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Economies of Scale v Economies of Volume – LWRs

Nuclear Institute - SMR Conference

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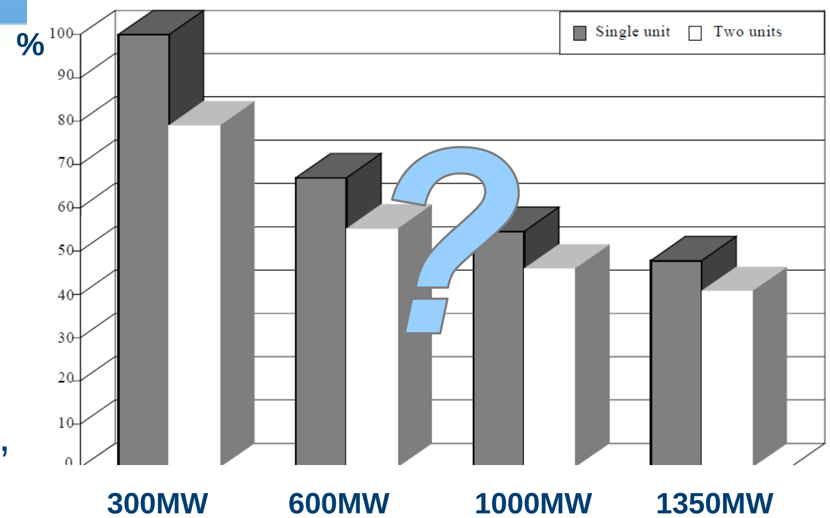
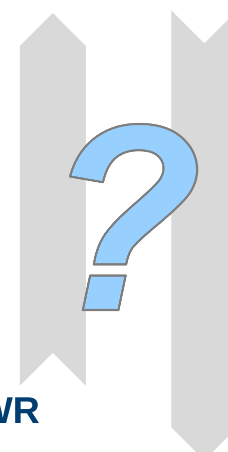
Conventional View of the Cost Problem

- Specific costs fall with increasing unit size;
- First of class has additional one-off costs of ~20%
- Predicted unit scaling index range varies with commodity: -0.8 structures, to -0.2 turbines;
- Some cost savings for twin over single units but afterwards savings are small;
- Standardisation and shorter construction timescale are the best ways of reducing capital costs;
- SMRs will have a big economic hill to climb.



OECD-NEA Reduction of Capital Costs in NPP 2000 [2]

Scaled SMR £7k/kWe



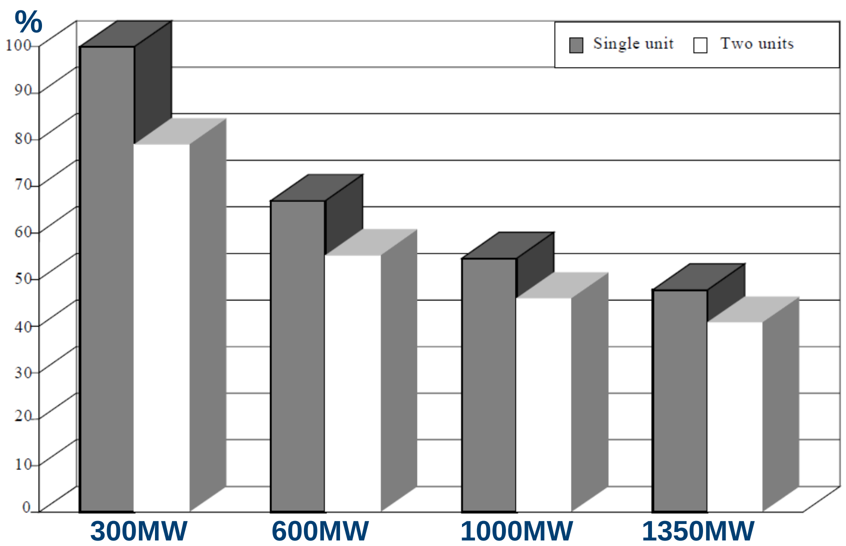
Large LWR £3k/kWe

1. Design simplification
2. Multiple units one site
3. Production learning
4. Standardisation
5. Short build schedule
6. Finance savings

