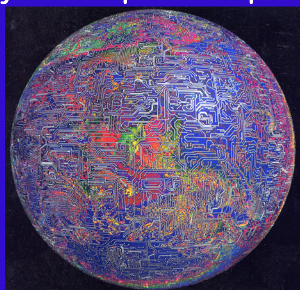
SCIENCE

Energy consumption and production



Prof Peter O'Donoghue

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Energy

defined as the ability to do work

- potential energy (stored)
- kinetic energy (of motion)
- thermal energy (heat)
- chemical energy (stored in bonds between atoms)
- nuclear energy (bound within nucleus of atom)
- electromagnetic energy (electricity, magnetism, light, X-rays, microwaves, radio waves, etc)

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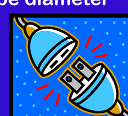
Electricity

= electron flow

DC (direct current) – one way (battery)
AC (alternating current) – two way pulse (sine function)

Electricity	plumbing analogy
I = Current (amps)	similar to flow rate
V = Voltage (volts)	similar to water pressure
R = Resistance (ohms)	similar to pipe diameter



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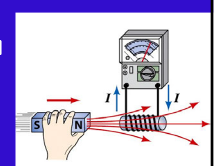
Electromagnetic energy

Faraday found current in coiled wire:
- when brought near magnet
- alternated when - magnet rotated
  - coil rotated



principle of dynamo
kinetic E (rotation) → electrical E

principle of motor
electrical E → kinetic E (rotation)

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ELECTRICITY BILL

Electricity Tariff - Tariff 11 & 33-Domestic+Controlled S

	Meter Number	Previous Reading	Current Reading	Usage kWh	@Rate c/kWh	Amount $
From 21 May 2009 to 30 Jun 2009 - Bill Days 40						
Peak Use						
Tariff 11 Domestic	206317	97478	98284.1	806.1	14.8100	119.38
Off Peak Use						
Tariff33 Cont Supply	206320	93902	94475.5	573.5	8.8900	50.98

Total electricity (energy) used = 1379.6 kWh

What is a kWh? kilowatt.hour

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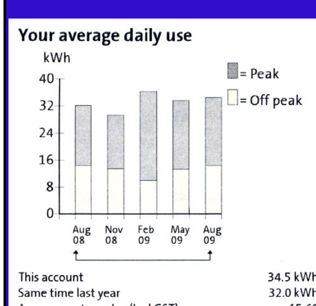
ELECTRICITY BILL

Check units?



Units for energy = kWh
Total E used = 3172 kWh

But graph shows rate
(average daily use)
Period covered = 92 days
Average daily use = 34.5

Units should be kWh/d
(energy / time = power)

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UNITS

ENERGY kWh amount

POWER kWh/d rate

Look at units for power!
Can you spot an inconsistency?

h/d = time / time
cancel out
giving actual units for power as kW

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POWER (kW = kWh/d)

Does it make sense in terms of SI units?

FORCE: Newton's second law of motion
Force (newtons) = mass (kg) x acceleration ($m\ s^{-2}$) [$1\ kg\ m\ s^{-2} = 1\ N$]

WORK: application of energy over distance
Work, energy (joules) = force (N) x distance (m) [1 N m = 1 J]

POWER: rate of energy usage
Power (watts) = work, energy (J) / time (s) [$1\ J\ s^{-1} = 1\ W$]

[Algebraic reshuffle $1\ J\ s^{-1} = 1\ W$ ≡ 1 J = 1 W s]

Energy is a quantity (measured in kWh) [1kWh = 3.6 million J]
Power is a rate (measured in kW or kWh/d) [1 kW = 24 kWh/d]
[40W = 1 kWh/d]

