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Technological Status & Economics of Nuclear and Renewable Sources of Electricity

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Context: Risks of Nuclear Energy Post 2000 are Unchanged or Worse

- Proliferation of nuclear weapons via enrichment or reprocessing pathways – WORSE
- Superb terrorist target – WORSE since 11 Sept. 2001
- Risk of rare but devastating accidents – WORSE than believed pre-Fukushima
- Long-term management of high-level wastes – UNCHANGED
- Managing low-level wastes: several cancers per year over several 100,000 years – UNCHANGED
- High cost – MUCH WORSE

Current Global Status of Nuclear Energy

- At April 2011, 437 operating reactors in 30 countries; 7 fewer than 2004 peak
- Total generating capacity 375 GW (pre-Fukushima), generating 2558 TWh p.a. (2009) -- slight decline since 2005
- Proportion of electrical energy generation has declined substantially from 17% in 2001 to about 13% in 2011
- Biggest growth in China, also some growth in Russia, India and South Korea
- Only 2 reactors (Gen III) under construction in western countries (Finland & France); both are over time & over budget
- Many retirements expected over next 20 years
- Further decline in % generation inevitable
- Economic implications of decline

Four Generations of Nuclear Power Stations

Generation	Description
I	Early British (Magnox); almost extinct
II	Almost all operating commercial reactors. Commercially available, but rarely built within scheduled time and budget.
III	EPR under construction in Europe & AP1000 in China. Slightly improved versions of Gen II. Some ‘passive’ systems. Pre-commercial stage; no operating experience.
IV	Mostly fast (neutron) reactors; capacity to ‘breed’ plutonium. R&D & Demonstration stages.

Global Status of Nuclear & Renewable Technologies

Market penetration ↑

			Energy efficiency; hydro; GenII nuclear
			On-shore wind
			Biomass combustion
		Off-shore wind	Conventional PV
Novel PV; Integral Fast Reactor	Marine; hot rocks; fast reactor (GenIV)	Solar thermal; GenIII nuclear	Conventional tidal & geothermal
R&D	**Demonstration**	**Pre-commercial**	**Commercial**

Technology status →

After Foxon (2005)

Weapons Proliferation Partially or Totally from Non-Military Nuclear Technology

<u>Programs producing bombs</u>

- UK
- France
- China
- India
- Pakistan
- North Korea
- South Africa (closed)
- Iran (in progress)

<u>Programs discontinued before bombs produced</u>

- Brazil
- Argentina
- Algeria
- South Korea
- Taiwan (twice)
- Libya
- Australia

Each new nuclear power country directly or indirectly increases risk of nuclear war

Problems & Errors in Estimating Nuclear Costs

- Limited data: best from UK and USA
- Biased cost estimates from manufacturers
- Choice of unrealistically low discount rate
- Using accounting methods that shrink capital cost
- Overestimating operating performance (capacity factor)
- Ignoring subsidies and other life-cycle costs, especially realistic insurance.
  Without these subsidies, no country would have nuclear energy.

Incomplete Economics of Fukushima Melt-Downs

- Housing 180,000 evacuees
- Health & social security costs
- 30 km radius exclusion zone
- Decommissioning the reactors
- Radioactivity damage to local agriculture, fisheries, etc
- Impact on national industries, eg tourism, manufacturing
- Partial cost estimate by Japan Center for Economic Research: US$71–250 billion
- Most costs uninsured: TEPCO only covered for $1.5 billion
- Evacuation of Tokyo 'worst case scenario'

Subsidies to Nuclear Energy in USA

- Research & development
- Uranium enrichment
- Waste management
- Decommissioning
- Stranded assets paid for by ratepayers and taxpayers
- Loan guarantees covered by taxpayers
- Limited liabilities for accidents covered by communities
- Accumulated total estimated = 2006US $100 billion (Public Citizen) and US $9 billion p.a. (Koplow 2007)

