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SMRs will transform the Nuclear Industry

ICE – BuildOffsite 2016 Conference

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April 2016

UK Energy Policy
– mix of clean sources 80% cut CO_2 by 2050

- UK Government **energy policy is now:**
  - **Double the scale of electricity** in our energy mix by 2050: - supplied by:
    - 30,000 large **wind**mills ~80GWe (nominal) or 20-25 GWe (mean)
    - Some **gas** to fill the gap, balance the system and set the price level;
    - **16 GWe of large nuclear** to replace old AGRs & coal, using multiple reactor designs:

      4 EPRs (1650MWe) by EDF

      4 or 5 ABWRs (1350MWe) by Hitachi

      3 AP1000 (1100MWe) by NuGen Westinghouse/Engie
    - Second phase ~**25 GWe lo-CO_2 r**equired.

EDF/AREVA - EPR

Hitachi/Horizon - ABWR

NuGen/Westinghouse - AP1000

SMRs in UK

B&W/Bechtel mPower Reactor

- SMRs based on LWR technology considered now in UK because:
  - Construction cost and scale of conventional reactors make them:
    - Too **big to fund**,
    - Too **slow to construct** to meet power market needs;
    - Too **expensive** to make nuclear energy **competitive**.
- **SMRs** make use of the **economies of volume** not of scale**;**
- **SMRs** will require the whole nuclear supply chain to be redesigned, and many components and systems - to be designed for factory manufacture and site assembly;
- **Support for SMR development** – preparation for licensing, sites, funding of FOAK?

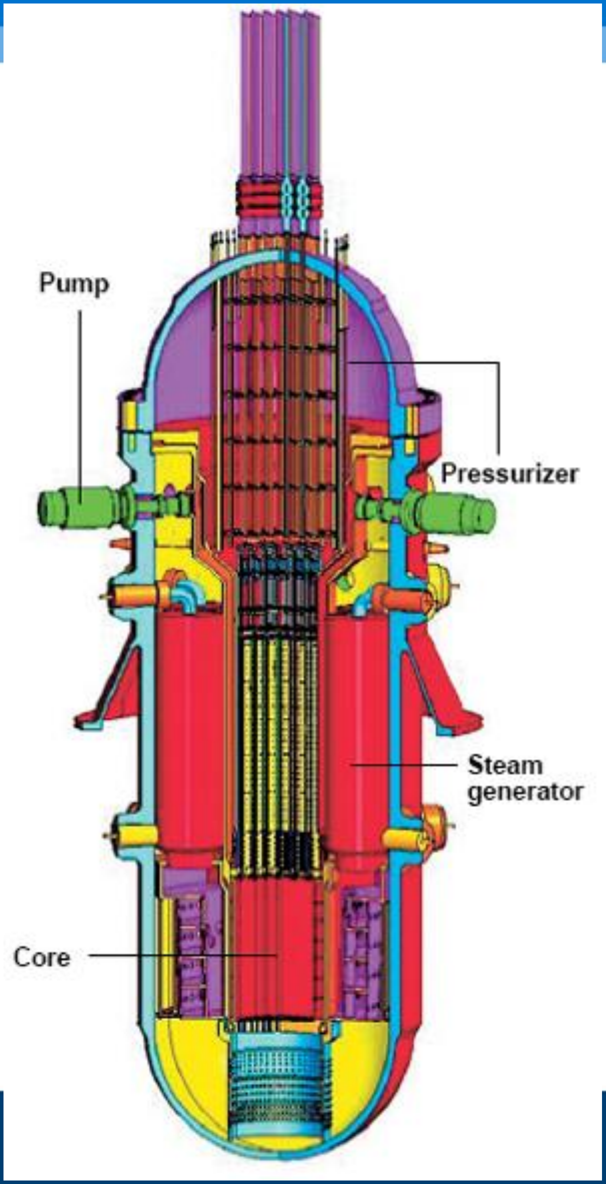
SMRs - change the industry

SMR **Small Modular Reactor**

- **Small** less than 300MWe
- **Modular** either add power incrementally,
  or made in modules
- **Reactor** realistic proposals for deployment
  in 2030s are Light Water systems