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Check units

Kinetic Energy:	KE = ½ m v^2	[= kg ($m\ s^{-1})^2$]
		[= kg $m^2\ s^{-2}$]
Potential Energy:	PE = m g h	[= kg m s^{-2} m]
		[= kg $m^2\ s^{-2}$]
Energy:	E = m c^2	[= kg ($m\ s^{-1})^2$]
		[= kg $m^2\ s^{-2}$]
		[= N m]
		[= J]
		[= W s]
		[= kWh]
Power:	P = E/t	[= kW]
		[= kWh/d]

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UNITS

ENERGY kWh amount

POWER kWh/d rate

Use this as our currency

[= rate of energy use per day]

Calculate average per person

kWh/d pp

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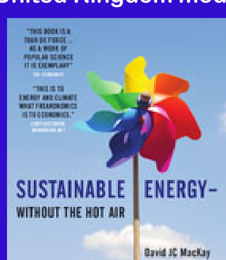
Modeling E consumption/production

David MacKay 2009 – Cambridge
www.withouthotair.com [free pdf]
United Kingdom model



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World CO_2 emissions

Burning fossil fuels dumps ~ 30 $GtCO_2e/y$ into atmosphere

Small compared to: 440 $GtCO_2e/y$ from biosphere
330 $GtCO_2e/y$ from oceans

BUT, biosphere extracts 440 $GtCO_2e/y$
oceans extract 330 $GtCO_2e/y$
harmonious balance through evolution

Problem is that extra amount added by humans
is not extracted, utilized, sequestered, etc.

THUS, it is a cumulative problem

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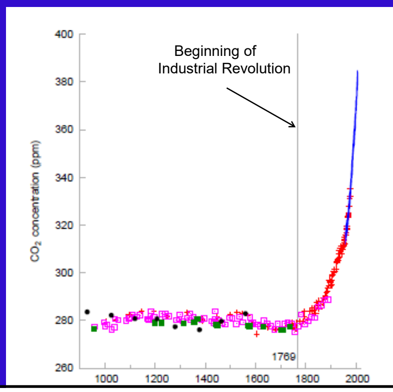
Atmospheric carbon dioxide



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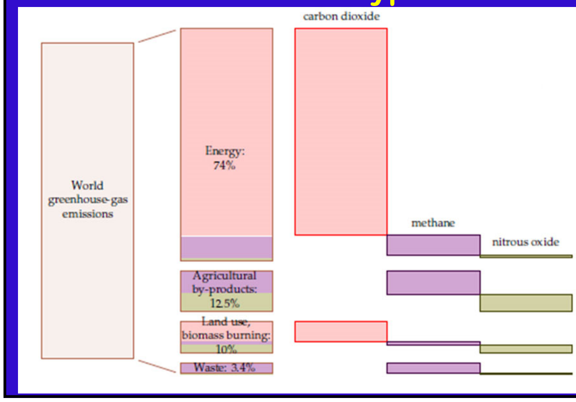
Source and type



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Australian CO_2 emissions

World emission ~ 30 $GtCO_2e/y$

(population of 6 billion, ⇒ ~ 5 $tonsCO_2e/y$ per person)

BUT, not all countries are equal

Australian emission ~ 0.5 $GtCO_2e/y$

(population of 20 million, ⇒ ~ 25 $tonsCO_2e/y$ per person)

Regrettably, we are the champions!!!

Ranked fourth in world (behind Qatar, UAE & Kuwait)

(worse than USA & Canada)

WHY? Life-style, tyranny of distance, over-reliance of coal

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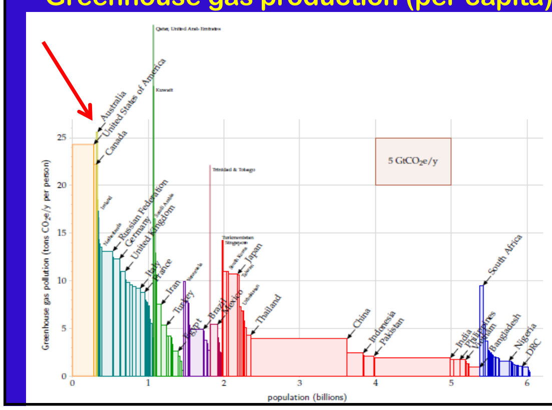
Greenhouse gas production (per capita)



