

Tree pit bio-filtration system, Beechway Ave, Brooklyn Park

Examples of different types of rain garden (http://www.epa.sa.gov.au/files/10792_raingarden_info.pdf)

Vegetated swale; an example of water-sensitive urban design (http://www.naturalresources.sa.gov.au/files/sharedassets/adelaide_and_mt_lofty_ranges/images/water/vegetated-swale-underdale-gen.jpg)

Managed aquifer recharge

Managed aquifer recharge (MAR) refers to the process whereby water, such as stormwater or wastewater, is captured and injected into underground aquifers. MAR allows excess water to be captured during wet months, stored underground helping to replenish otherwise depleted aquifers, and then be re-extracted during dry months.

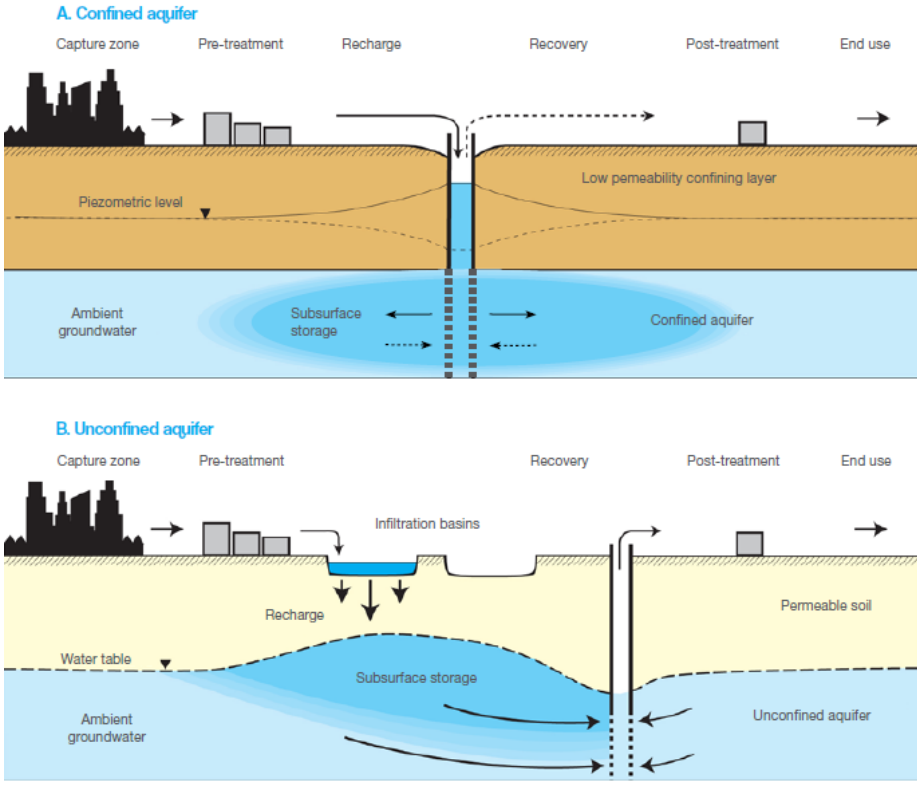
In Adelaide, this technique is successfully used by a number of local councils as a water management technique, enabling them to utilise the stormwater resource that falls in their urban and rural catchments, to reduce their community's reliance on mains ultimately sourced from reservoirs in the Mt Lofty Ranges or the River Murray.

The City of Marion recently installed wetlands and engineered a MAR facility at Oaklands Park: (3:17); for more information visit the videos at

https://www.youtube.com/watch?v=vRA5oU09Lwk and
https://www.youtube.com/watch?v=RMHJEsNUoHE

MAR is often used in conjunction with wetlands. The water is first treated in the wetland, removing excess sediments, nutrients and pollutants before being injected underground. If the water is not treated prior to injection, there is a risk that the suspended sediments in the water could clog the pore spaces in the aquifer, preventing water from moving through it. In the worst case scenario this could permanently damage the **permeability** of the aquifer.

The following figure shows two common techniques used in MAR with respect to **confined** or **unconfined aquifers**.



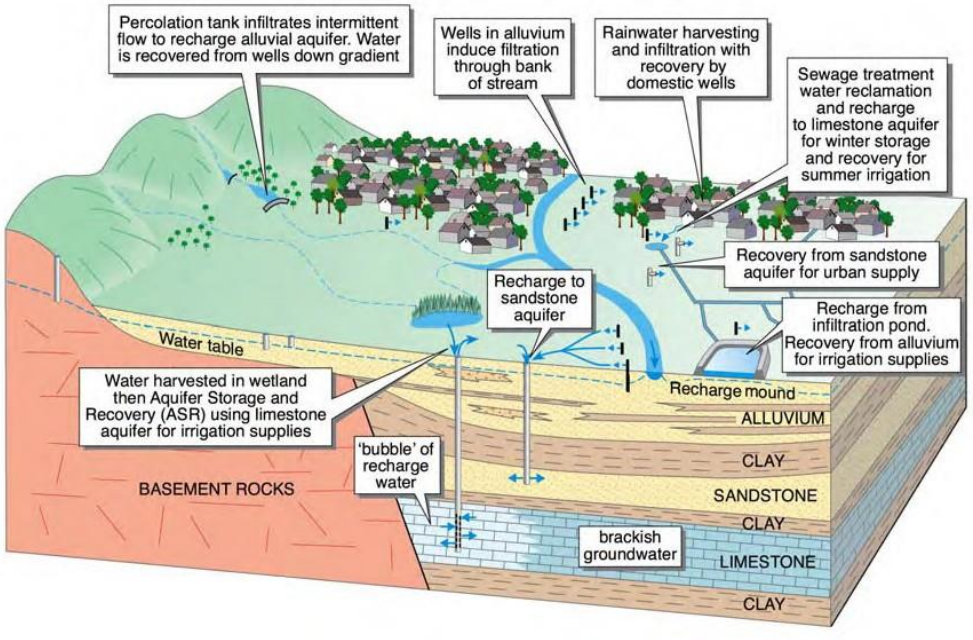
Techniques used in MAR
(http://groundwater.com.au/media/W1siZiIsIjIwMTQvMDkvMDQvMDRfNDFfMThfMzBfR3JvdW5kd2F0ZXJfaW5fQXVzdHJhbGlhX0ZJTkFMX2Zvcl93ZWIucGRmIl1d/Groundwater%20in%20Australia_FINAL%20for%20web.pdf p 31)

The first technique (A) is commonly used in Adelaide. This is because the aquifers suitable for MAR are located deep underground, beneath multiple layers of clay and rock which prevent the downwards movement of water from the surface. These aquifers are said to be confined. A well (water bore) is sunk into the target aquifer and water is pumped, under pressure, into the aquifer. This forms a 'bubble' of injected water to form within the aquifer. When it is deemed that water is needed at the surface, the same bore is used to pump water from the aquifer back to the surface.

When groundwater is located closer to the surface, and the soils have a high **permeability**, technique B can be used. Here, water is collected in an 'injection basin' which gives the water sufficient time to soak into the ground. The water can then be pumped out via a shallow well for reuse at the surface.

Technique B, the recovery of water from an unconfined aquifer, has been used since the 1960s in the Burdekin Delta, Queensland.

There are many other methods used to achieve MAR, as outlined in the figure below.



MAR is adapted to the local situation, and is usually governed by the type of aquifer, topography, land use and intended uses of the recovered water. This diagram shows a variety of recharge methods and water sources making use of several different aquifers for storage and treatment with recovery for a variety of uses. An understanding of the hydrogeology of the locale is fundamental to determining options available and the technical feasibility of MAR projects. Recharge shown here occurs via wells, percolation tanks and infiltration basins. (Adapted from Gale 2005, with permission)
(https://www.researchgate.net/publication/304620744_Managed_aquifer_recharge_an_introduction_Waterlines_Report_Series_no_13_February_2009_National_Water_Commisssion_Canberra)

Additional resources

Understanding stormwater:
http://www.epa.sa.gov.au/environmental_info/water_quality/programs/stormwater/understanding_stormwater

Stormwater pollution prevention:
http://www.epa.sa.gov.au/environmental_info/water_quality/programs/stormwater/pollution_prevention_for_business_activities

Further information on Adelaide's coastal waters:
http://www.epa.sa.gov.au/environmental_info/water_quality/programs/adelaide_coastal_waters

Importance of Adelaide's wetlands:
http://www.epa.sa.gov.au/environmental_info/water_quality/programs/wetlands

Technical manual for water-sensitive urban design in Greater Adelaide:
https://www.sa.gov.au/topics/planning-and-property/land-and-property-development/planning-professionals/water-sensitive-urban-design

Strategic plan for region, including detailed information on seagrass communities in SA: http://www.naturalresources.sa.gov.au/adelaidemtloftyranges/about-us/our-regions-plan

MAR: https://www.environment.sa.gov.au/managing-natural-resources/water-use/water-resources/stormwater/managed-aquifer-recharge

Scales of MAR: https://www.environment.sa.gov.au/managing-natural-resources/water-use/water-resources/stormwater/managed-aquifer-recharge/mar-scales

- **Explain how over-extraction of groundwater from near-coastal aquifers may cause inflow of sea water**

What is groundwater?