Nuclear Capital Cost Escalation, USA, 2003–09

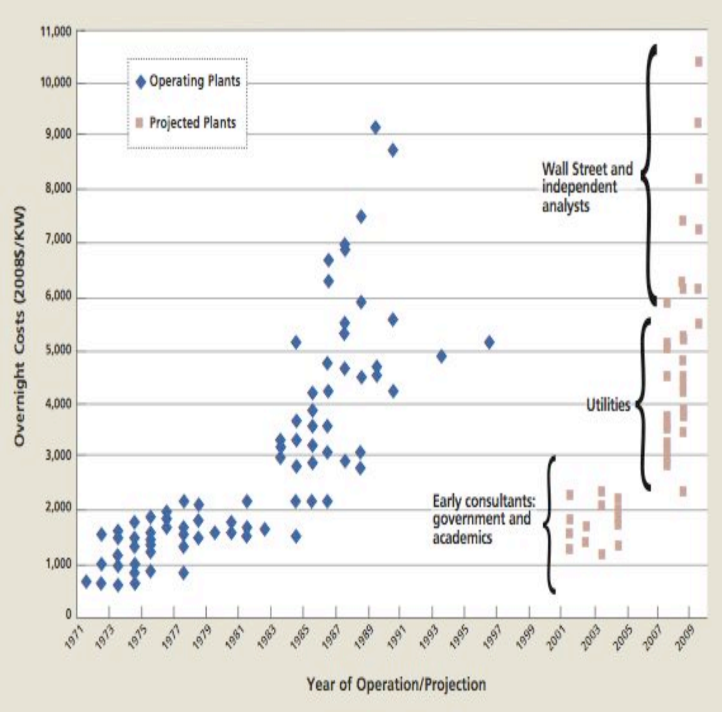
Study	Capital cost (US $/kW)	Energy cost* (US c/kWh)
MIT (2003)	2000 + IDC	6.7–7.5
Keystone Center (2007)	3600–4000	8.3–11.1
Harding (2007)	4300–4550	10–12.5
MIT (2009) update	4000 + IDC	8.4
Moody's (2008)	7500	—
Severance (2009)	7400 10,500 projected	17.5–21 25–30

* Cost of energy depends on assumed discount rate, financing method & capacity factor; IDC = interest during construction

‘Overnight’ Capital Costs of Nuclear Power, USA

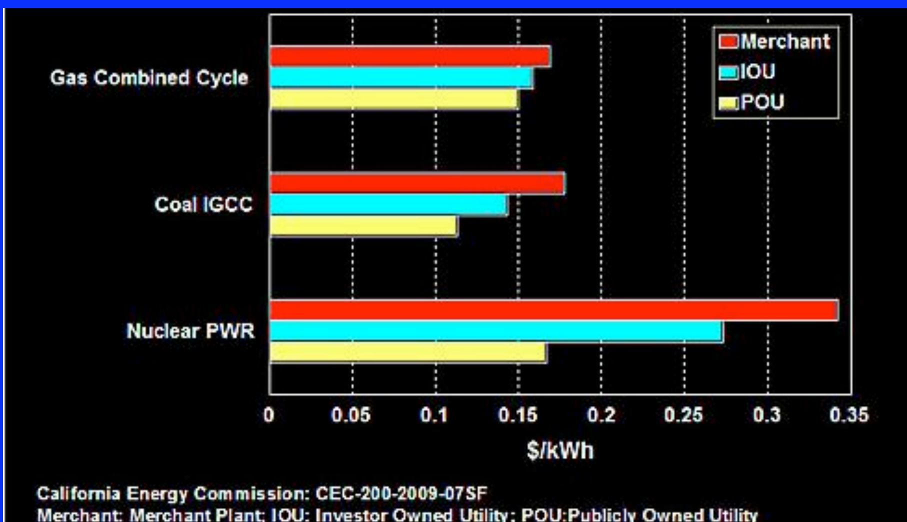
(Cooper 2009)

‘Overnight’ costs ignore interest during construction.