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Australian power consumption

Australians emit ~ 25 $tonsCO_2e/y$ per person

Equates to:

Power consumption = rate of energy use

= 7.9 kW pp [1 kW = 24 kWh/d]

= 190 kWh/d pp

Sources:

- fossil fuels (coal, gas, oil)
- renewables (hydroelectricity, solar, wind, geothermal)

Consumption:

- most as electricity (domestic/industrial power)
- internal combustion engines (automotive power)

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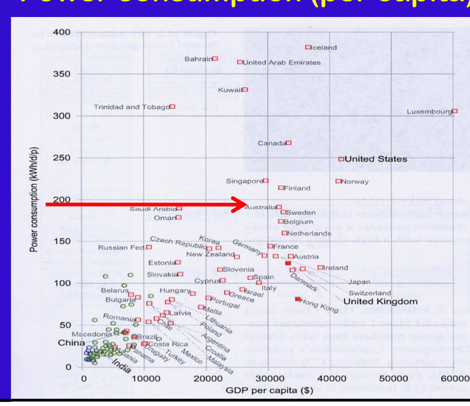
Power consumption (per capita)



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Power consumption (Oz)

TOTAL 190 kWh/d per person

Cars	
Planes	
Household	
Lighting	
Gadjets	
Food/farming	
Manufacturing	
Public services	

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Power consumption: cars

Consider average daily use of car

Fuel calorific value = 10 kWh/L

Energy per day = $\frac{\text{distance travelled per day pp}}{\text{distance per unit fuel}}$ x energy per unit fuel

= $\frac{\text{50 km/day pp}}{\text{12 km/L}}$ x 10 kWh/L

= 40 kWh/d pp

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Power consumption: planes

Boeing 747 uses 200,000 L fuel to carry 400 passengers a distance of 14,000 km [fuel calorific value = 10 kWh/L]

Energy used for single return flight once per year

= $\frac{\text{distance travelled per day pp}}{\text{distance per unit fuel}}$ x energy per unit fuel

= $\frac{\text{(2 x 14,000 km) / 365 days}}{\text{(2 x 14,000 km) / [(2 x 200,000 L) / 400 persons]}}$ x 10 kWh/L

= 27 kWh/d per person

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Power consumption: household

$E_{hot\text{-}water}$ = heat capacity x volume x temperature difference

E_{shower} = 4200 J/L/°C x 30 L x (50-10)°C = 5 MJ (= 1.4 kWh)

Power used for one 5 minute shower per day = 1.4/12 = 0.1 kWh/d]

Energy used by electric kettle per day = power x time used per day
= 3 kW x 0.5 h/d = 1.5 kWh/d

Cooking (stove, oven, microwave, kettle) (~3kW appliances) =	5 kWh/d
Cleaning (bathing, washer/dryer, dishwasher) (~2.5 kW) =	5 kWh/d
Cooling (refrigerator, freezer) (0.1 kW) =	2 kWh/d
Air-conditioning (heating/cooling) (1 kW) =	24 kWh/d

TOTAL = 36 kWh/d

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Power consumption: light

Average home uses ~ 20 globes for 6 hours per day
- 10 incandescent globes require 1 kW power
- 10 low-energy globes require 0.1 kW power

Energy used per day for:

household lighting = (power x time) / av. no. people per home
= (1.1 Kw x 6 h/d) / 2 persons
= 3.3 kWh/d pp

workplace lighting = 1.6 kWh/d pp
street lighting = 0.1 kWh/d pp

TOTAL = 5 kWh/d pp

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Power consumption: gadjets

Appliance with power rating of 40 W = 1 kWh/d
but only used for fraction of each day

	quantity (no.)	x	rating (W)	=	sum (kW)	x	usage (h/d)	=	Power (kWh/d)
Computer/printer	2		100		0.2		4		0.8
TV/DVD/VCR	2		100		0.2		3		0.6
Xbox/PS/Wii	2		200		0.4		2		0.8
CD/stereo/radio	2		100		0.2		2		0.4
Chargers (phone,...)	4		5		0.02		24		0.5
Vacuum cleaner	1		1600		1.6		1		1.6
Lawn mower	1								0.3