SMR £2.4k/kWe

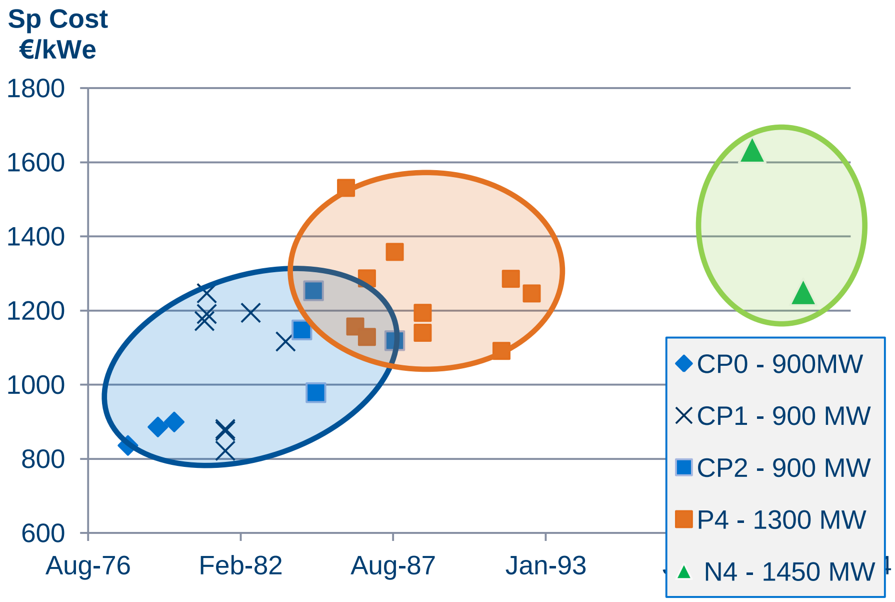
Scaling: Forecasts meet Reality - France

- Cost forecasts based on power scaling effect are unsupported by the data for France.



Forecast Scaling Effect - France

OECD-NEA Reduction of Capital Costs in NPP 2000 [2]



French Data - Specific Construction Costs €/kWe 2010

Cour de Compte (2012) [13]

Costing Methodology

$$\textit{Specific Cost/Specific Cost}_0 = (\textit{Power/Power}_0)^a * (y)^b$$

Scaling + Learning + Regulation

Specific Cost:

a = 0 no scaling

a <0 scaling effects:

a is often taken to be in range **-0.5 to -0.35**

Wright Progress index [8]

y % man-time saving for *b* doublings of unit/volume, *y* in the range 70-100%

where *b* = Ln(*n*)/Ln(2) for ***n*** units

Nuclear Industry: Learning rate (1-*y*) = **3-5%**

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Power Scaling Indices

Power scale index = Specific power index +1

- Major power scaling survey used by Carelli [3] SMR study from Bowers 1983 [4] covering 1968-1982;
- OECD/NEA 2000 [2] based on Woite 1978 [3]

  Whole plant scale index: 0.4-0.7, with subsystems indices:

Typical scaling factors	
Package	**Scaling factor (n)**
Structures	0.2
NSSS	0.3
BOP	0.4
Turbine plant	0.75
Electric plant	0.37
Miscellaneous	0.2

- Similar figures in OECD/NEA SMR study 2011 [5]
- Scale indices based on:
  - Part of the program,
  - estimates and actual
  - Build duration independence fallacy.