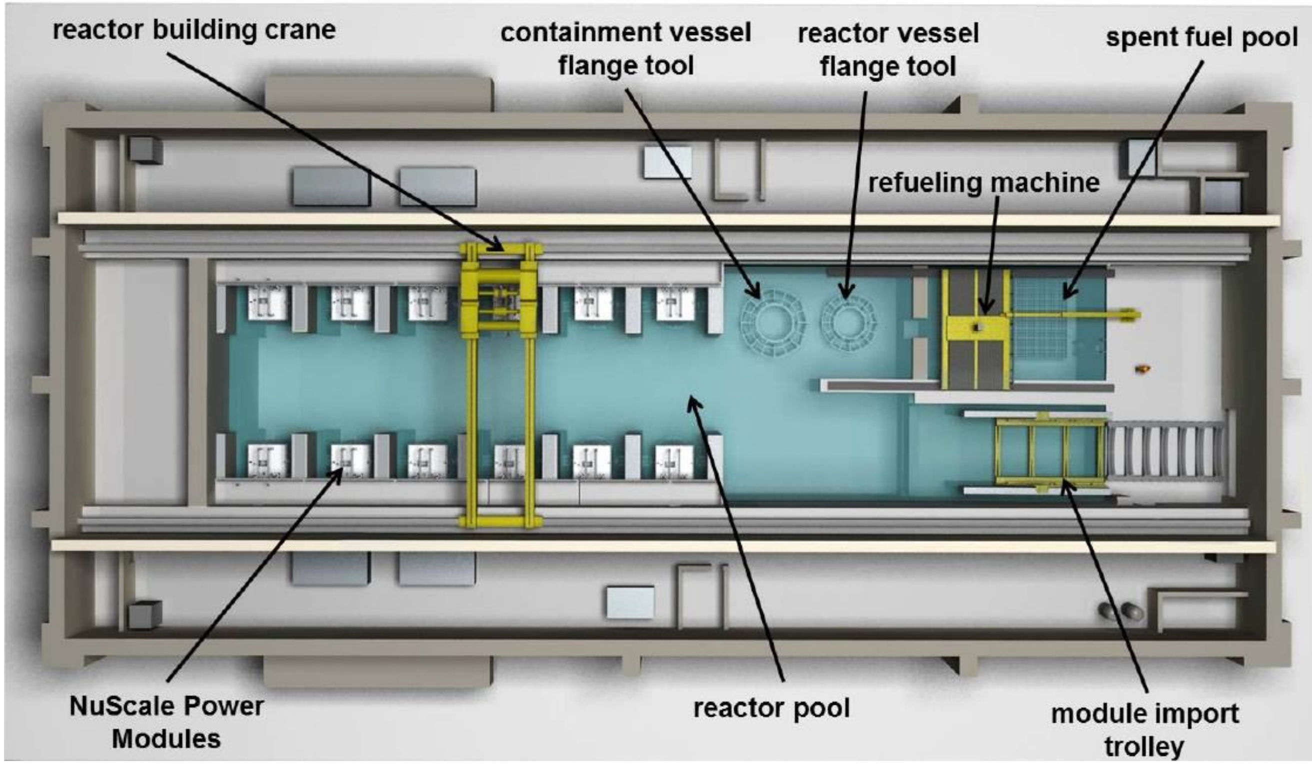
15,000 reactor years of experience,

innovation - how they are made.