TOTAL = 5 kWh/d

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Power consumption: food/farming

One 65 kg person uses 2,600 Calories per day (= 2.6 million calories) ~ 3 kWh/d

Item	Consumption – Production	Power
milk, cheese	consume 0.75 L/d, 450 kg cow produces 16 L/d, uses 450 x 3/65 kWh/d (0.75/16 x 450 x 3/65)	1 kWh/d
eggs	eat 2 eggs/d, chicken lays 290 eggs/yr, eat 120 g/d @ 3.3 kWh/kg (2 x 365/290 x 0.12 x 3.3)	1 kWh/d
meat 	eat 100 g/d each of chicken, beef and pork, (50, 1000 & 400 days nurture @ 3/65 kWh/d/kg)	7 kWh/d
fruit/vegies	eat 250 g/d, 200 days nurture @ 3/130 kWh/d/kg	1 kWh/d
pets	cats, dogs and horses, 1 per 10 persons	3 kWh/d
TOTAL		13 kWh/d

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Power consumption: manufacturing

Item	Consumption x embodied production cost	Power
drink containers (aluminum cans/bottles)	5 units/d @ 0.6 kWh/unit	3 kWh/d
packaging (glass/paper/plastic/steel)	0.4 kg/d @ 10 kWh/kg	4 kWh/d
computer (1 every 2 years)	1/(2x365) unit/d @ 1500kWh/unit	2 kWh/d
print (newspapers/magazines/junk mail)	0 .2 kg/d @ 10 kWh/kg	2 kWh/d
house (1 every 100 years, 2.3 persons)	1/(100x365x2.3) @ 84000	1 kWh/d
car (1 every 15 years)	1/(15x365) units/d @ 76000 kWh/unit	14 kWh/d
roads (building/upkeep over 50 yrs)	1/(50x365) m/d @ 36000 kWh/m	2 kWh/d
road transport	51billion t-km / (365 x 20 million pop) @ 1 kWh/t-km	7 kWh/d
shipping	2000billion t-km / (365 x 20million pop) @ 0.015kWh/t-km	4 kWh/d
water treatment	160 L/d @ 0.002 kWh/L	0.3 kWh/d
sewage treatment	100L/d @ 0.002 kWh/L	0.2 kWh/d
supermarkets	5000 units / (365 x 20 million) @ 3.6 GWh/unit	0.5 kWh/d
imports (55 million tonnes per yr)	2 kg/d @ 10 kWh/kg	20 kWh/d
TOTAL		60 kWh/d

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Power consumption: public services

Australian government annual budget $560 billion (GDP)

Energy consumption greatest in ADF

3.2% GDP spent on defence = $18 billion

25% spent on energy = $4.5 billion
@ 14.8cents/kWh = 30 billion kWh per year
= 83 million kWh per day

Population of 20 million
gives 4 kWh/d per person

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Power consumption (Oz)

	kWh/d per person
Cars	40
Planes	27
Household	36
Lighting	5
Gadjets	5
Food/farming	13
Manufacturing	60
Public services	4
TOTAL	190

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What can we do about energy consumption?

- Use less!
  - mandates profound life-style changes (sell car, do not fly, limit gadjets, reduce lighting, make household more efficient, eat less, buy less..)

Should your generation expect less than what your parents have?

