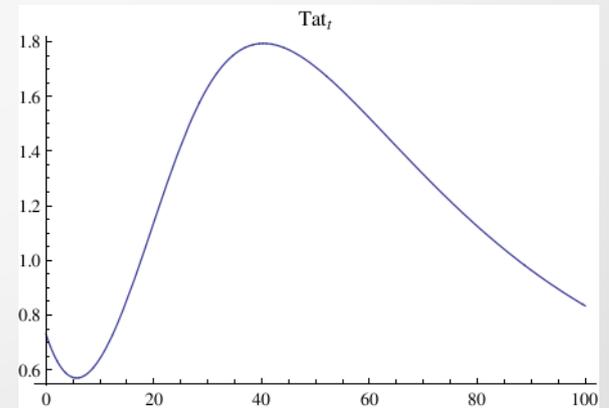
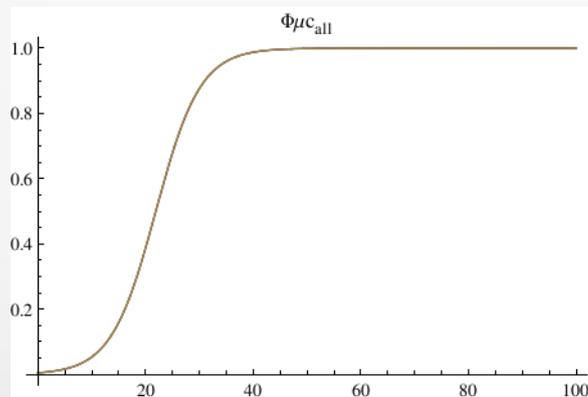
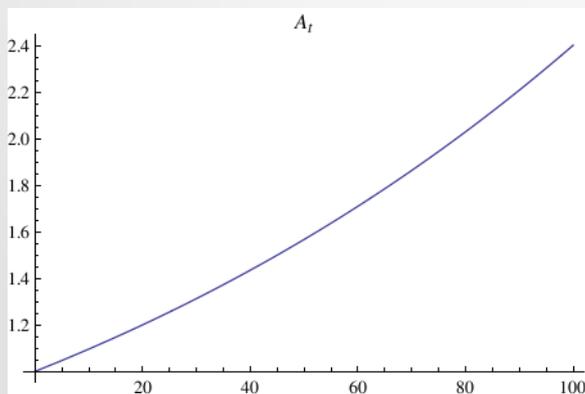


# Dr Stuart Nettleton, This Is Life Today Sydney Think Tank, April 2016

## Climate Change & Energy Policy



# Chernobyl 1986

- The reactor had no containment building
- European media have created the impression that 100s thousands of people were killed
- UN / WHO epidemiological studies
  - damage to people has been remarkably limited - among the general population radiation doses were relatively low and no fatalities
  - radiation deaths - 28 people directly attributable between 1987-2004 ,19 other causes that may be attributable & 40-50 valiant cleanup volunteers
  - never been any deformed children
  - no correlation between high levels of background radiation and cancer
- The damaged reactor was one reactor out of 4 and the 3 others continued operating until 1990s

# Fukushima Daichii

- No deaths from radiation, 15,000 from earthquake & tsunami
- Human error in design (wall 10m too low & generators for pumps not inside) – other nuclear plants hit by the tsunami, one in Northern Japan was at epicentre and hit by much bigger tsunami, another in Tokyo hit but ok
- Radiation 10% of Chernobyl - WHO can't identify epidemiological health effect
- Japan's 48 reactors shut down, only Sendai online
  - \$40bn pa of fossil fuel energy imports to replace nuclear
  - Without nuclear Japan has Paris Agreement target of -26% of 2013 levels by 2030, -37% if it has nuclear
  - Japan only 6% self-sufficient in oil & gas
- Mayor of Fukushima people (in new town) thanked Robert Stone for showing Pandora's Promise – Prism Gen IV promising option for on-site processing of radioactive debris