SMART Korea

Modules and Modular

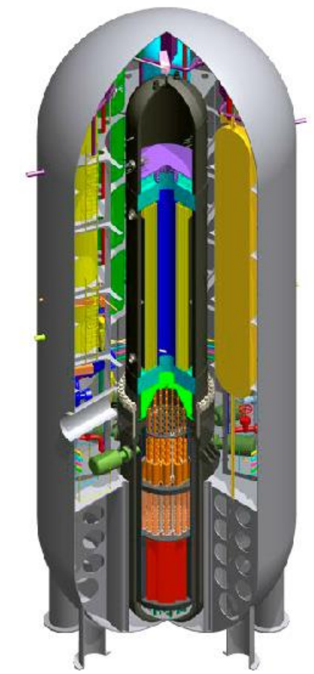


NuScale Power plant with 12 Power Modules – 540MWe

NuScale 45 MWe Power Module

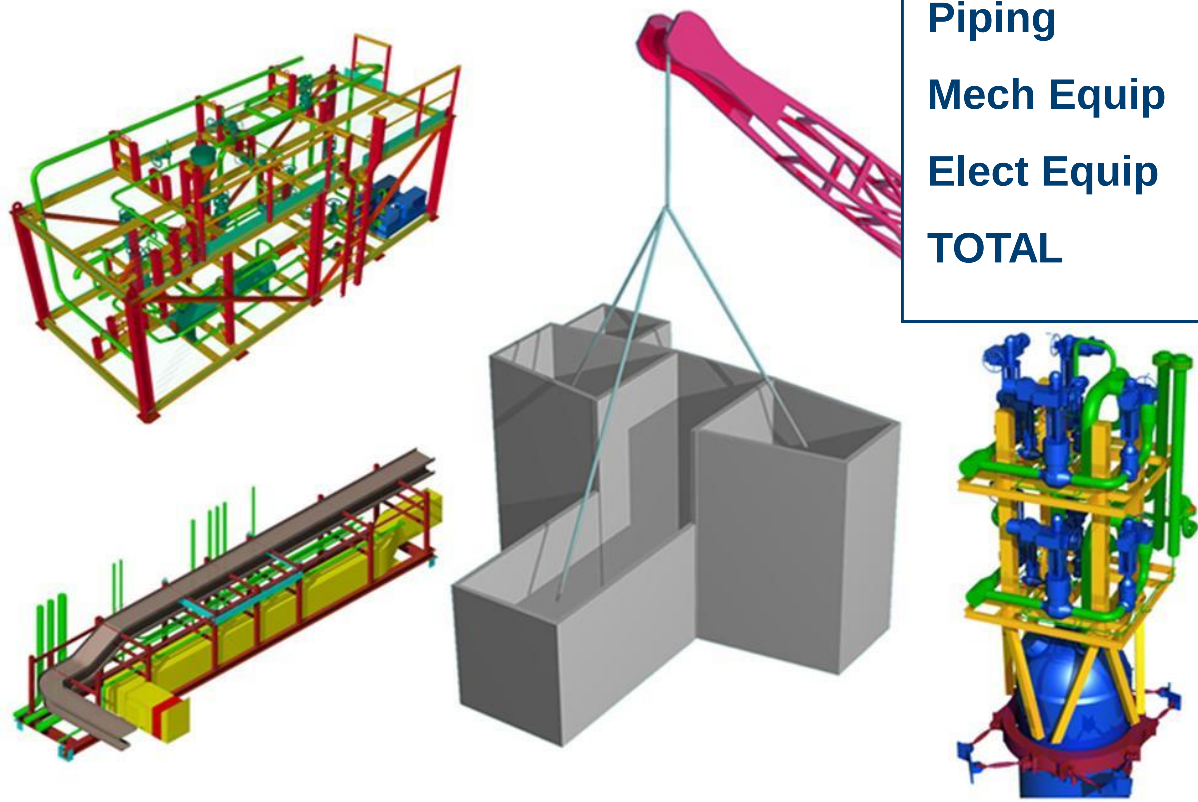
Modules and Modular

Westinghouse SMR



Module Type	Number
Structural	122
Piping	154
Mech Equip	55
Elect Equip	11
TOTAL	342

Pump/Valve Module



Raceway Module

Structural Module

Depressurization Module

- **Westinghouse AP1000** designed for construction from modules;
- Modules made off-site in factories and/or assembled into super-modules at site;
- Construction by modules lifted into position

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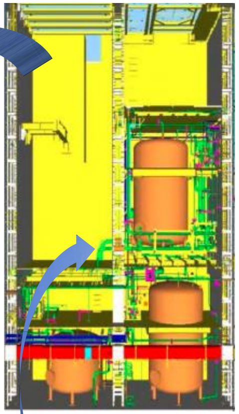
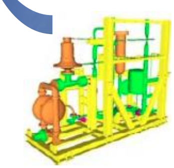
Major Modules Built On-site – AP1000 Sanmen