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SCIE1100: Advanced TAPIS

Week 3: Energy production

Prof Peter O'Donoghue
Faculty of Science, UQ

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Power production *

Fossil fuels
Coal, gas, oil

Renewable E
Wind
Solar
Hydroelectricity
Wave
Tide
Geothermal

Nuclear energy

Sources in Australia:
- fossil fuels (coal, gas, oil)
- renewables
(hydroelectricity,
solar,
wind,
geothermal)

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Power production: fossil fuels

Fossil fuels (coal, gas, oil)
Current global consumption 6.3 Gt/yr
Known reserves (mostly coal) = 1,600 Gt

To be sustainable, needs to last 1,000 years
Allows annual consumption = 1.6 Gt/yr
Divided by 6 billion people, gives ~6 kWh/d per person

Standard coal power stations only 37% efficient
Technology for clean coal (carbon capture and storage) unavailable

Only enough coal left for 250 years (if no population growth)
or 60 years (with 3.4% population growth)

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Power production: wind

Wind (onshore)

Turbines size-constrained, spaced for clear air, generate 2 W/m^2
But: only 10% efficient, only work in moderate wind speeds,
so only ~1% land in Australia suitable

Power/person = [efficiency] x wind power/unit area x area/person
= [10% x 1%] x 2 W/m^2 x 384,000 m^2/person
= 768 W per person
~ 20 kWh/d per person

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Power production: wind

Wind (offshore) (shallow, < 25 m)

Winds stronger and steadier, generate 3 W/m^2
Turbine problems with corrosion, still only 10% efficient
Shallow inshore area ~ 160,000 km^2
But only 25% available (fishing, shipping, reefs, ..)

Power/person = [efficiency] x wind power/unit area x area/person
= [10% x 25%] x 3 W/m^2 x 8,000 m^2/person
= 600 W per person
~ 15 kWh/d per person

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Power production: wind

Wind (offshore) (deep, 25-50 m)

Platforms more expensive, generate 3 W/m^2
Turbine problems with corrosion, still only 10% efficient
Suitable coastal area ~ 320,000 km^2
but only 25% available (fishing, shipping, reefs, ..)

Power/person = [efficiency] x wind power/unit area x area/person
= [10% x 25%] x 3 W/m^2 x 16,000 m^2/person
= 1200 W per person
~ 30 kWh/d per person

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Power production: solar

Sunshine (midday, cloudless day, at Equator) = 1000 W/m^2

But compensate for : latitude (tilt) — Oz ~70% that of Equator
daily variation — average ~ 40% midday
cloud cover — sun shines ~ 35% of day

Yields average solar power per area = 100 W/m^2

Solar power
- Thermal (heat water)
- Photovoltaic (produce electricity)
- Biomass (grow plants to eat or for biofuel)

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Power production: solar

Solar (thermal)

Simplest technology – panel to heat water, 50% efficient
Average solar power = 100 W/m^2
Assume everyone gets 10m^2 panels on roof

Solar heating = efficiency x area panels/person x average power
= 50% x 10 m^2 x 100 W/m^2
= 500 W [40 W = 1 kWh/d]
= 12 kWh/d per person

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Power production: solar

Solar (photovoltaic)

Developing technology – gallium arsenide photovoltaic cells
Convert sunlight into electricity, 20% efficient
Average solar power = 100 W/m^2
Assume everyone gets 10m^2 panels on roof

Solar power = efficiency x area panels/person x average power
= 20% x 10 m^2 x 100 W/m^2
= 200 W [40 W = 1 kWh/d]
= 5 kWh/d per person

Could be increased 2-10 fold by establishing large solar farms but defeated by logistics of transporting it over large distances (incl. o/s)

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Power production: solar

Solar (biomass)
Grow plants: - to eat (food)
- to burn (fuel, wood)
- for biofuel (ethanol, diesel)
- for biogas (methane by-products)

Convert sunlight into carbohydrates, best plants only 0.5% efficient
Average solar power = 100 W/m^2
In Australia, crops cover 21 million hectares (= 21 x 10^{10} m^2)
Assume 25% used for fuel, 75% for food

Bioenergy = efficiency x area/person x average power
= 0.5% x 2,625 m^2 x 100 W/m^2
= 1300 W [40 W = 1 kWh/d]
= 33 kWh/d per person