# Paris Agreement: UNFCCC COP 21

- 190 countries agreed to reduce greenhouse gas emissions
  - 22 Apr 2016 - 175 signed but ratified by only 15 small countries, need 55 covering 55% emissions, have until 2020
- Limit temp rise to 2C (1.5C if possible), already 0.84C
  - requires 50% of energy to be carbon free by 2028, now 9%
  - national plans and 2020 timing consistent with 3-4C
- Australia's controversial target
  - -26% to -28% of 2005 levels by 2030
  - +11% if we don't receive deafforestation concessions

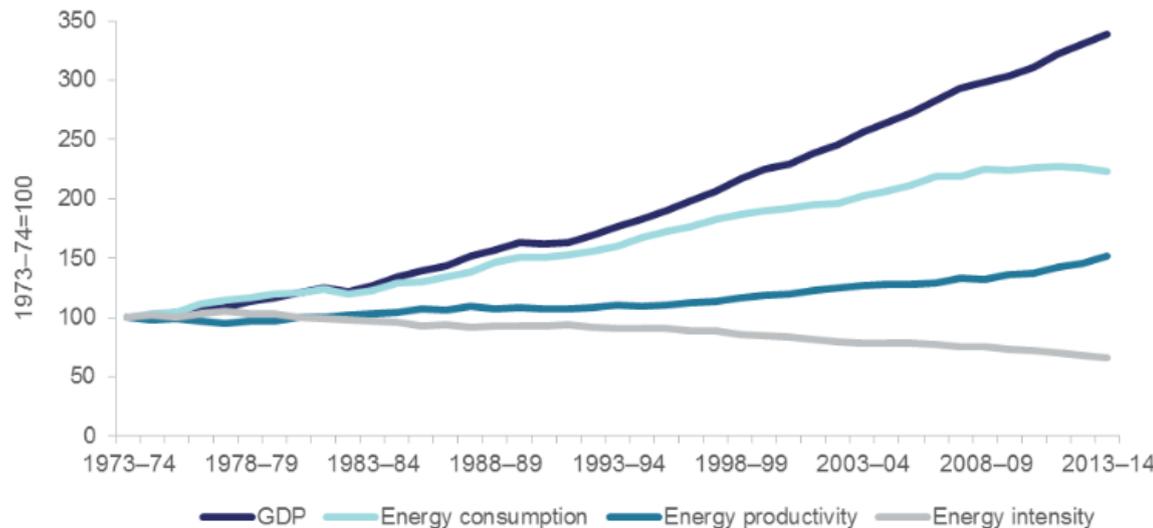
# Population and Resources

- Global population expansion
  - adding 228,000 people per day
  - population expand from 7.2bn today to 9-11 billion
  - improved living standards: 3-4 billion new middle class
  - 80% in mega-cities: increasing from 28 to 70 in 2050
- Huge fossil fuels consumption
  - per day: 3.7m bbls oil, 932kt coal, 395m m<sup>3</sup> gas, generating 4.1mt CO<sub>2</sub>
  - Quite likely that double the energy is needed by 2050

# Australia's challenge

- 6% of all energy from renewables
- to become zero emissions we need to convert the other 94%
- while the size of the pie doubles

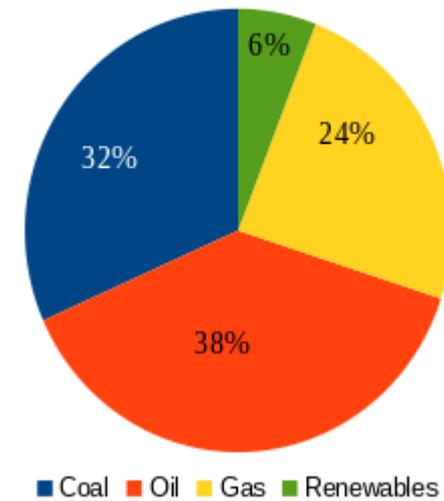
Figure 3.1: Australian energy intensity and energy productivity



Source: Department of Industry and Science (2015) *Australian Energy Statistics*, Table B.