Heavy Lift – AP1000 Sanmen

- Sanmen CA20 Auxiliary Building 700 tne

  including safety sub-modules





- Sanmen CA01 SG shield & refuelling canal - 950 tne

SMR scaling for Size/Output – Yes, cost is higher, but less than thought

- Why scaling does not work for Nuclear? Cantor & Hewlett 1988 [1]

1% increase in size -> scaling effect reduces expected cost by - 0.65%

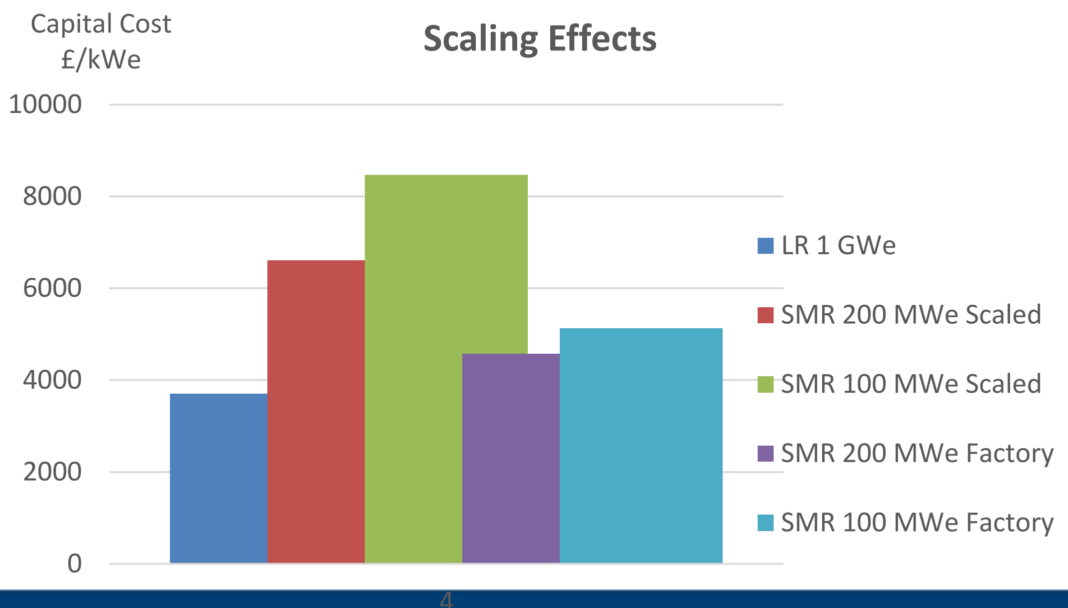
1% increase in size -> increase in build schedule & additional costs + 0.78%

net effect increase cost **+ 0.13%**

Similar effects, noted in France & Japan

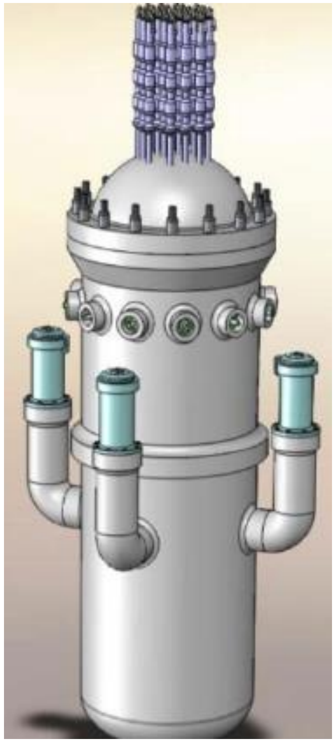
Alternative approach:

- Scaling is sound for factory-based equipment,
- Site construction – schedule increase offset savings;
- More modest increase in costs for
  200 MW (+24%) &
  100 MW (+39%) SMRs;
- Specific costa are consistent with finding of Abdullah 2013 [4]