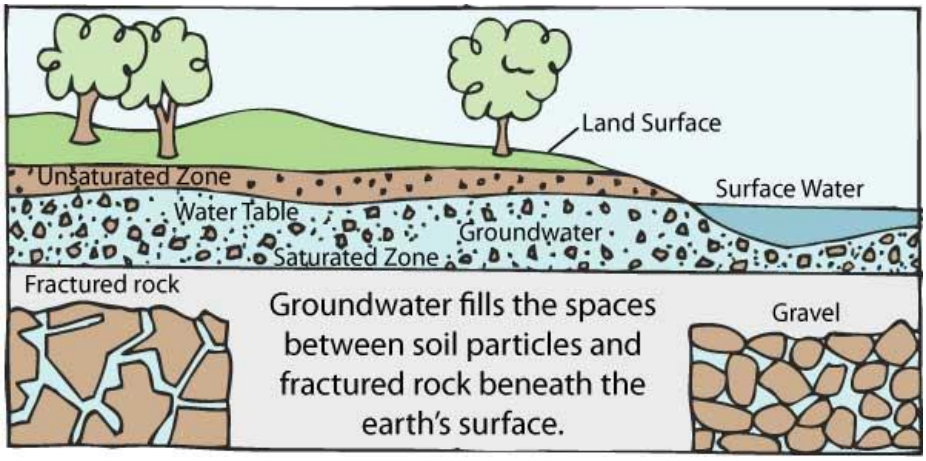
Please watch the short video (3:29) that introduces the concept of **groundwater** at https://www.youtube.com/watch?v=2dshTDiYpLA

Another video (5:45) deals specifically with the Adelaide region's groundwater resources, including MAR can be accessed at https://www.youtube.com/watch?v=Z2HQY5A3o-s

It is often thought that groundwater exists as underground streams of water: This is very rarely the case. Rather, groundwater refers to the water that fills and saturates tiny pore spaces in soils, gravels, rock and rock fractures beneath Earth's surface. There are two primary sources of groundwater:

- Water that infiltrates the ground after rainfall, and
- Rivers and streams that drain or leak into the ground.

An **aquifer** is an underground geological unit which is capable of **storing** and **transmitting** groundwater. Aquifers vary greatly in terms of their composition, the quality and quantity of water they can transmit and their connectivity with other aquifers, surface streams, lakes and the ocean.



Basic schematic of the modes of occurrence of groundwater (http://www.groundwater.org/get-informed/basics/groundwater.html)

Groundwater is a vital source of fresh water: Globally, groundwater represents about 98% of available fresh water – 60 times as much as that found on Earth's surface in creeks, rivers and lakes. There are many regions in Australia, particularly arid areas, that depend on groundwater as the only reliable source of water.

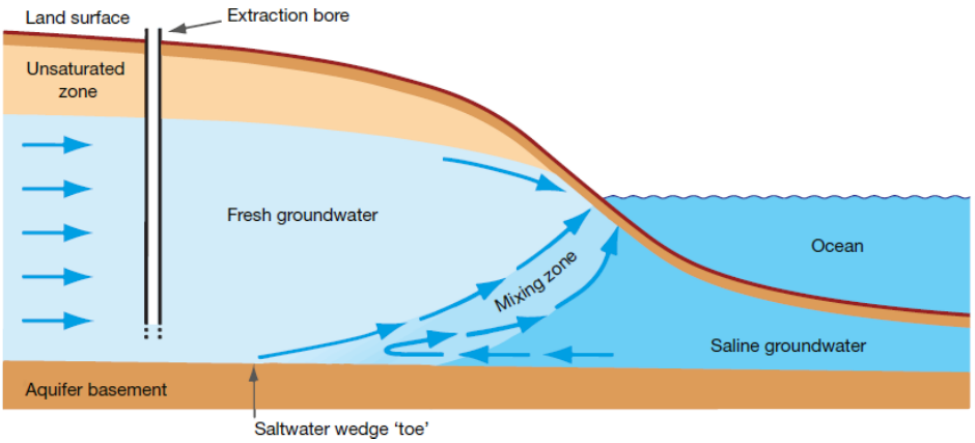
Groundwater is a finite resource. If water is taken out of an aquifer faster than it is replaced, it is possible for the aquifer to run out of usable water. In some instances, over extraction of water from an aquifer can cause permanent damage to that system.

A large proportion of Australia's population lives close to the sea in coastal areas. Consequently, a particularly high demand is placed on coastal groundwater aquifers.

The figure below, shows a schematic representation of a simplified conceptual model of seawater intrusion into a coastal aquifer. In the model, the groundwater aquifer extends under the ocean surface and becomes increasingly saline as it extends offshore; the water transitions from low salinity fresh groundwater to saline groundwater. The saline groundwater extends inland as a 'wedge', beneath the fresh groundwater – a mixing zone has formed between the two.

Question: Why does less saline water 'sit' above more saline water and why might the saline groundwater extend inland as a wedge at the bottom of the aquifer?

Answer: Water of higher salinity is denser as it contains more dissolved salts. Therefore, denser fluids sit at the bottom of the aquifer. This difference in density also creates a difference in ***hydraulic head****, causing the more saline water to 'push' inland.*



Simplified conceptual model of seawater intrusion into a coastal aquifer (http://groundwater.com.au/media/W1siZiIsIjIwMTQvMDkvMDQvMDRfNDFfMThfMzBfR3JvdW5kd2F0ZXJfaW5fQXVzdHJhbGlhX0ZJTkFMX2Zvcl93ZWIucGRmIl1d/Groundwater%20in%20Australia_FINAL%20for%20web.pdf)

The groundwater model described in the figure is realistic – in a natural system, equilibrium is reached between fresh and saline groundwater, with the 'toe' of the wedge remaining in a reasonably fixed position.

If the amount (pressure) of freshwater within a coastal aquifer changes, this can potentially alter the position of the wedge's toe. When the toe of the wedge is drawn inland, this is referred to as **saltwater intrusion**. Saltwater intrusions occur when there has been over extraction of fresh groundwater in coastal areas.

List the types of human induced (anthropogenic) changes that could impact the amount of freshwater within a coastal aquifer. Think about the mechanisms that allow water to enter and exit the aquifer. Consider urbanisation, water use (pumping) and changes in rainfall (climate change).

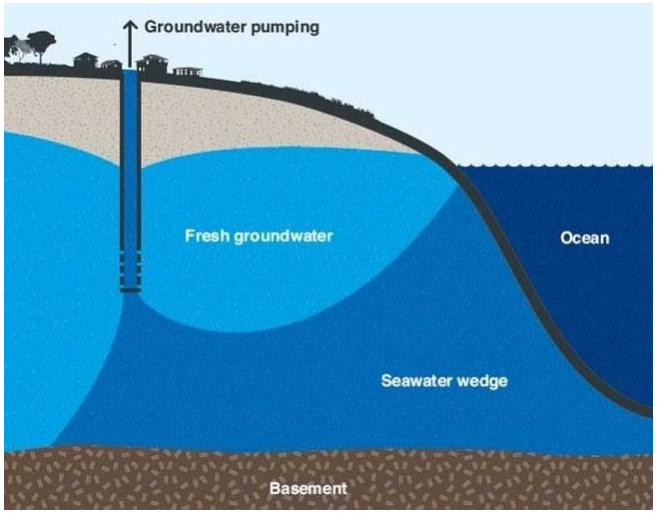
Please watch another video (7:12) concerning current resource condition of groundwater in the Adelaide region at https://www.youtube.com/watch?v=yHGo9xDYFRY

One of the primary causes of saltwater intrusion in coastal aquifers is pumping. Cities, towns, industry and agriculture often utilise groundwater extracted from coastal aquifers. Saltwater intrusion can occur when the rate of water extraction from an aquifer is not matched by the amount of recharge into the aquifer. Unlike a rainwater tank or dam, coastal aquifers do not simply 'run dry' when all the water has been used-up. Rather, due to physical processes, more saline water is drawn into the aquifer to compensate for the water that has been pumped on the coastal plain.

The figure below illustrates the types of changes that can be expected within an aquifer where fresh groundwater has been pumped out at a faster rate than it could be replaced. Two important features are present:

Firstly, a **cone of depression** has formed around the pumping well. Like any fluid, groundwater flows from areas of high elevation and pressure to areas of low elevation and pressure. In **hydrogeology**, this combination of elevation and pressure is referred to as **hydraulic head**. *Groundwater will always flow from high hydraulic head to low hydraulic head*. Thus, for water to flow towards a well, the hydraulic head close to the well must be lowered. In an **unconfined aquifer**, this lowering of hydraulic head is observed as a cone of depression, i.e. the lowering of the water table proximal to the well.

Secondly, the **seawater wedge** has been drawn inland and towards the well due to lower (freshwater) hydraulic head where the groundwater enters the screened (lower) well.



Diagrammatic representation of seawater intrusion into a coastal aquifer as a result of pumping (http://www.groundwater.com.au/media/W1siZiIsIjIwMTQvMDYvMjMvMDNfMzlfMDhfMTNfU1dJX0ZpZ3VyZTIuanBnIl0sWyJwIiwidGh1bWIiLCI2NzB4Il0sWyJlIiwianBnIl1d/SWI-Figure2.jpg)

The other potential cause of seawater intrusion in coastal aquifers is a reduction in the amount of water recharging the aquifer. Urbanisation reduces the amount of water that can infiltrate into the ground, thereby reducing recharge. Climate change modelling suggests that average rainfall will be reduced in some parts of Australia, further reducing the groundwater recharge.