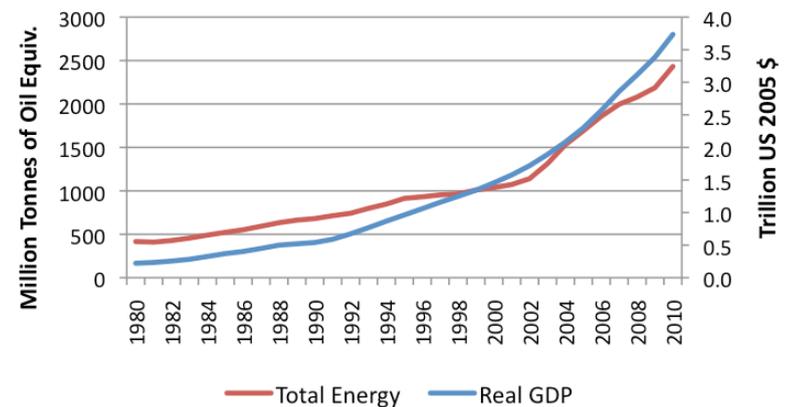
Australian Energy Consumption 2013-14

Australian Energy Statistics (Table C)



■ Coal ■ Oil ■ Gas ■ Renewables

China - Total Energy and Real GDP



# nuclear @ Paris Agreement

- Technology neutral
  - No prescriptive framework of technology specific targets - only 1 mention of renewables
  - Throw everything we have at solving this problem - let nuclear compete on its merits
  - Major change from 2 decades of exclusion - Al Gore & Bill McKibben insisted on 100% renewables
- Pro-nuclear environmental groups represented:
  - James Hansen (Columbia), Kenneth Caldeira (Carnegie), Kerry Emanuel (MIT), Tom Wigley (Uni Adel)
  - Others though screening of Robert Stone's 2013 film Pandora's Promise:
    - Richard Rhodes, Pulitzer Prize Winner "The Making of the Atomic Bomb"
    - Mark Lynas, environmental activist
    - Stewart Brand, Founder and Publisher of the Whole Earth Catalog
    - Gweneth Cravens author "Power to Save the World"
    - Michael Shellenberger, president & Co-founder of the Breakthrough Institut

# James Hansen summarised

- Using fossil fuels is dangerous and staring us in the face
  - Climate impacts are irreversible
  - We are at the point of instability of ice sheets and sea level rise of 7m with consequences that are huge
  - Half the species facing extinction
- Clearly next generation nuclear has a big potential to be part of the solution
  - We need to provide next gen nuclear to China to India as immoral not to because we have used their part of the carbon budget
- Combination of renewables and nuclear
  - Sweden has shown the way forward
  - Nuclear will make the difference between the world missing or achieving climate targets

# Life cycle costs of current renewables & nuclear

Table 1. Estimated levelized cost of new generation resources, 2018

U.S. average levelized costs (2011 \$/megawatthour) for plants entering service in 2018

Plant type	Capacity factor (%)	Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system levelized cost
<b>Dispatchable Technologies</b>						
Conventional Coal	85	65.7	4.1	29.2	1.2	100.1
Advanced Coal	85	84.4	6.8	30.7	1.2	123.0
Advanced Coal with CCS	85	88.4	8.8	37.2	1.2	135.5
<b>Natural Gas-fired</b>						
Conventional Combined Cycle	87	15.8	1.7	48.4	1.2	67.1
Advanced Combined Cycle	87	17.4	2.0	45.0	1.2	65.6
Advanced CC with CCS	87	34.0	4.1	54.1	1.2	93.4
Conventional Combustion Turbine	30	44.2	2.7	80.0	3.4	130.3
Advanced Combustion Turbine	30	30.4	2.6	68.2	3.4	104.6
Advanced Nuclear	90	83.4	11.6	12.3	1.1	108.4
Geothermal	92	76.2	12.0	0.0	1.4	89.6
Biomass	83	53.2	14.3	42.3	1.2	111.0
<b>Non-Dispatchable Technologies</b>						
Wind	34	70.3	13.1	0.0	3.2	86.6
Wind-Offshore	37	193.4	22.4	0.0	5.7	221.5
Solar PV <sup>1</sup>	25	130.4	9.9	0.0	4.0	144.3
Solar Thermal	20	214.2	41.4	0.0	5.9	261.5
Hydro <sup>2</sup>	52	78.1	4.1	6.1	2.0	90.3