SMRs & Schedule

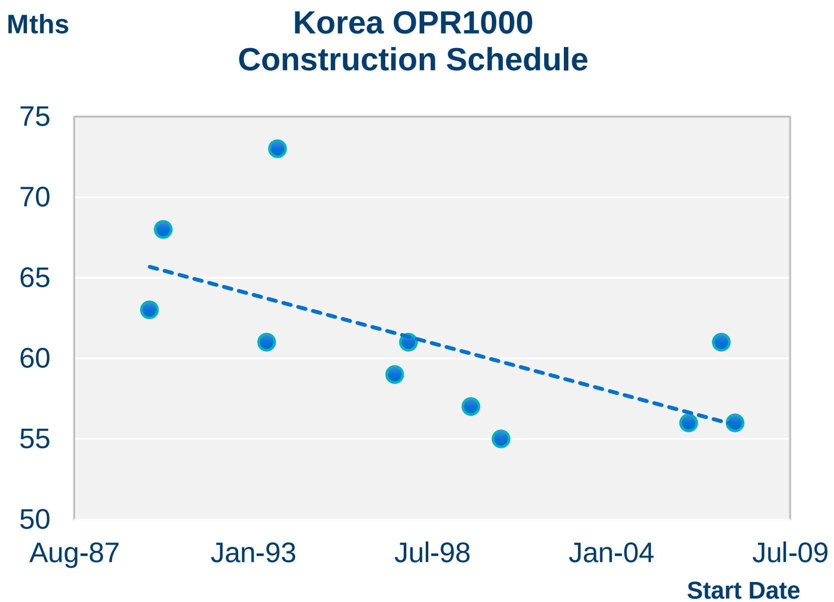
- For potential clients for SMRs (utilities & their funders), three most important features are:
  - **Much shorter construction schedule;**
  - **Much greater certainty** about the construction schedule;
  - **Lower interest payments** during construction reducing LCOE;
- Schedule achievement is strongly influenced by the methods of planning, organisation and construction/assembly methods;
- World-wide LWR data is consistent with **36-40 mth construction schedule** for SMR, with the combined effects of scale, modularisation & learning effects;
- Important effect of modularisation on schedule;



CNNC ACP100

Schedule & Modularisation

- Best Practice - Modularisation has been used in Japan with ABWR since 1990 and in Korea with OPR1000 since about 1995;
- Modularisation is a strong feature of AP1000 – designed for 54 month schedule - but Westinghouse is still learning and no AP1000 have been yet been completed.
- Experience of effect of modularisation on schedule:
  - **Japan (ABWR)** – progressive improvement in modularisation, scheduling and work practices has taken 12 months from ABWR schedules - from 60 mths to 48 mths;
  - **Korea (OPR1000)**– adoption of Japanese methods including modularisation from 1995 for OPR1000 has reduced average schedule from 66 mths to 55 mths.



***IAEA 2015** PRIS Database Report Table 14.*

Programme Design

- The design of the SMR production & roll-out will determine its economic success;
  - **Learning rate depends on regular rates of production** – minimum required 10 per year;

    Large reactor - low production <1 per year ➡ learning rate 0-5%

    SMR production rate 10 per year ➡ learning rate 8-10%
  - **Standardisation is key**:
    - ➢ Design, Production, Assembly/Site construction, Commissioning;

    which means: design envelope, safety regulation, technical standards etc.
  - SMR cost learning rate increases with increased **factory cost share** – promoted by centralised manufacture, & less local manufacture;

	Factory share	**Mean Learn Rate**
1- Factory modules follow large reactor practice	46%	8%
2 - Modularisation of safety & systems & structure	65%	10%