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Power production: hydroelectricity

Hydroelectricity
Need altitude and rainfall to harvest gravitational power (potential energy) of water
Most rain runs off, is used by plants or evaporates (only ~ 10% could be used for hydroelectricity)

PE_{grav} = m g h
= (volume x density) g h
= (rainfall x density) x gravity x altitude

[Density of water = 1,000 kg/m^3 , Gravity = 10 m/s^2]

Lowlands altitude < 500 m (with 100 m drop)
Highlands altitude > 1,000 m (with 300 m drop)

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Power production: hydroelectricity

Hydroelectricity (lowlands)
Area Australia = 7.68 million km^2, but 85% is < 500 m high, and only ~ 10% of that would have suitable altitude drop of 100 m
Average rainfall only ~ 400 mm/yr, but assume it all sees a turbine

Power per unit area = 400 mm/yr x 1000 kg/m^3 x 10 m/s^2 x 100 m
= 0.4 m/yr x 1,000,000 kg.m^{-1}.s^{-2}
= 0.4/(365x24x60x60) m/s x 10^6 kg.m^{-1}.s^{-2}
= 0.01 kg.s^{-3} [1 W = 1 kg.m^2.s^{-3}]
= 0.01 W/m^2

Multiply by area/person (32,500 m^2 per person for lowlands)
= 325 W [40 W = 1 kWh/d]
= 8 kWh/d per person

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Power production: hydroelectricity

Hydroelectricity (highlands)
Area Australia = 7.68 million km^2, but only 0.5% is > 1,000 m high
Assume that is all has a suitable altitude drop of 300 m
Average rainfall ~ 800 mm/yr, and assume it all sees a turbine

Power per unit area = 800 mm/yr x 1000 kg/m^3 x 10 m/s^2 x 300 m
= 0.8 m/yr x 3,000,000 kg.m^{-1}.s^{-2}
= 0.8/(365x24x60x60) m/s x 3 x 10^6 kg.m^{-1}.s^{-2}
= 0.06 kg.s^{-3} [1 W = 1 kg.m^2.s^{-3}]
= 0.06 W/m^2

Multiply by area/person (1,900 m^2 per person for lowlands)
= 114 W [40 W = 1 kWh/d]
= 3 kWh/d per person

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Power production: wave

Wave (sun makes wind makes waves, when wind > 0.5 m/s)
Wave energy collectors
(floating articulated snakes perpendicular to wave direction)
(flexion around articulation generates energy, but only 25% efficient)
(power of waves measured at 40 kW/m of exposed coastline)
Australian coastline 20,000 km (but only 2% with sustained oceanic waves)

Wave power = efficiency x power/length coastline x length per person
= 25% x 40 kW/m x 0.02 m per person
= 200 W [40 W = 1 kWh/d]
= 5 kWh/d per person

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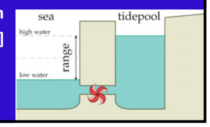
Power production: tide

Tide (gravitational interaction between Earth and Moon)
Two tides per day (6.25 hr period), predictable, regular, everlasting
Use water flowing back and forth to turn turbine
(establish tidal pools/lagoons, tidal stream farms, barrages)
Tide range of 4 m (current of 2 knots, ~1 m/s) may generate 3 W/m²
Tide turbines cheap, hidden underwater, 50% efficient
Australian coastline 20,000 km, tidal currents up to 1 km offshore,
Assume only 40% accessible/suitable

Tidal power = efficiency x power per unit area x area per person
= 50% x 3 W/m² x 400 m²/person
= 600 W [40 W = 1 kWh/d]
= 15 kWh/d per person



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Power production: geothermal

Geothermal (~50 milli-W/m² at surface of Earth)
- heat trickling through mantle from core (~10 milli-W/m²)
- radioactive decay in crust (~40 milli-W/m²)
Available near surface at special 'hot-spots'
Rate-limited (cannot exceed extraction limits)
Crust 40 km thick, 500°C at 40 km depth
Optimal depth to drill for extraction ~ 15 km, deliver 15 milli-W/m²
Area of Australia = 7.68 million km², but only 3% suitable/active