## Nuclear Cost Estimates from Recent Public Service Commission Filings

Company	Plant Capacity (MWe)	Overnight Capital Cost (\$/kWe)	Total Project Cost (Billion \$)
SCE&G/Santee Cooper	2,200	3,719	9.8
FP&L	2,200	3,483 – 5,063	12.1 – 18.0
Progress	2,200	4,260 <sup>6</sup>	17.2 – 22.5

## The Cost of New Generating Capacity in Perspective for Generation III/III+ (Nuclear Power Institute Feb 2013)

Assumes gas prices will stay at very low US 2011 levels (however already very high in Europe & elsewhere)

Assumes "old nuclear" capital cost will stay at very high 2011 levels - low cost passive Gen IV coming

Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013 AEO2013 Early Release Overview

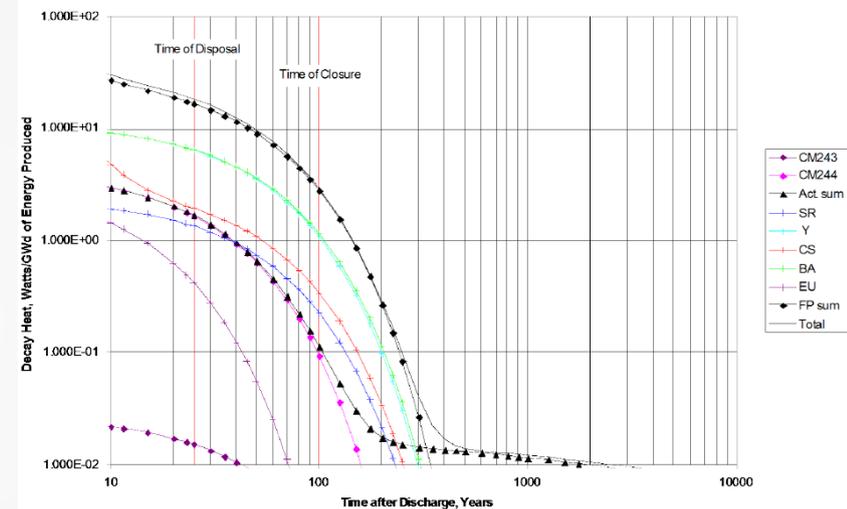
# Most existing nuclear will need to be closed

- Neutron flux embrittles, swells & decreases corrosion resistance
  - Impurity production, atom displacement & ionization
  - Big issue in pressure vessels operating at 2,000 psi
- Core vessel life around 60 years
  - R. A. Knief 2008 (problem 3.19) Vessel has maximum tolerance for  $10^{21}$  neutrons/cm<sup>2</sup> of high energy neutrons (i.e. Fast Fluence >1MeV). Reactor has  $5 \times 10^{11}$  neutrons/cm<sup>2</sup>-sec of Fast Fluence. Life of core =  $10^{21} / 5 \times 10^{11} = 63$  years
- Regulatory approval for increased life
  - Most reactors approaching end of 40 year life
  - Extend life from 40 to 60 years?
    - Should the life of existing reactors be extended?
    - Germany's decision “no”
    - Lot of ongoing research in these areas