Projected Costs of Electrical Energy, California 2018

Source: California Energy Commission (2010, Table 5)



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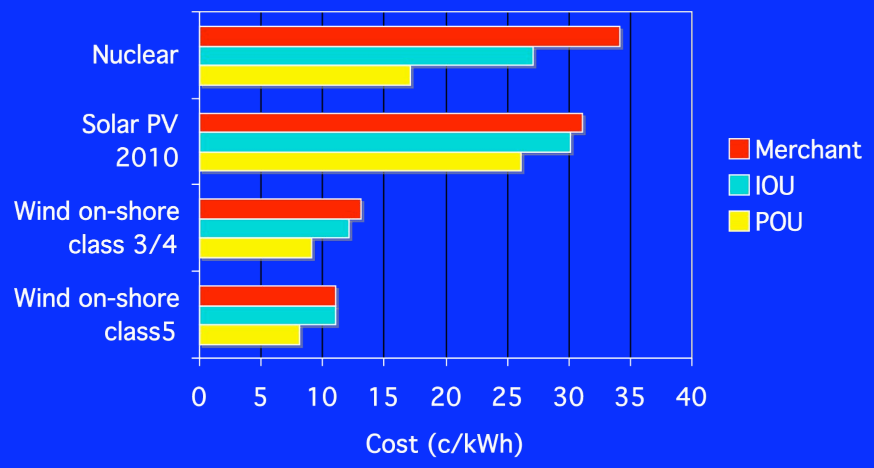


IOU = Investor Owned Utility; POU = Public Owned Utility; costs are the subsidised costs.

Projected Costs of Electrical Energy 2018

Source: California Energy Commission (2010, Table 5)

Technology	Rated power (MWe)	Merchant (c/kWh)	IOU (c/kWh)	POU (c/kWh)
Gas turbine, open cycle, peak-load	100	95	74	37
Combined cycle gas	500	17	16	15
Coal IGCC without CCS	300	18	14	11
Biomass IGCC without CCS	30	17	16	14
Nuclear, Westinghouse AP-1000	960	34	27	17
Geothermal flash	30	12	13	12
Hydro, small, developed site	15	16	16	12
Solar, parabolic trough	250	30	29	26
Solar PV, single axis	25	31	30	26
Wind, on-shore, class 3/4 site	50	13	12	9
Wind, on-shore, class 5 site	100	11	11	8
Wind, off-shore, class 5 site	350	211	20	15

Source: California Energy Commission, (Klein 2010, Table 5).

Notes: In-service year: 2018; currency: nominal US 2018 dollars; The costs include insurance costs and US federal and Californian tax benefits; nuclear and off-shore wind appear in this 2018 table. The general increase in prices in this table, compared with Table 4, reflects the end of the federal tax credits and the use of nominal currency.

Some Low-Carbon, Non-Nuclear, Energy Scenarios

Year	Location	Authors	Targets
2000	Global	Sørensen & Meibom	100% RE, central & local scenarios
2011	Global	Jacobson & Delucchi	100% RE
2011	Global	Ecofys	100% RE
2008	N. Europe	Sørensen	100% RE with H_2
2010	UK	Kemp & Wexler	Zero carbon (all sectors)
2010	Germany	Klaus et al.	100% RElec
2009	Denmark	Lund & Mathiesen	100% RE
2003	Japan	Lehmann	6 scenarios up to 100% RE; H_2 storage
2010	NZ	Mason et al.	100% RElec
2011	Ireland	Connelly et al.	100% RE
2011	Australia	Elliston, Diesendorf, MacGill	100% RElec

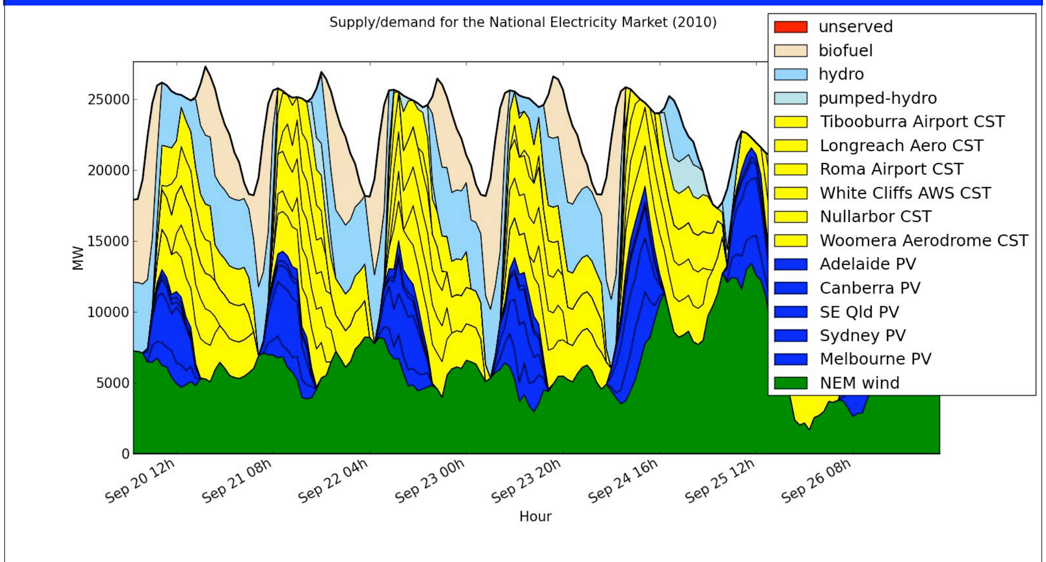
RE = Renewable energy; RElec = Renewable electricity