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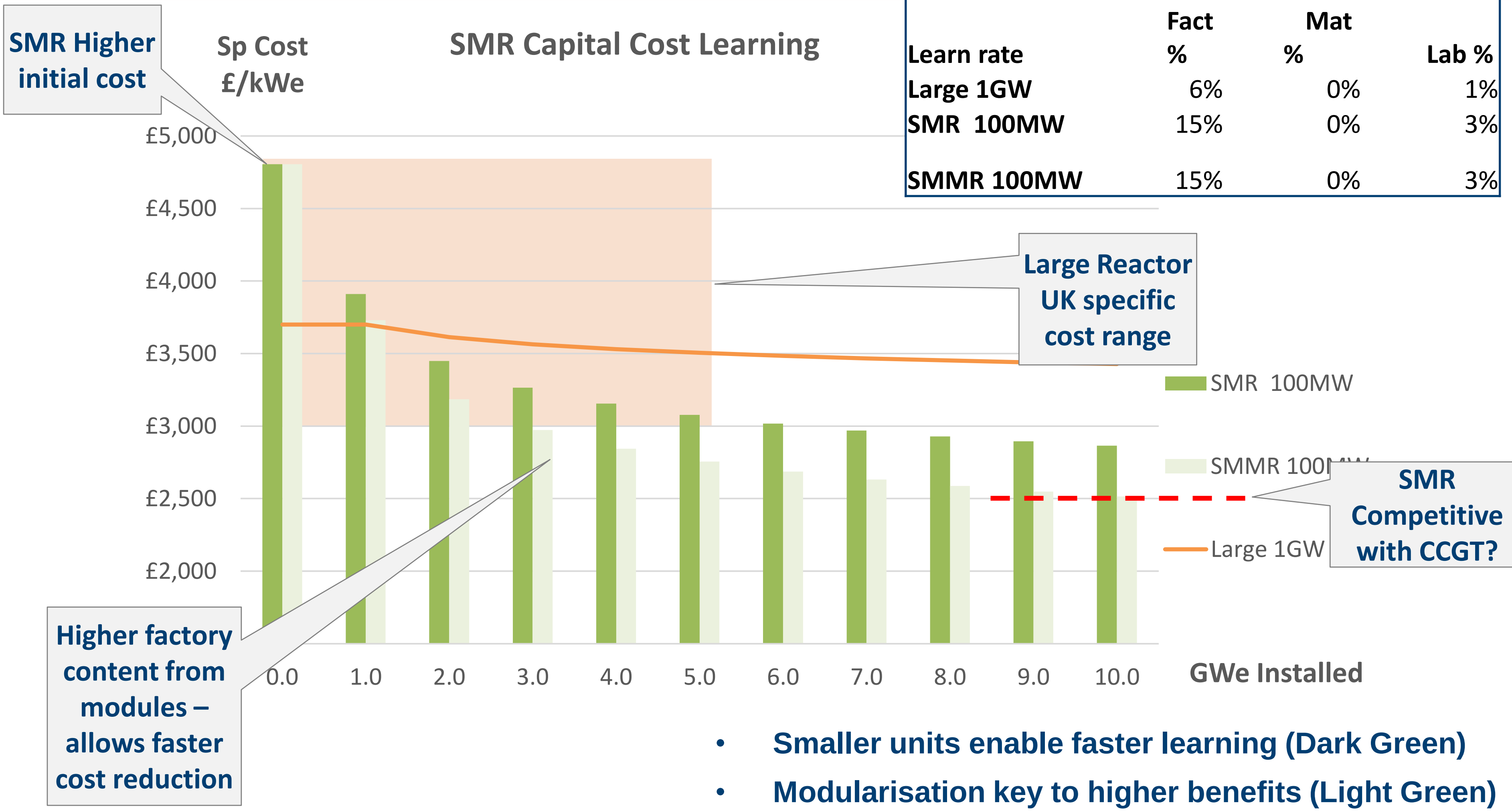
Scaling, Learning & Modul’n

Cost Share	Fact %	Mat %	Lab %
Large 1GW	30%	15%	55%
SMR 100MW	46%	12%	42%
SMMR 100MW	65%	10%	25%

Learn rate	Fact %	Mat %	Lab %
Large 1GW	6%	0%	1%
SMR 100MW	15%	0%	3%
SMMR 100MW	15%	0%	3%



- **Smaller units enable faster learning (Dark Green)**
- **Modularisation key to higher benefits (Light Green)**

What will it take to make SMRs a competitive reality?

1. **Volume to** achieve production rate to drive down costs below other low carbon sources;
   - Cost competitiveness depends on:
     - Volume for production rate of **10 units pa** – from UK plus partner country & export;
     - Radical modularisation to expand factory cost share.

UK Demand to 2050 (UK ETI 2015 [12])

- 16 GWe large reactors planned by 2035
- Further 25 GWe of nuclear to meet UK Climate change objectives at lowest cost;
- Available sites constrain number of large reactors;
- Many more SMRs sites are available.

2. Common **design licensed in more than one country**:
   - UK program must be concentrated on a single design;
   - Tackle licensing issues;
   - Common technical standards across several countries;
3. Contractors with **different skills** to deliver SMRs as a **product, not a project**;
   - Coordination of supply chain
   - Repeatability of delivery
   - Continuous improvement of 'how to deliver'

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