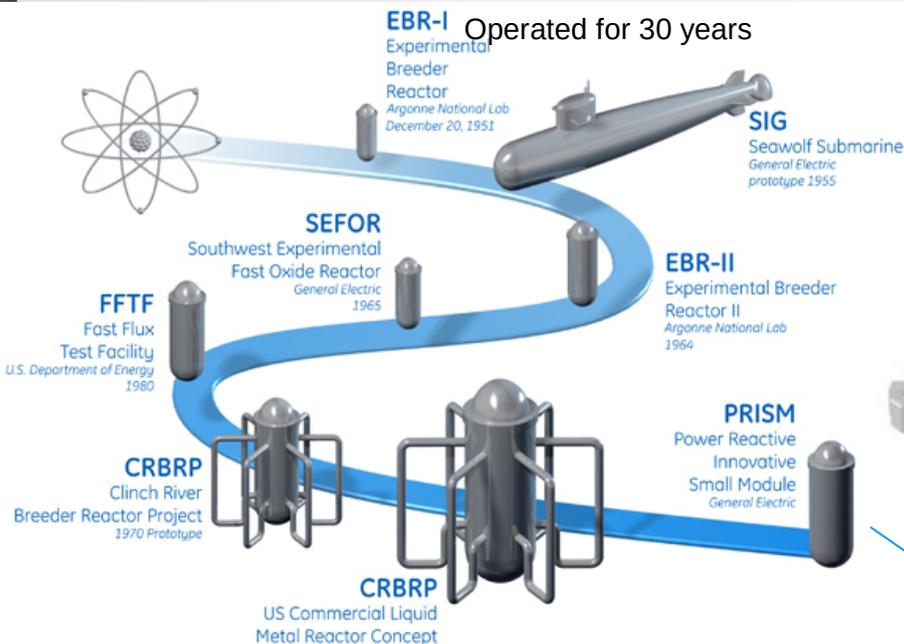
# Gen IV (IFR, fast breeder)

- Start any point in nuclear transmutation cycle
  - Light water reactor nuclear waste, Pu war-heads, Uranium, Thorium
  - Never have to enrich uranium
- No Fukushima-like meltdown – if turn off systems then the reactor stops
- Nuclear waste 0 trace Pu and Actinide fission products in glass or ceramic form
  - 1 tonne pa per 1GW electric capacity
  - Half-life 300 years  $\ll$  10,000 years for  $^{239}\text{Pu}$  &  $^{240}\text{Pu}$
  - Waste to background radiation levels: IFR 800 years, Light Water 10,000 years
- Can't extract weapons grade Pu - need a research reactor
- Uses ~100% of fuel (~0.5% LWR) - David J. C. MacKay, chief scientist at the DECC, UK says British plutonium contains enough energy to run the country's electricity grid for 500 years. "Are fast-breeder reactors the answer to our nuclear waste nightmare?" Pearce, Fred (2012-07-30), The Guardian (London).

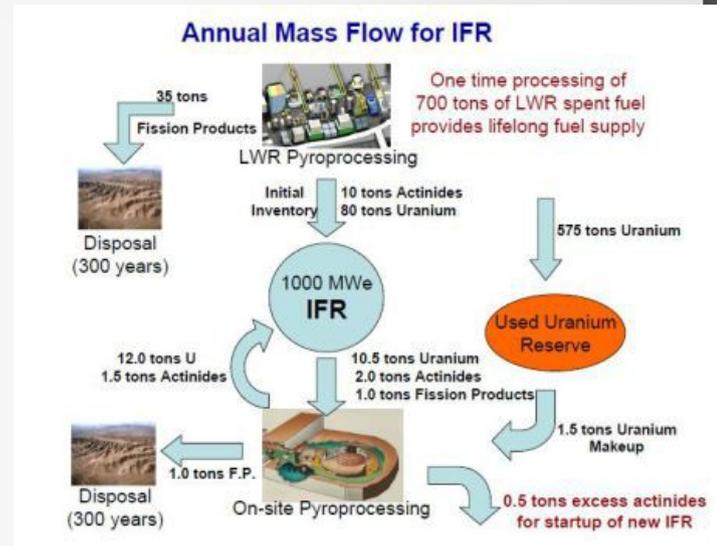
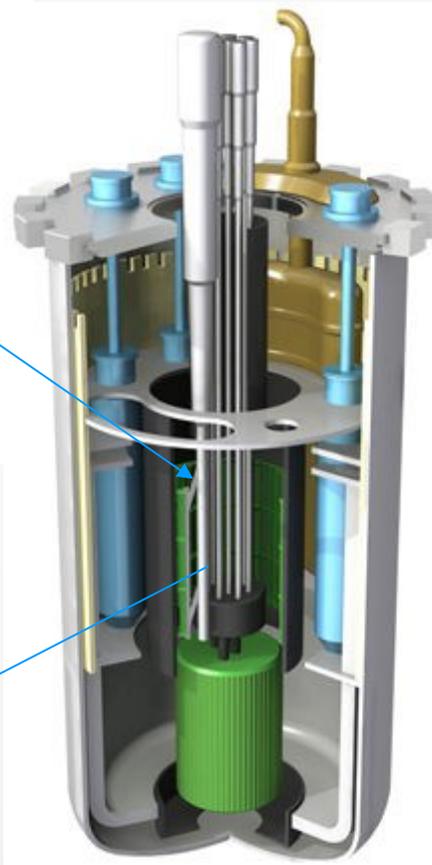
Spent PWR Fuel Decay Heat w/o Pu, Am & Np