In totality, the combination of increased pumping, urbanisation and climate change is placing coastal aquifers under stress. The sustainable use of groundwater will be key in ensuring this important resource remains available for future generations.

? *Is the term "sustainable groundwater use" an oxymoron? Or put another way, is there such a thing as "sustainable use of groundwater"?*

Further resources concerning groundwater

What is groundwater?: http://groundwater.com.au/what-is-groundwater

Groundwater Essentials booklet (former National Water Commission): http://webarchive.nla.gov.au/gov/20160311095403/http://archive.nwc.gov.au/library/topic/groundwater/groundwater-essentials

Groundwater in Australia (National Centre for Groundwater research and Training, Flinders University): http://groundwater.com.au/media/W1siZiIsIjIwMTQvMDkvMDQvMDRfNDFfMThfMzBfR3JvdW5kd2F0ZXJfaW5fQXVzdHJhbGlhX0ZJTkFMX2Zvcl93ZWIucGRmIl1d/Groundwater%20in%20Australia_FINAL%20for%20web.pdf

- **Explain how pollution of groundwater can result from a variety of rural, urban, and industrial activities.**

Crop dusting in the Mid North of South Australia. Agricultural chemicals can drain off the land and end-up in water supply systems (http://ramblingsdc.net/Australia/OldPhotos/CropSpraying_3cs.jpg)

Sources and mechanisms of groundwater pollution

Please watch the following videos:

"Sources of Groundwater Contamination" (3:26) at https://www.youtube.com/watch?v=9-JBr76ITQA

"How pollutants enter groundwater" (4:35) at https://www.youtube.com/watch?v=5xs1jLlbztE

"Groundwater contamination in South Australia" (1:11) at
https://www.youtube.com/watch?v=GyaXbaPCS-Q

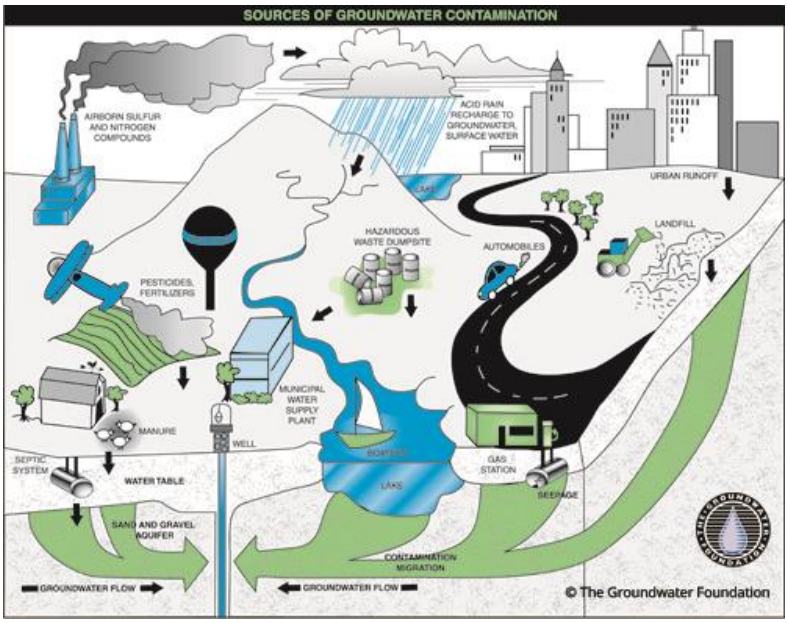
Groundwater is an integral part of the global water cycle. As water moves through the water cycle, it can collect contaminants along the way. Contamination may occur naturally within the groundwater system or may be introduced from external sources, particularly as a result of human activity (**anthropogenic contamination**).

Examples of anthropogenic contamination include:

- septic systems
- improper hazardous waste disposal
- underground storage tanks (especially for petroleum)
- landfills
- sewers and leaky pipes
- pesticides and fertilisers
- faulty or abandoned wells
- mining activities.

For further information on anthropogenic contamination visit
https://www.epa.gov/sites/production/files/2015-08/documents/mgwc-gwc1.pdf

The figure below identifies some of the primary routes of groundwater contamination.



Sources of groundwater contamination (http://www.groundwater.org/get-informed/groundwater/contamination.html)

Table 1 TYPICAL SOURCES OF POTENTIAL GROUND WATER CONTAMINATION BY LAND USE CATEGORY

Category	Contaminant Source	
Agriculture	Animal burial areas	Irrigation sites
	Animal feedlots	Manure spreading areas/pits
	Fertilizer storage/use	Pesticide storage/use
Commercial	Airports	Jewelry/metal plating
	Auto repair shops	Laundromats
	Boat yards	Medical institutions
	Construction areas	Paint shops
	Car washes	Photography establishments
	Cemeteries	Railroad tracks and yards
	Dry cleaners	Research laboratories
	Gas stations	Scrap and junkyards
	Golf courses	Storage tanks
Industrial	Asphalt plants	Petroleum production/storage
	Chemical manufacture/storage	Pipelines
	Electronics manufacture	Septage lagoons and sludge sites
	Electroplaters	Storage tanks
	Foundries/metal fabricators	Toxic and hazardous spills
	Machine/metalworking shops	Wells (operating/abandoned)
	Mining and mine drainage	Wood preserving facilities
Residential	Fuel oil	Septic systems, cesspools
	Furniture stripping/refinishing	Sewer lines
	Household hazardous products	Swimming pools (chemical storage)
	Household lawns	
Other	Hazardous waste landfills	Recycling/reduction facilities
	Municipal incinerators	Road deicing operations
	Municipal landfills	Road maintenance depots
	Municipal sewer lines	Storm water drains/basins
	Open burning sites	Transfer stations

Source: U.S. EPA, 1991a.

Typical sources of potential groundwater contamination (https://www.epa.gov/sites/production/files/2015-08/documents/mgwc-gwc1.pdf)

Additional resources

Sources of groundwater contamination: http://www.groundwater.org/get-informed/groundwater/contamination.html

Site contamination in SA: http://www.epa.sa.gov.au/environmental_info/site_contamination

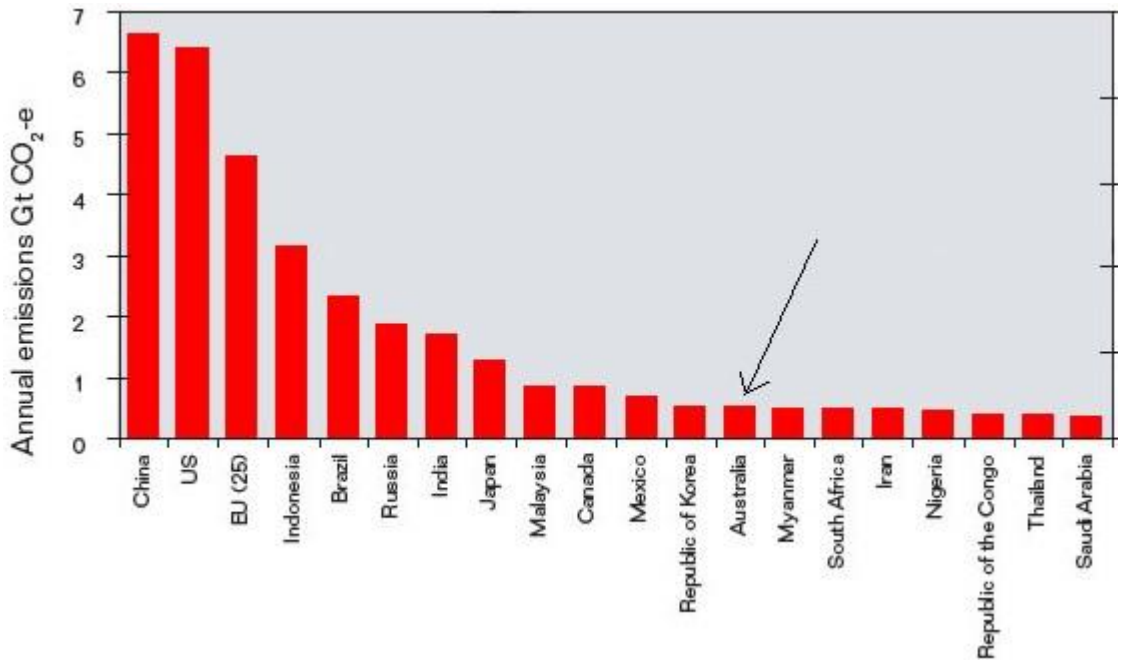
The effective use of energy resources is constrained by factors including waste disposal, and the efficiency of available technologies to collect, store, and transfer the energy

- **Compare the advantages and disadvantages of using renewable and non-renewable energy resources**