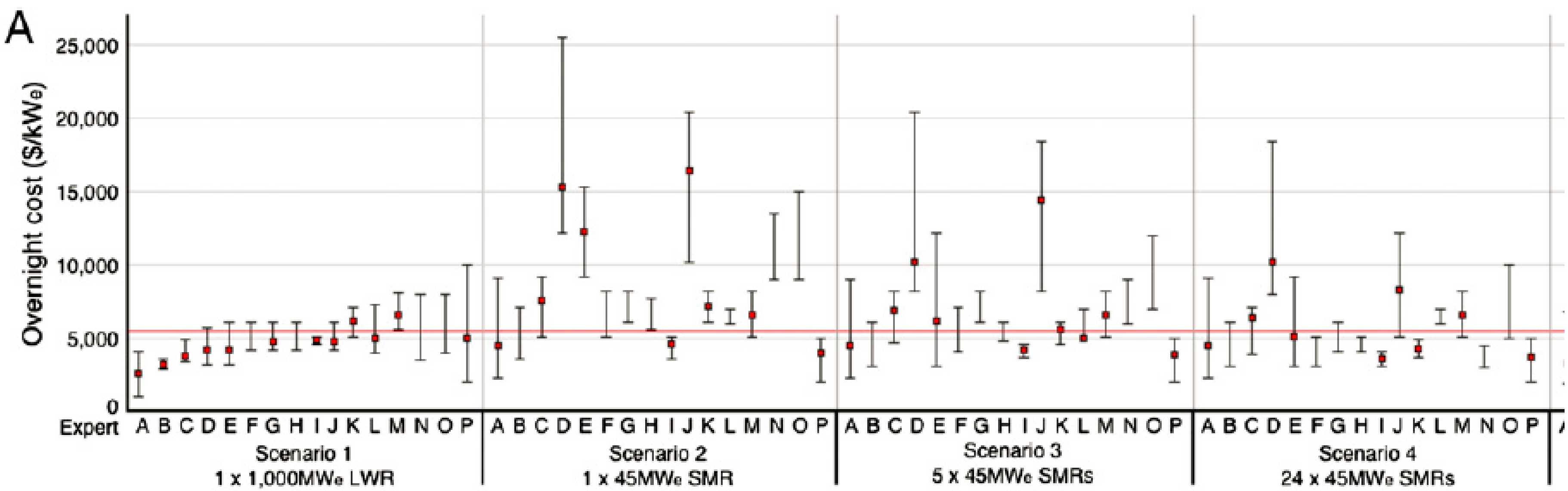
Author	Year	Scale exponent n	Note
[–]	1968	0.75	LWR total cost
[–]	1968	0.51	Total cost
McNelly and Koke	1969	0.64	Total cost
Bennett Bowers	1971	0.68	Total cost
Leedy and Scott	1973	0.4	LWR direct Cost
Davis	1975	0.47	BWR total cost
Mandel	1976	0.46	LWR total Cost
Woite	1976	0.71	Direct and indirect costs
Comtois	1977	0.86	LWR total costs
	1977	0.76	LWR total costs
Mooz, Rand	1978	0.8 / 0.5 / 0.7	LWR regression analysis of historical data; marginal statistical significance. Different assumptions
Mooz, Rand	1979	1	LWR regression analysis of historical nuclear plants; no statistical-significant economies of scale was found
Crowley	1978	0.45	Direct and indirect costs
Woite	1979	0.4	PWR direct and indirect costs
Gehring	1979	0.24	LWR direct and indirect costs
	1979	0.49	Total costs. It was used CONCEPT CODE 5
Fjeldsted	1980	0.59	Total costs; source: F.S. Aschenr, Planning Fundamentals of Thermal Power Plants, John Wiley and Sons, New York (1978) Include allowance for escalation and interest during construction
McMahon	1980	0.43	Direct and indirect costs
Nieves et al., Battelle	1980	0.25	Regression analysis of historical data; direct and indirect costs and constant dollar interest during construction. For nuclear units Komanoff found a 13% cost reduction in €/kW(e) for doubled size
Komanoff	1981	0.8	Regression analysis of historical data; direct and indirect costs
McMahon	1981	0.43	Total costs; 0.92 for 100–600-MW(e) oil fired units
Crowley	1981	0.4	Direct costs
Nobile and Kettler	1982	0.63	Regression analysis of historical data; direct and indirect costs and constant dollar interest during construction.
	1982	0.53	LWR Direct and indirect costs.
	1982	0.63	LWR Engineering cost estimates
Perl	1982	0.49	Regression analysis of historical data

SMR Economics – Cost Data Analyses

Country (plants)	Sp. Power	Learning	Comment	Reference
US (67)	0.14	3-5%	Extended build duration of larger units absorbs any scale savings. Learning offset by regulatory changes. FOAK +20%	Cantor & Hewlett 1988 [11] U of Chicago 2004 [12]
France (58)	0.15	0-10%	Extended build duration larger units absorbs any scale savings. Onsite learning high 10% but programme effects offset by regulatory changes	Cour de Compte [13] Rangel & Levesque [14]
Japan (34)	0.07	as US above	Better correlation with total cost than overnight – learning derived statistically –.fit data. FOAK +20%	Marshall & Navarro [15]
UK Magnox (8)	-0.14	~5%	Some scale & learning – AGRs little of either!	Hunt [16]
S Korea (12)	0	5%	OPR 1000 benefited from strong drive for learning. No scale effect is evident.	Adjusted published KEPCO data - APR1400 estimates as not complete.
Canada (12)	0	0%	No consistent power scaling or learning effects evident.	Thomas [17]