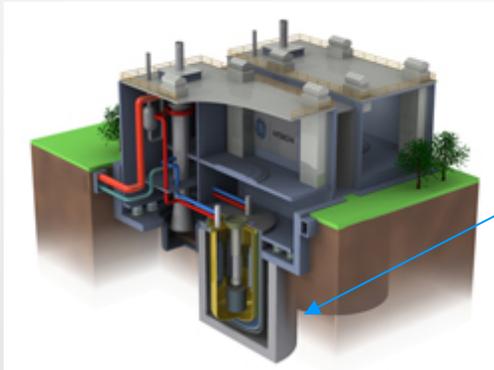
# Gen IV PRISM Power Reactor Innovative Small Module



- 622 MW PRISM block Sodium Cooled & Passively air cooled



UK Chief Scientist says the new 'fast' plants could provide enough zero-emission electricity to power the UK for more than 500 years with existing Pu stocks



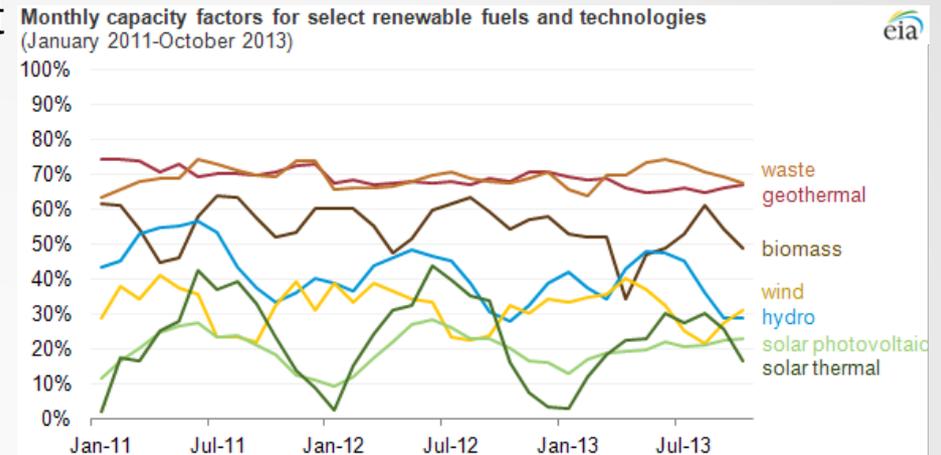
- Source: Barry Brook The Case for Near-term Commercial Demonstration of the Integral Fast Reactor, 23 October 2012 <http://bravenewclimate.com/2012/10/23/the-case-for-near-term-commercial-demonstration-of-the-integral-fast-reactor/#more-5949>

Sources:

- [http://www.ge-energy.com/products\\_and\\_services/products/nuclear\\_energy/prism\\_sodium\\_cooled\\_reactor.jsp](http://www.ge-energy.com/products_and_services/products/nuclear_energy/prism_sodium_cooled_reactor.jsp)
- <http://www.theengineer.co.uk/energy-and-environment/in-depth/prism-project-a-proposal-for-the-uks-problem-plutonium/1016276.article>