Geothermal power = efficiency x power/unit area x area/person
= 50% x 0.015 W/m² x 10,000 m²/person
= 75 W [40 W = 1 kWh/d]
= 2 kWh/d per person

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Power production (Oz)

SOURCE		kWh/d per person
Fossil fuels	coal, gas, oil	6
Wind	onshore	20
	offshore shallow	15
	offshore deep	30
Solar	thermal	12
	photovoltaic	5
	biomass	33
Hydroelectricity	lowland	8
	highland	3
Wave		5
Tide		15
Geothermal		2
TOTAL		154

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Power deficit

Total power production	154 kWh/d per person
Total power consumption	190 kWh/d per person
Deficit	36 kWh/d per person

Where will it come from?
What sources are left?

Nuclear energy (fission, fusion) 1-420

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Nuclear energy

Nuclear energy

- fission (using heavy elements, uranium)
- fusion (using light elements, deuterium/tritium)

$$E = mc^2$$

All about inter-conversion of matter and energy

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BIG BANG

Theory of Everything (Universal Theory)

- electromagnetic force (wave/particle)
- gravitational force (attraction)
- strong force (overcome repulsion)
- weak force (radio-active decay)

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Power production: nuclear energy

Nuclear energy (fission, using heavy elements, uranium)
(fusion, using light elements, deuterium, DT/DD)

Energy available per atom is 1,000,000 x greater than chemical energy

Fossil fuels	16 kg/d consumed pp	produces 30 Kg CO_2/d
Uranium	2 g/d consumed pp	produces 0.25 g waste

Source of radioactive elements
- ground (estimated reserves 27 million tons uranium)
- ocean (estimated reserves 4.5 billion tons uranium)

Usage
- once-through reactor (energy from ^{235}U (discard ^{238}U)
- fast-breeder reactor (energy from ^{238}U), 60x more efficient

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FISSION

Fission = splitting atom (using a neutron)
only Uranium and Plutonium generate self-sustaining reactions
Plutonium not found naturally (formed when U-238 absorbs a neutron to become U-239 which then decays in days to Pl-239)

Uranium found naturally in earth (foci) and seawater (3.4 ppb)
Occurs as three isotopes: U-244, U-235, U-238
U-238 is most abundant but cannot sustain a reaction
U-235 makes up 0.7% of natural deposits
reactors use enriched (boosted) blend so U-235 is 3.5-5.0%
made into pellets and then put in long fuel rods
use gas centrifuges for enrichment (can be used for weapons)

light water reactor (core -> water -> turbine)
fast breeder reactor (core -> liquid salt/metal -> water -> turbine)
Thorium reactors (Th-232 + n -> Th-233 which decays to U-233)

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FISSION

440 reactors in the world
provided 13% of energy in 2011

135 defunct reactors
only 17 dismantled

disasters
Chernobyl 1986 Ukraine
Fukushima 2011 Japan

dangerous radiation
waste products
long half-lives

Figure . Chart showing the decay chain of the uranium and thorium series isotopes and the half-lives of each isotope (in green). Alpha decays are shown by the vertical arrows (↓) and beta decays by the diagonal arrows (↗).