Non-renewable energy

Fossil fuels

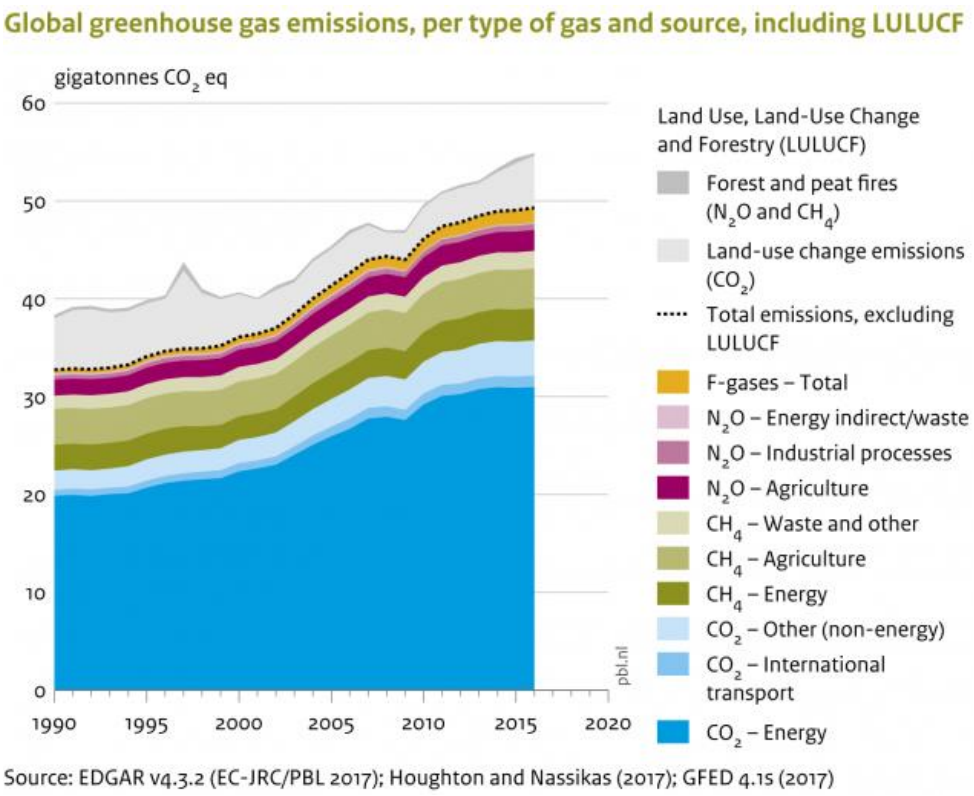
In this course we have already looked at non-renewable forms of energy, namely fossil fuels such as coal and gas. Unfortunately, fossil fuels produce greenhouse gases, and that we wish to avoid.



Total annual emissions of greenhouse gas emitters in 2006 (http://www.blueplanet.nsw.edu.au/cftc--australias-greenhouse-gas-emissions/.aspx). In 2006, Australia's emissions were the equivalent to 28 tonnes of CO_2 per person per year.

The data in the above figure indicate that Australia is a major producer of greenhouse gases. Indeed, given that Australia has a miniscule population compared to the top eight CO_2 emitters, the 2006 data suggest that per head of population Australia was the worst greenhouse gas emitter.

Are there more recent data available on the internet, and if so how has Australia performed in terms of CO_2 emissions between 2006 and more recently?



Total global greenhouse gas emissions between 1990 and 2016 (http://www.pbl.nl/en/infographic/global-greenhouse-gas-emissions-per-type-of-gas-and-source-including-lulucf). LULUCF = land use, land use change and forestry.

Carefully study the data in the above figure that shows how the world's annual (anthropogenic) greenhouse gases are derived. Which component(s) of the total CO_2 (equivalent) emissions are more sustainable than others?

Renewable energy

We have already discussed some forms of **renewable energy**. In summary these are:

- wind energy,
- solar energy,
- geothermal energy,
- tidal and wave energy, and
- biofuels (that combust to produce greenhouse gases)

With the exception of biofuels, once wind, solar, geothermal and tidal energy facilities are operational, they are almost free greenhouse gas free.

If there were no limitations and disadvantages to these alternative clean energy technologies, there would be little to stop mankind dispensing with the

burning of fossil fuels. We could immediately and rapidly phase-out greenhouse gas-producing non-renewable forms of energy (i.e. coal and gas-fired power plants), and power our cities and industries with 100% clean green energy. Clearly this is not the case – clearly there are logistic and socio-economic problems with alternative energy technologies.

Every day 73,000 TW (terrawatts) of solar energy shine upon Earth's surface – this is ~ 10,000 times society's daily global energy use (https://www.investopedia.com/articles/investing/053015/pros-and-cons-solar-energy.asp). However, we only capture a miniscule amount of that energy for conversion to electricity.

The "Electropedia" website at http://www.mpoweruk.com/electricity_demand.htm is a great resource for renewable energy technologies.

? Recycling solar panels

Solar panels are made from multiple materials, and although the cost of solar panels has decreased significantly over the last decade they are still expensive to produce. In topic 2 (Earth's Resources) we considered the element indium and how that was required to make PV panels.

Other than indium, what raw materials are required to make solar panels and which countries have the largest reserves of them?

Moreover, they are made from many valuable materials that ideally should be saved from landfill – for several reasons. Modern society already produces huge quantities of so-called e-waste that is expensive or impossible to recycle (figure below).

E-waste (http://www.webmediagear.com/world-news/e-waste-recycling-the-answer-to-your-home-electronic-waste/)

What recycling programs exist for PV panels. And how much energy is required to recycle their components? Is it presently cost-prohibitive to recycle solar panels?

Battery storage of electrical energy

Please watch the excellent ABC TV *Catalyst* video (28:52) on domestic battery storage in Australia at https://www.youtube.com/watch?v=yxABosWfuus.

In the video, the home owner Josh produces more electricity than he needs and therefore "pumps" it back into the grid.

Some facts about Josh's electricity:

- He earns 7 cents per kWh for all excess electricity he returns to the grid (when the Sun shines)
- At night, he buys electricity at 28 cents per kWh.
- 60% of Josh's electricity consumption is at night.
- He generates 67% more electricity than he needs.

The mathematics are such that, if the electricity company, paid Josh for the full value of the electricity his panels generate, he could actually make some money (a profit) from his electricity infrastructure.

However, the net effect is that although Josh produces more electricity than he consumes, he still has an electricity bill to pay. The electricity company wins twice – firstly from Josh and secondly from another consumer to whom Josh's electricity is sold to, almost certainly for the full 28 cents per kWh.

Adelaide's as the world's first carbon neutral city?

In the video it is mentioned that the City Council of Adelaide since 2015 has offered a $5000 rebate/subsidy scheme for solar panel installations. How will the Council recoup this money?

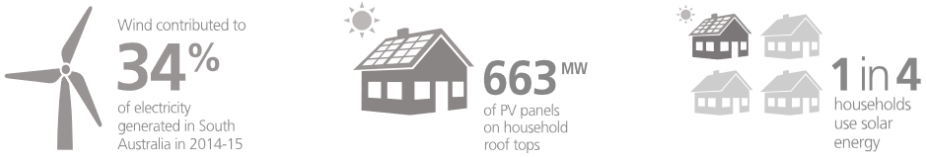
The Government of SA has a dedicated website for promoting ambitions to make Adelaide the world's first **carbon neutral** city at http://www.climatechange.sa.gov.au/carbon-neutral-adelaide. Don't forget to view the links accessible from this site.

Another interesting site to consider is that of Green Cross Australia at http://www.greencrossaustralia.org/bushfires/interactive-green-building-guide.aspx.

Is the government's goal of making Adelaide a carbon neutral city plausible? Justify your answer.

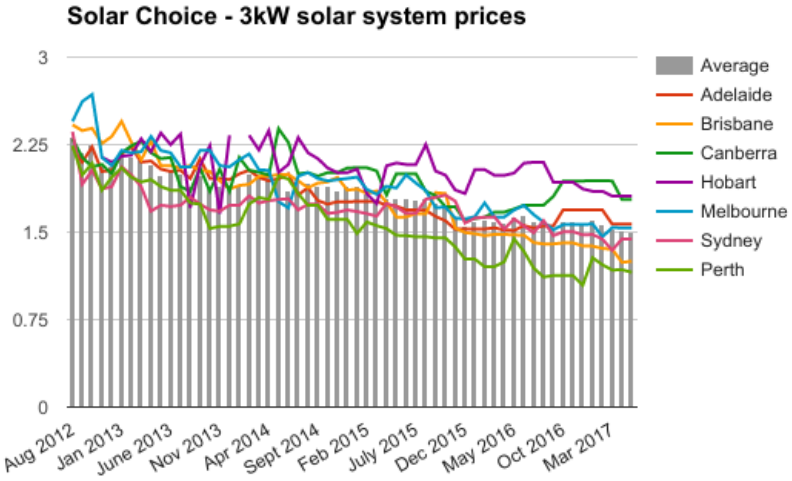
The **Low Carbon Living CRC** (Cooperative Research Centre) is a part-government funded research consortium tasked with helping Australia make

a transition to a more environmentally and climate friendly future. Visit the CRC at http://www.lowcarbonlivingcrc.com.au/research



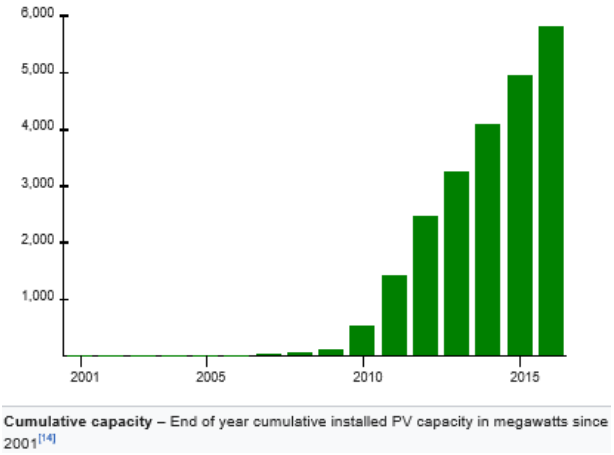
Infographic on renewable energy in SA accessed on 24 Nov 2017 at http://www.climatechange.sa.gov.au/open-for-investment