# Are renewables sufficient for Paris Agreement?

- Many people think renewables will be sufficient
- Issues:
  - Can ramp-up wind and solar to a certain point but then face the issue that low 0.3 capacity factors require natural gas backup
  - Environmentalists pessimistic unless we use a lot less energy per capita
  - Can't put many solar panels on the roof of megacity high rise - need terawatts 24x7
  - Wind power requires a lot of land – for example nearly 2,200 square km of turbine-covered land to equal the output of a typical 2 unit nuclear plant and huge cabling costs
  - A person living today uses about four times as much energy as a person did in the early 1900s - we can't keep reducing - we are finding new uses
- Google's RE<C project concluded after 4 years that renewable energy:
  - not cheaper than coal
  - incapable of providing the amount of energy that modern societies need to operate



# US first mover green energy bubble has burst

- Since 2009 dozens of solar-focused companies around the globe have disappeared
- Today: SunEdison world's largest renewable energy development co bankruptcy from \$10bn valuation
- Solyndra solar module manufacturer burned through \$527m in government loans & closed
- Abengoa multinational solar & biofuel giant in restructuring proceedings
- Solazyme algae-based biofuels abandoned the energy markets
- NRG alternative energy converting to conventional energy
- First Solar solar panels & develops solar farms being sued by shareholders
- All failures due to lack of viable business model - no investor confidence in "build it & they will come"
- Now must find enough customers to support the costly infrastructure green must first build, despite:
  - Paris Agreement
  - Extension of US tax credits for green energy
  - US Senate broad energy bill that promotes clean energy
  - US government approved a major new transmission line to move wind-generated electricity east from the Great Plains

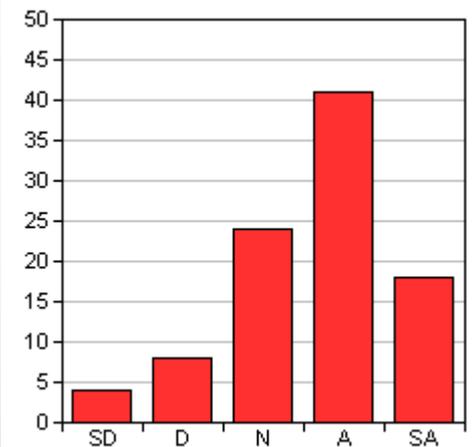
# Decarbonise by 2050 with new IFRs

- Replace current fossil fuel electricity generation (61 pa) & most of the world's 500 nuclear plants (40 year life 63yr embrittlement failure) (16 pa)
- Provide additional energy for population increase from 7.1bn to 9.6-11bn and increased living standards (54 pa)
- Provide sufficient energy to produce sufficient water by desalination (almost for free as this is what the IFRs do at night)
- Convert the transport sector from oil to electricity and hydrogen (eg electrolysis) (almost for free as this is what the IFRs do at night)
- France and Sweden have shown a large and fast build program can work
  - France in 1979 was 20% nuclear, 11 years later in 1990 was 80% nuclear and the rest renewables - at the same time doubled its consumption with conversion of home heating and mass transport to electric
  - All without mass producible reactors like the Prism reactor

# Summary

- Nuclear is 75 years old but in some ways still in early stages - risk and fear abound, proving safety is not enough
- Gen IV Integral Fast Reactor - passively safe, minimal nuclear waste, cleans up nuclear waste
  - mass production is cheaper and faster (36 months) - potential to meet the required build program
  - water desalination and hydrogen fuel to convert the transport sector
  - ability to vary power and complement renewables low capacity factor - large amounts of Gen IV nuclear is the only feasible option to enable & maximise renewables
- Renewables and Gen IV nuclear together provide the means to solve climate change
  - We need to act very quickly to safeguard climate risk - have to continue to use new types of nuclear energy while we become comfortable with it
  - Nuclear power is at the nub of the Obama administration's "all of the above" strategy – Trump supports & Clinton "agnostic"
  - Microsoft founder Bill Gates and PayPal co-founder Peter Thiel invested \$2 billion into a few dozen nuclear start-ups
  - Young people are receptive to Gen IV nuclear

*Student survey: I think we should use both renewables and nuclear power to solve global warming*





Questions

Thank you