Atomic Number	Element	U-235 Series				
92	Uranium	U-235 7.04 x 10^8 yrs				
91	Protactinium	↓	Pa-231 3.25 x 10^4 yrs			
90	Thorium	Th-231 25.5 hrs	↓	Th-227 18.7 days		
89	Actinium		Ac-227 21.8 yrs	↓		
88	Radium			Ra-223 11.4 days		
87	Francium			↓		
86	Radon			Rn-219 3.96 sec		
85	Astatine			↓		
84	Polonium			Po-215 1.78 x 10^{-3} sec		Po-211 0.516 sec
83	Bismuth			↓	Bi-211 2.15 min	↓
82	Lead			Pb-211 36.1 min		Pb-207 stable lead (isotope)

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FISSION

break down heavy element

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{94}_{36}Kr + ^{139}_{56}Ba + 3\ ^{1}_{0}n$$

uranium-235 neutron uranium-236 krypton-94 barium-139 neutrons

mass lost = 0.185 u = $3x10^{-28}$kg

$\Rightarrow E = mc^2 = 2.8x10^{-11}$J
(all from one fission)

cumulative chain reaction
energy from 1kg = $8x10^{13}$J

(= 2 tonnes coal)
(supply Sydney for 2 days)

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FISSION

energy generation in nuclear reactor

- use 2-4% uranium-235
  (concentration too low for explosion)
- generates enormous amount of heat
  (need coolant to avoid melt-down)
  (use heat to drive steam turbines to produce electricity)
- once-through reactors v. fast-breeder reactors
  (60-fold difference in efficiency)
- all plagued with problems of radio-active waste
  (half-lives $10^3 – 10^9$ years)

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Radio-activity

particles

- alpha (helium nucleus) ${}^{4}_{2}He$
- beta (electron) ${}^{0}_{-1}e$ + $\bar{V}_e$ (anti-neutrino)
- gamma (high E photons) ${}^{0}_{0}\gamma$ [extremely penetrating]
- positron (+ electron) $\overset{1}{{}^{0}e}$ + V_e (neutrino)
- neutron emission $\overset{0}{{}^{1}n}$
- electron capture proton → neutron + V_e + X-rays

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FUSION

theoretically generate more E than fission
3.4x10^{14}J per kg cf. 8x10^{13}J

but must have huge KE to overcome repulsion between positively charged particles (in order of 10^{7} k)

- use particle accelerator (too small for E production)
- use gravitational force (e.g. sun)
- use fission bomb to ingnite fusion bomb

obvious technological problems

recent breakthrough
- use radiation to heat gaseous plasma confined in magnetic field (tokomak apparatus)

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FUSION

join light elements (releases more E, products stable, less r-a)

$${}^{1}_{1}p + {}^{1}_{1}p \rightarrow {}^{2}_{1}D + {}^{0}_{1}e + V_e + E$$
proton proton deuterium positron neutrino energy

$${}^{1}_{1}p + {}^{2}_{1}D \rightarrow {}^{3}_{2}He + {}^{0}_{0}\gamma + E$$
proton deuterium helium-3 photon energy

$${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}p + {}^{0}_{0}\gamma + E$$
helium-3 helium-3 helium-4 protons photon energy

'hydrogen-burning'

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Power production: nuclear energy

Nuclear energy (fission, fusion)
Estimated power production in kWh/d per person

FISSION	mined Uranium	ocean Uranium	mined Thorium
Once-through	0.55	7	4
Fast breeder	33	420	24

FUSION	mined Lithium	ocean Lithium	ocean Deuterium
Fantasy reactor	10	105	30,000

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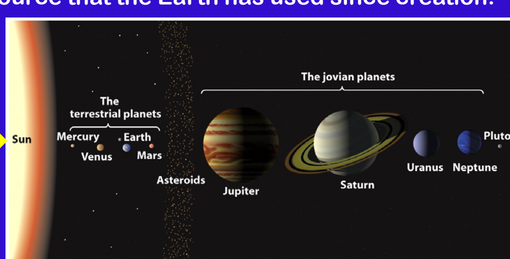
Are we doomed to a nuclear future?

Unequivocally, YES!

But if we are smart, we will use the same nuclear source that the Earth has used since creation!



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Energy flow

solar energy

photosynthesis

chloroplasts

→

6 CO_2 (carbon dioxide) + 6 H_2O (water) $C_6H_{12}O_6$ (glucose) + 6 O_2 (oxygen)

←

mitochondria

glycolysis

chemical energy

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