Installation and rebate schemes around the year 2010

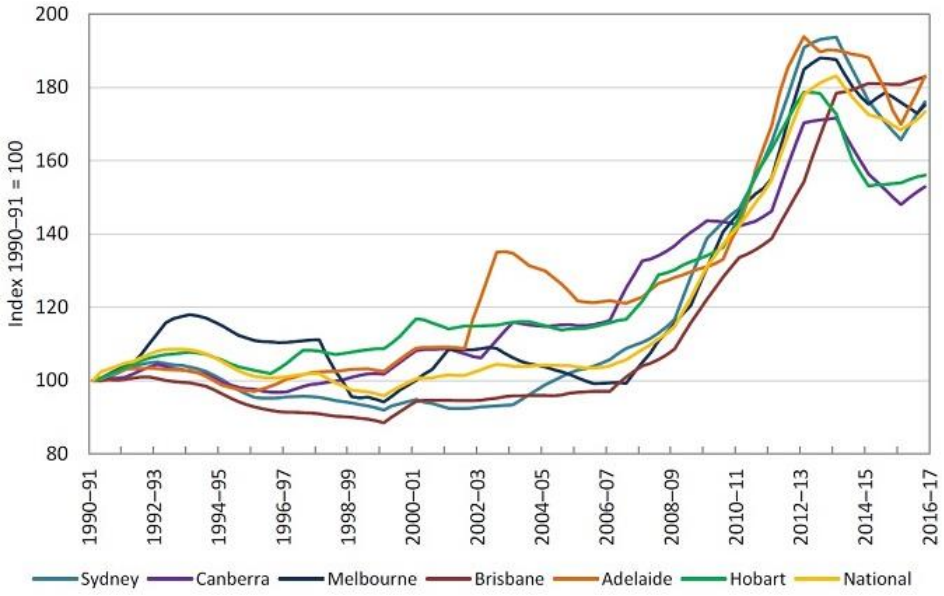


Cost of 3 kW solar system prices between August 2012 and March 2012 (https://www.solarchoice.net.au/blog/3kw-solar-pv-systems-pricing-output-and-returns/)

Around the year 2010, many South Australian home owners received very generous subsidies from government and electricity companies. Firstly, home owners were subsidised for the initial installation. At that time, a home owner was typically out of pocket ~ $2500 for installation of a 1.5 kW entry-level system – this was much less than the unsubsidised retail price. Secondly, once their systems were installed, home owners, received remarkably generous feed-in tariffs of ~52 cents per kWh, and the contracts were to last until ~ 2025. In contrast, the present rates is about 6 to 12 cents per kWh (https://www.solarchoice.net.au/solar-rebates/solar-feed-in-rewards).



Growth of PV capacity in megawatts since 2001 (https://en.wikipedia.org/wiki/Solar_power_in_Australia)



Increasing cost of electricity in Australian states normalized to 1990-91 (http://www.abc.net.au/news/2017-10-16/graph-shows-retail-price-index-of-electricity-in-australian-cap/9052884)

Wikipedia's website on growth of photovoltaics is essential viewing at https://en.wikipedia.org/wiki/Growth_of_photovoltaics.

What have been the socio-economic consequences (both intentional and unintentional) of the introduction the solar rebate scheme? When considering this question, also consider the consequences to those households that have never (and never will) installed solar panels.

*Electricity prices relative to **purchasing power parity** of selected counties in 2011 (http://reneweconomy.com.au/graph-of-the-day-average-electricity-prices-around-the-world-24207/)*

In Australia, since 2010 the amount of electricity used, indeed the total energy per capita, has been falling. The reason for this are several fold. Find out more at https://theconversation.com/why-is-electricity-consumption-decreasing-in-australia-20998.

Tesla batteries

If you have time, please watch a humorous video by a "do-it-yourself" American electrician and how he powers his country home at https://www.youtube.com/watch?v=i19MYQxRJIc.

This above video was filmed by a fellow who absolutely loves his "new green energy"; however, it is presented in a way to completely turn-off his audience. It's worth watching from an entertainment value, but it is hardly an effective advertisement for alternative energies. Believe it or not, there is a part 2 video from the same fellow which focuses on his wind power system! Unfortunately, our friendly American never tells how much his system costs – probably a huge amount.

The lesson from the do-it-yourself American's video is that if alternative energy technologies are to become mainstream, they need to be marketed so as to be easily understood and appealing, much like the video below by Elon Musk.

This video on the Tesla Powerwall is essential viewing and accessed at https://www.youtube.com/watch?v=bvlolmFX-rc.

Some other video resources on Tesla:

- "Tesla Solar Roof" video (10:09) – Cost Estimate with Powerwall 2 and electricity cost (https://www.youtube.com/watch?v=RjGwX0Pnn7A)

- A video (5:54) "Tesla Solar Tiles – My Thoughts" video (https://www.youtube.com/watch?v=aApTQ1VjhFA)
- A video (32:18) on the Tesla Model 3 – the coolest car of 2017 (https://www.youtube.com/watch?v=te6VqldjTT8)
- A video (9:53) on the future of the power grid, Hawaii (https://www.youtube.com/watch?v=RjGwX0Pnn7A).

The world's largest battery in South Australia

During Q4 2017, Tesla built the world's largest Li ion battery backup array at Jamestown in South Australia. Completed ahead of schedule on 1 December 2017, the 100 MW battery (129 MWh), costing $50 million, is 3 times bigger than anything previously built, and was commissioned under intense media scrutiny and political pressure in the aftermath of the 2016 South Australian Energy Crisis. A brief introduction to this project is provided in the short video (2:14) at https://www.youtube.com/watch?v=1BtOfnekhUQ.

A "60 Minutes" video (22:50) on Australia's energy crisis and an interview with Elon Musk is accessible at https://www.youtube.com/watch?v=T9nrdyix-hw. This is an important video to watch as it covers state and Federal government politics and considerations. The video also discusses the new "lithium mining boom".

World's largest lithium ion battery, surrounded by the Hornsdale Windfarm (http://www.ecogeneration.com.au/worlds-largest-tesla-battery-switches-on-at-hornsdale-wind-farm-south-australia/)

It is claimed that the 100 MW battery would provide back-up for ~30,000 homes in case of a black-out. The battery facility is now coupled to the 99-turbine Hornsdale Windfarm, 200 km north of Adelaide.

Why integrate the world's biggest battery exclusively at a windfarm that only produces ephemeral power? Would it not have made better sense to have the battery charged by baseline electricity from the Torrens Island gas-fired power station, much closer to Adelaide?

Lithium ion batteries

If battery storage of electricity is to become common and less expensive, the world will require significant and reliable supplies of some essential raw materials. Materials required to make Li ion batteries are in particular **lithium**, **cobalt** as others.

Blackouts welcome Tesla's mega-battery

AAP

Construction workers at the Tesla battery yesterday

SAMANTHA HUTCHINSON

Wild weather in South Australia has brought down power lines and triggered blackouts in the communities around the state's Tesla battery on the day it was switched on.

South Australia yesterday flicked the switch on the world's largest lithium-ion battery in a bid to shore up the reliability and diversity of its power supply this summer.

But wild weather triggered blackouts in the suburbs around the Tesla battery, with data from SA Power Networks showing 208 homes in suburbs around Jamestown lost power yesterday afternoon after storms damaged equipment.

Parts of Jamestown and about a dozen surrounding suburbs, including Hornsdale, which is home to the Hornsdale Wind Farm powering the battery, saw the lights go off, with the network operator putting the outages down to the storm and equipment breakages.

All suburbs were expected to be reconnected to power last night.

The wild weather came as South Australian Premier Jay Weatherill unveiled the battery, which billionaire Tesla founder Elon Musk finished just 63 days into a self-imposed 100-day deadline.

The 100MW battery forms the showpiece of the government's $550 million energy strategy which uses diesel generators, conventional coal-fired and gas energy, in addition to the state's exploding number of solar and wind farms to keep the state powered over summer. The $50m battery can power up to 30,000 homes for over an hour in the event of a major blackout.

Mr Weatherill said the state had made history. "South Australia is now leading the world in dispatchable renewable energy, delivered to homes and businesses 24/7. Neoen and Tesla approached the state government with their bold plan to deliver this project, and they have met all of their commitments, ensuring South Australia has back-up power this summer."

A spokesman for the Premier said the nature of the storm damage to the transmission lines meant that the battery wouldn't be able to power homes because equipment needed to be repaired to reconnect the homes to the grid.

The battery's reliability was tested on Thursday, when it began dispatching about 59 megawatts into the state's electricity network as temperatures rose above 30C.

Former Business Council of Australia chief executive Tony Shepherd argued the South Australian government's $50m investment in the battery could have been better spent on more cost-efficient and reliable energy sources. "So this will supply 5 per cent of (South Australian) households for how long? A 200MW gas turbine is lying idle at Pelican Point which can operate 24/7," he said.