Simulation of 100% RE in Australian National Electricity Market: Highlights

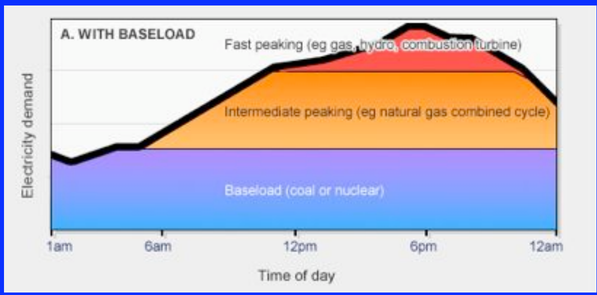
Elliston, Diesendorf & MacGill (2011; 2012 submitted)

- Hour by hour simulation of actual demand and hypothetical renewable energy supply in 2010.
- Supply system comprises commercially available technologies --wind, PV, CST + thermal storage, hydro & biofuelled gas turbines
- Actual hourly solar and wind data
- A range of 100% renewable electricity systems meet the reliability standard.
- Principal challenge is meeting peak demand on winter evenings.
- Solved by biofuelled gas turbines and demand management.
- The concept of 'base-load' power plants is found to be redundant.

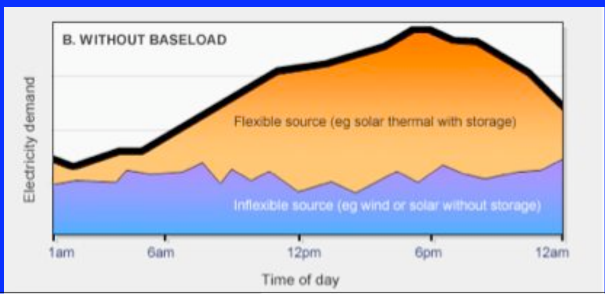
Simulation of 100% Renewables in Australian National Electricity Market: A Sample



Meeting Demand with & without Base-Load Stations



Source:
David Mills



Principal Renewable Electricity Options for Malaysia

- 'Negawatts' to reduce wasteful demand: eg efficient energy use, solar hot water and solar air conditioning
- Solar photovoltaics (PV), with optional battery storage for evening peaks
- Biomass from crop and forest residues -- both direct combustion and gasification before combustion; base-load or peak-load
- Mini-hydro
- Geothermal: both in Malaysia and possibly by transmission line from Indonesia
- Long-term future trade in RE: eg solar hydrogen imported in tankers from Australia

Conclusion

- No operating experience with Gen III & IV nuclear ==> little basis for costing
- True costs of nuclear are much greater than costs claimed by proponents
- Nuclear needs huge subsidies, which take resources from health, education, etc.
- Since 2002, capital costs of nuclear escalated rapidly; meanwhile costs of renewables are declining, especially PV
- In 2010, nuclear mid-range Wall St ‘overnight’ cost estimates could not compete with most energy efficiency, solar hot water, landfill gas, on-shore wind, most large-scale hydro, or bioelectricity from residues
- In addition, by 2018, it’s unlikely that nuclear could compete with off-shore wind, concentrated solar thermal with thermal storage, or even PV
- Nuclear involves huge construction projects and so is a very slow technology to grow and deploy
- Malaysia has significant renewable energy resources, which offer clean energy, more local employment and rapid deployment