Expert Estimates of SMR costs

- Group of 23 separate industry estimated cost of large LWR (1000MW), single and multiple NuScale (45MW) and mPower (225MW) systems – Abdulla [1]
- Clear consensus that SMRs would be quicker to build 33-37 versus 58 months;
- SMR cost estimates have a wide range, with large uncertainties – but give an impression



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Break-even Volumes (Reactor Units)

SMRs can be cost competitive

200MW Sp. Power Learning	-0.35	-0.3	-0.25	-0.2	-0.15	-0.1
3%	>500	>500	>500	>500	>500	>500
4%	>500	>500	>500	>500	>500	3
5%	>500	>500	>500	>500	32	2
6%	>500	>500	>500	95	10	2
7%	>500	>500	218	27	6	2
8%	>500	>500	63	13	4	2
9%	>500	146	29	9	3	2
10%	445	62	17	6	3	2

100MW Sp. Power Learning	-0.35	-0.3	-0.25	-0.2	-0.15	-0.1
3%	>500	>500	>500	>500	>500	>500
4%	>500	>500	>500	>500	>500	3
5%	>500	>500	>500	>500	>500	2
6%	>500	>500	>500	>500	77	2
7%	>500	>500	>500	>500	23	3
8%	>500	>500	>500	121	12	3
9%	>500	>500	>500	48	8	2
10%	>500	>500	262	25	6	2

- SMRs will have higher costs if power scaling is important and learning rates are low;
- SMRs can be cost effective for specific scale indices ~-0.2 and learning rates > 6%;
- Number of units to become competitive v LR in relative small ~3-50 (6-10GW) for 200MW unit;
- 100MW unit reactor size has a narrower feasible range than 200MW unit size.

Modelled values:

- Comparison between LR - 1000MW with SMR - 100/200MW unit size;
- Reactor costs split 50/50 labour & materials, Materials learning rate 2% applied to all cases;
- LR comparator with overall learning rate of 3%, including 2% for materials;
- Project interest rate 8% for construction periods assumed: SMR: 36 months, LR: 60 months.

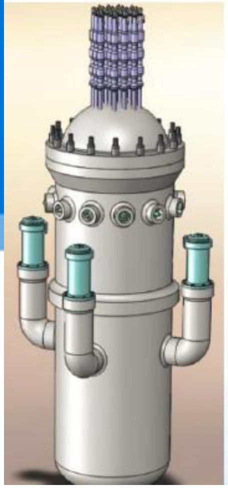
Break-even Volumes (GWs)

	Specific Power Scale	Overall Learning	Break-Even	Comment
Conventional assumptions	-0.35	3%	>100GW	Not economically feasible
Low power scaling & Learning	-0.2	3%	>100GW	Ditto
Low power scaling , Mid Learning	-0.2	7.5%	2.8GW for 200MW 15GW for 100MW	Significant contribution of lower construction interest for viability
Low power scaling, High Learning	-0.2	10%	1GW for both 100 & 200MW	Very competitive costs – unit size: determined by supply chain needs.

Potential of designed for manufacture reactor system

Conditions for Cost Competitive SMRs

ACP100



Scaling:

- Simplify the design, less components, less systems;
- Operate within current LWR & steam technology understanding, not at the edge;
- Design plant for manufacture, not construction: whole plant and systems, not just the reactor vessels and components.
- One design that can accommodate most of world's requirements – a global standard 50/60 Hz
- Alignment of design certification standards, with a level stability of regulation.

Learning:

- Design for factory manufacture and site assembly - whole plant and all systems;
- Detailed design for manufacture done with global suppliers/partners;
- Manufacturing engineering, jigs, tools and fixtures as part of development;
- Launch and forward order profile that support a minimum supply chain 'drum beat';
- Global supply chain that ensures 'learning by doing' – 10 per year minimum?

Are these the skills of low volume manufacturing rather than construction?

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