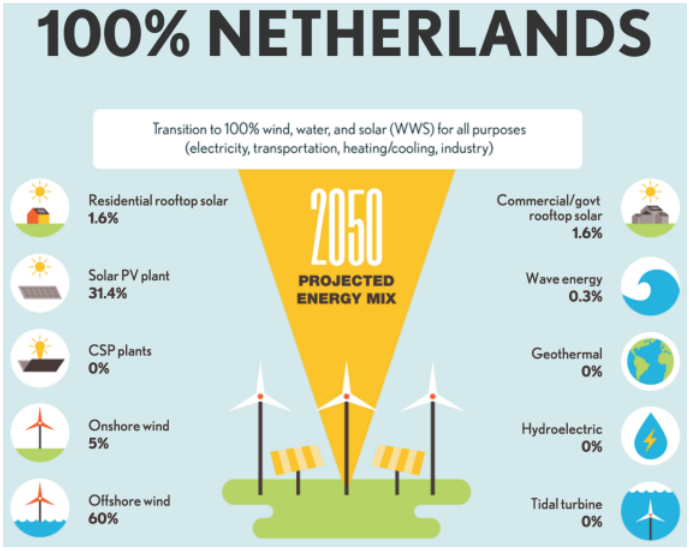
Article from page 7, The Weekend Australian, 2-3 December 2017

Use the internet to research the price for lithium and cobalt over the last decade or so. How have Li and Co prices trended over the last 10 years of

data? With respect to these price trends, what will be the consequences to both consumers of lithium ion batteries and renewable energy in Australia?

What countries have the largest resources of Li and Co? Can you predict whether most Li ion batteries manufactured 5 years from now will be produced in Australia or China?

Netherlands' projected energy mix in 2050



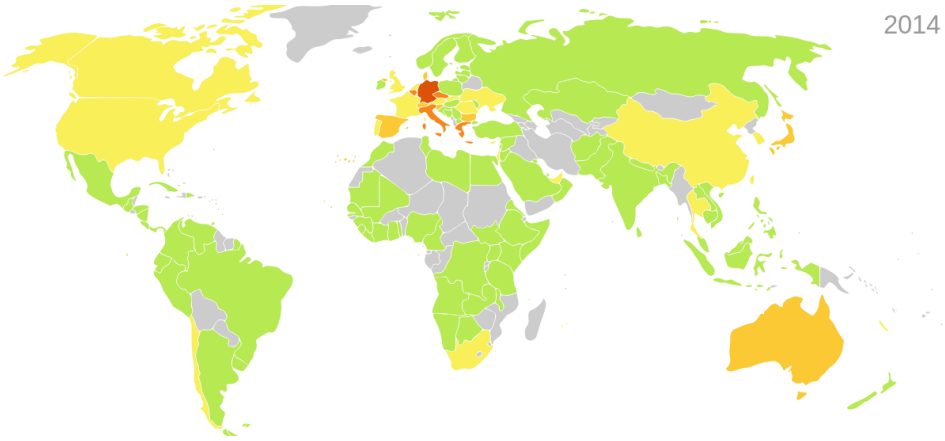
Netherlands projected energy mix in 2050 (https://cleantechnica.com/2016/01/23/solutions-project-139-countries-can-hit-100-renewable-energy/)

The above infographic is only a suggested "futuristic" energy mix by the CleanTechnica website. For equivalent info graphics on the USA, UK, Canada, France, Germany, Italy and Japan, see https://cleantechnica.com/2015/06/23/how-the-us-uk-canada-japan-france-germany-italy-can-each-go-100-renewable/). None-the-less, many advanced economies in the world have clearly defined "energy mix" goals and seem to be making significant progress towards clearly defined energy goals. The Netherlands (a **unitary state**) with a HDI of 0.924 (7th highest in the world) is one such country.

What are the socio-political reasons that Australia (HDI of 0.939; equal second in the world) has been unable to articulate and publish clear national "energy mix" aspirations?

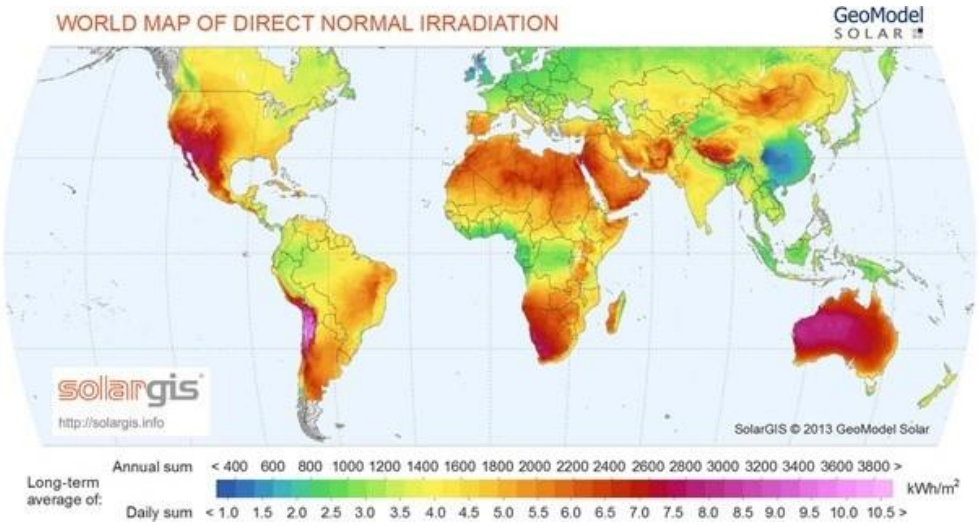
*What demographic, economic, socio-political and geographic advantages/disadvantages does a European country like the Netherlands have (over Australia which is a **federation**) in implementing changes required to transition to a zero carbon economy?*

Worldwide uptake of PV energy



Worldwide installed photovoltaic capacity in "*watts per capita*" by country. Estimated figures for year 2014 (see details in *File history* below). none or unknown <10 watts per inhabitant 10–100 watts per inhabitant 100–200 watts per inhabitant 200–400 watts per inhabitant >400 watts per inhabitant As of the end of 2014, world leading nations in terms of installed PV capacity per capita were Germany (474), Italy (308), Belgium (275), Greece (235), Czech Republic (203), Japan (183), Australia (179), Bulgaria (140), Switzerland (133), Slovenia (124), Spain (115), and Denmark (107). For comparison: Canada (48), Chile (20), China (21), France (86), India (2), Ireland (0.2), Malaysia (5), Mexico (1.5), South Africa (17), South Korea (47), Thailand (19), Turkey (0.7), United Kingdom (80), United States (57).

Worldwide growth of photovoltaics (https://en.wikipedia.org/wiki/Growth_of_photovoltaics)



World map of direct normal irradiance (http://www.solarpanelsmelbournevictoria.com.au/the-best-solar-regions-of-the-world/)

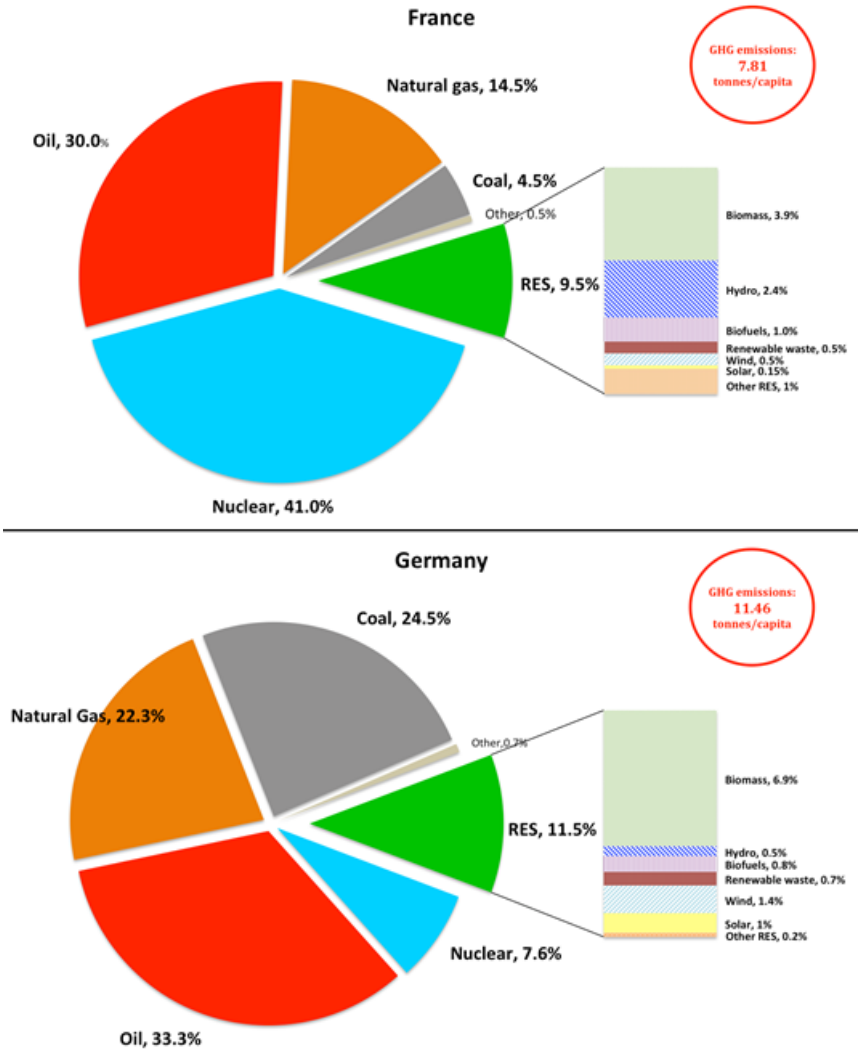
Find-out more on the pros and cons of solar energy at https://www.investopedia.com/articles/investing/053015/pros-and-cons-solar-energy.asp and *http://www.solarpanelsmelbournevictoria.com.au/the-best-solar-regions-of-the-world/*.

Germany's rapidly changing energy mix

It would appear that Germany is presently the leading the world for the uptake of renewable energy. Please read the *National Geographic Magazine* article on *"Germany could be a model for how we'll get power in the future"* at https://www.nationalgeographic.com/magazine/2015/11/germany-renewable-energy-revolution/.

Another website on how Germany generates its electricity is accessible at https://cleantechnica.com/2016/09/21/germany-generates-electricity/

Although the National Geographic article says that Germany will phase-out the last of its nuclear power-plants by 2022, it still relies heavily on nuclear power. In fact, Germany is somewhat following a "South Australian" model – or *vice versa*. South Australia decommissioned its last coal-fired power station in 2016 yet still imports coal-generated electricity from Victoria. Similarly, Germany will be rid of its nuclear power stations in the early-mid 2020s yet, from time-to-time, is likely to import a small quantity of nuclear-sourced electricity from France.



Comparison of France and Germany's energy mix (including transportation fuels) and greenhouse gas emissions circa 2014 (http://blog.iass-potsdam.de/2015/05/energy-transition-france-following-in-germanys-footsteps/)

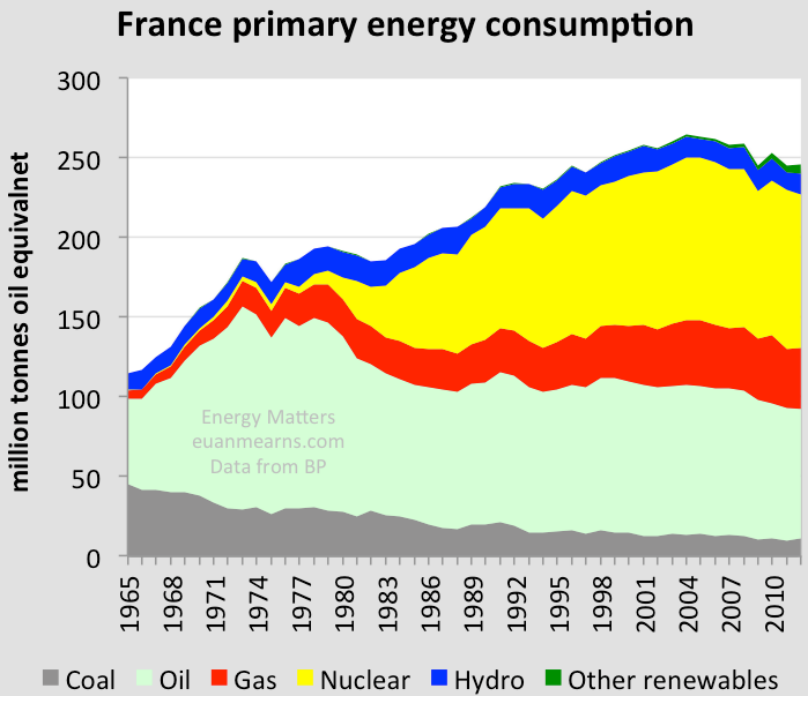
France's very skewed energy mix

France and Germany, although sharing a common border in central-western Europe currently have a very different energy mix. In combination, they have a total population of 149 million, a land area of 998,000 km^2, and a combined **GDP** (purchasing power parity) of US$7.0 trillion, i.e. in combination they comprise 14% of the world's economy.

South Australia is a similar size (983,000 km^2) but has a population of only 1.7 million, its economy is less than one-tenth of 1% of the world's. In other words, densely populated wealthy nations and regions (e.g. North America, Europe and Japan) have a **scale of economy** that Australia, in particular South Australia lacks. They have a capacity to manufacture and deliver goods and services with greater economic efficiency that does South Australia.

Although Germany has significantly more non-nuclear, greenhouse friendly electricity generation than does France, France's greenhouse gas emissions per capita are significantly lower than Germany's. This discrepancy is explained because *France generates more than 75% of its electricity from nuclear*. Indeed, France generates more nuclear power per head of population than any other country, and has 59 nuclear plants across its territory. Despite such a prominent role in France's economy, nuclear power plants have not scared away the tourists – France remains the number one tourist destination in the world.

What lessons (if any) can South Australia learn from the French and German approaches to their respective "energy mix"? Or are the demographics of these two European countries so different that comparisons are unhelpful? Justify your answers with defendable ideas.

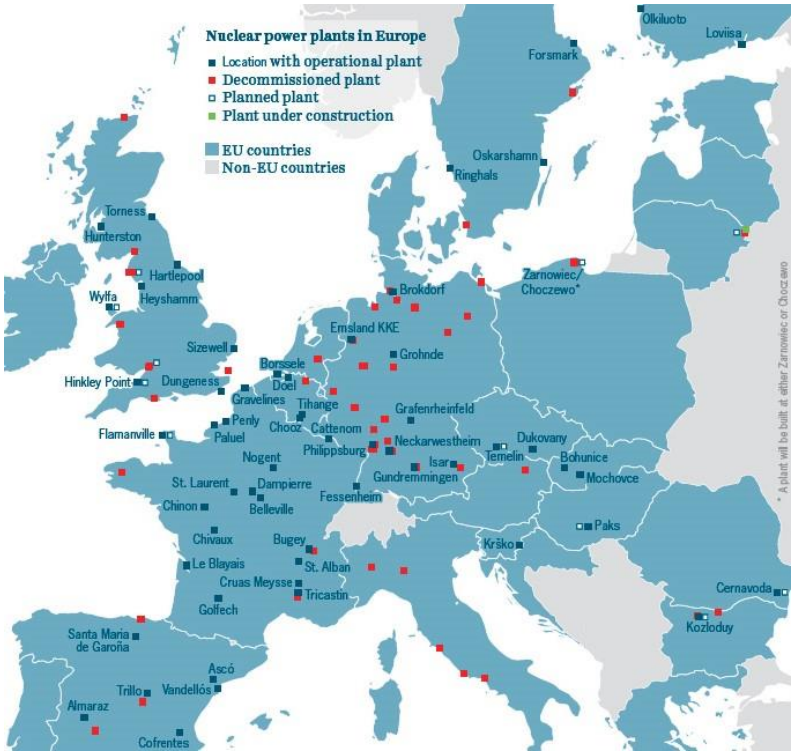


France's primary energy consumption between 1965 and 2012 (https://imgur.com/gallery/jZm26)

Until 1973, France's domestic consumption of oil approximately doubled every 10 years. However, in 1973 France suddenly changed its energy mix changed, and its rate of oil consumption dropped. What geo-political events around this time trigged the colossal shift in France's (and Germany's) energy mix?

How does the cost of electricity generation compare between France and Germany? In socio-economic terms, what are the "energy" messages from these data?

Nuclear power in Europe



Nuclear power plants in the European Union (https://www.wingas.com/en/media-library/gaswinner/archive/the-big-clearout.html)

Following the Fukushima disaster, some European countries decided to abandon nuclear energy entirely; however, others have taken an entirely different approach.

Find-out more on how the Europeans intend to embrace or reject a nuclear future at https://www.wingas.com/en/media-library/gaswinner/archive/the-big-clearout.html.

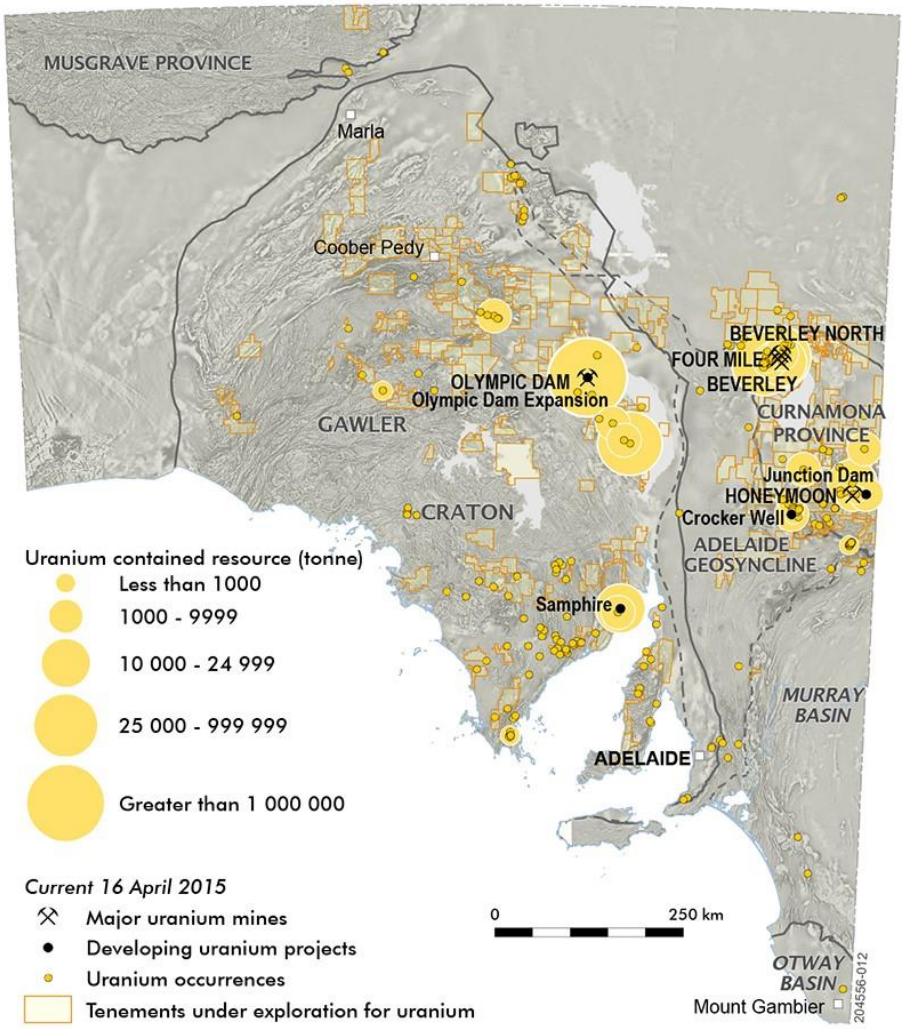
The future of South Australia's nuclear industry

Although South Australia has significant (potential) resources of wind energy and solar energy, it also has ~35% of the world's economically recoverable uranium.

An obvious proposition may be that the South Australian economy should leverage of what it has in plentiful supply. For example, Norway has very significant water resources, and the highest HDI in the world a statistic it has maintained for many years. It also has a remarkable 98% share of renewable energy from hydro-power (but that comes at a significant environmental cost).

2015–2016 Nuclear Fuel Cycle Royal Commission

At least some politicians are also thinking along the lines of a greater role of uranium in the SA economy. All of South Australia's known uranium deposits are located in the north and east of the state (figure below), and nearly all are located at considerable distance from major centres of human habitation and agricultural areas.



South Australian major uranium mines, uranium projects and mineral exploration tenements under exploration for uranium (http://minerals.statedevelopment.sa.gov.au/invest/mineral_commodities/uranium)

Using the SA Government website http://minerals.statedevelopment.sa.gov.au/invest/mineral_commodities/uranium as your first information source, research the terms of reference of the Royal Commission as well as its findings.

Summarise the outcomes of the Royal Commission and the so-called Citizens' Jury on the Nuclear Fuel Cycle. Whas a Citizens' Jury a useful way to approach the question of how South Australia uses its uranium?

Legacy of nuclear testing on Enewetak Atoll

"Runit Dome" on Enewetak Atoll (Marshall Islands) in the Pacific Ocean (http://www.abc.net.au/radionational/programs/saturdayextra/crater-created-by-nuclear-testing-on-enewetak-atoll/6932598)

Find out more about the nuclear waste dump at Enewatak Atoll and watch the very short video (1:19) at https://www.theguardian.com/world/2015/jul/03/runit-dome-pacific-radioactive-waste.

More information on Enewetak Atoll:

- Marshall Islands Dose Assessment & Radioecology Program (https://marshallislands.llnl.gov/enewetak.php)
- "A poison in our island" (http://www.abc.net.au/news/2017-11-27/the-dome-runit-island-nuclear-test-leaking-due-to-climate-change/9161442)

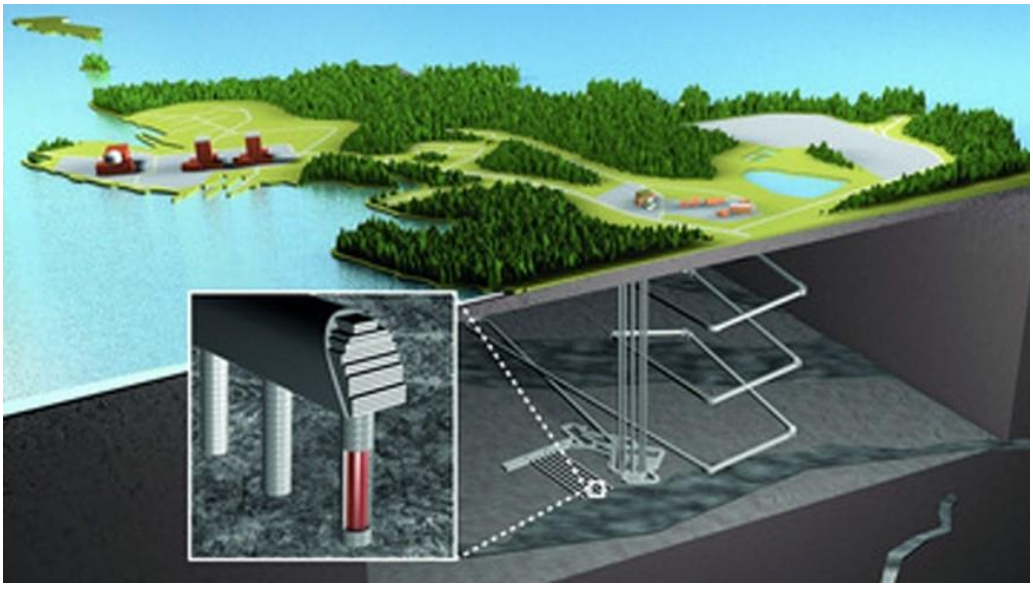
The concrete sarcophagus over the Enewetak waste dump is only 18 inches (45 cm) thick. How easy or otherwise will it be to relocate the waste if sea levels rise due to climate change?

Onkalo spent fuel nuclear fuel repository

One idea that was entertained by the media, politicians and scrutinised by the Royal Commission was the idea of a state-of-the-art, high-tech nuclear waste repository for South Australia – along the lines of what is presently being constructed in Finland (a unitary country). Somehow, despite being less than 20 km from a world heritage township, it has the financial backing and commitment of the Finish Government and people. It is also located on an island within Finland's populated coastal region.

The **Onkalo spent fuel nuclear repository**, is presently under construction as a **deep geological repository** for nuclear waste, and the world's first permanent

purpose-built repository, is presently being constructed close to the Olkiluoto Nuclear Power Plant in Finland. Finland presently has four nuclear reactors providing ~25% of the country's energy needs.



Schematic representation of Onkalo deep geological repository for nuclear waste. Tunnels are lined with storage spaces where spent nuclear fuel rods can be placed within extremely resistant disposal containers (http://nordic.businessinsider.com/finlands-100000-year-tombs-for-storing-nuclear-waste-is-drawing-the-worlds-admiration-2017-1/)

The role of the completed facility will be to house all of Finland's domestic nuclear waste, following a 1994 act of the Finnish Government that requires all of Finland's nuclear waste to be stored safely within Finland. Exportation of nuclear waste is expressly forbidden.

The facility is being constructed within hard, **competent** granitic rock, and designed to withstand two ice ages of a similar intensity of the last ice age, each expected to last, maybe 40 thousand years and erode 80 metres of rock. To achieve this, the *top* of the facility is at a depth of ~180–200 metres.

More information on Onkalo waste repository:

- The trailer for the film "*Into Eternity*" (https://en.wikipedia.org/wiki/Into_Eternity_(film))
- The full film "*Into Eternity*" (https://www.youtube.com/watch?v=ZUQ-Mhb4OVo).

This film is an outstanding documentary that begins with an overview of the dangers of radioactive waste and society's unpreparedness and incapacity to deal with its storage. This film is a "must watch"!

- A trailer of a documentary about the project (http://nordic.businessinsider.com/finlands-100000-year-tombs-for-storing-nuclear-waste-is-drawing-the-worlds-admiration-2017-1/)

- Finland's "100,000-year tomb for nuclear waste (http://nordic.businessinsider.com/finlands-100000-year-tombs-for-storing-nuclear-waste-is-drawing-the-worlds-admiration-2017-1/)

- Find out about the progress of Japan, the UK, the USA, Canada and Germany to construct permanent suitable repositories for its nuclear waste at http://www.nature.com/news/why-finland-now-leads-the-world-in-nuclear-waste-storage-1.18903.

  A report by *The Atlantic Daily* on the Onkalo facility (https://www.theatlantic.com/magazine/archive/2017/10/what-lies-beneath/537894/)

If South Australia were to construct a similar facility to the Onkalo waste repository, the construction phase would last the duration of ~ 30 SA parliamentary terms (30 x 4 = 120 years).

Where in South Australia would such a facility be sited and what other considerations should be entertained, including geotechnical, socio-political and economic? In particular, how would future climate change impact on the design and construction of a nuclear fuel repository for South Australia?

Given that South Australia presently supplies ~10–12 % of the world's uranium yellowcake (and with ~35–40% of the world's reserves), does the State of South Australia and the nation of Australia have a moral obligation to be a leading nation in the responsible and permanent storage of nuclear waste, and hence a sophisticated waste repository similar to that considered by the Nuclear Fuel Cycle Royal Commission?

How many Onkalo-sized repositories would be required to safely store the world's present stock-piles of spent nuclear fuel?