Programme Area: Nuclear

Project: System Requirements for Alternative Nuclear Technologies

Title: Project overview presentation and key findings

Context:

The purpose of the System Requirements for Alternative Nuclear Technologies project was to capture the high level technical performance characteristics and business-case parameters of small thermal plants, which will be of value to the potential future of the UK's energy system. The project included small nuclear reactors, enabling comparison with other small-scale plants, such as those powered by bio-mass. The project outputs will help enable the subsequent contrast of a range of specific technologies.

System Requirements for Alternative Nuclear Technologies

ANT Project: Overview & Key Findings

October 2015

Sam Friggens – Project manager & economist (Mott MacDonald)

Objective

What will Small Modular Reactors need to ‘do’, functionally and economically, to be of value to the UK’s future energy system?

NuScale 45MWe reactor (artists impression)

- “Frame the energy system requirements and expected cost envelope”
- Inform future assessments of SMRs technologies
- Complement other ongoing work on SMRs

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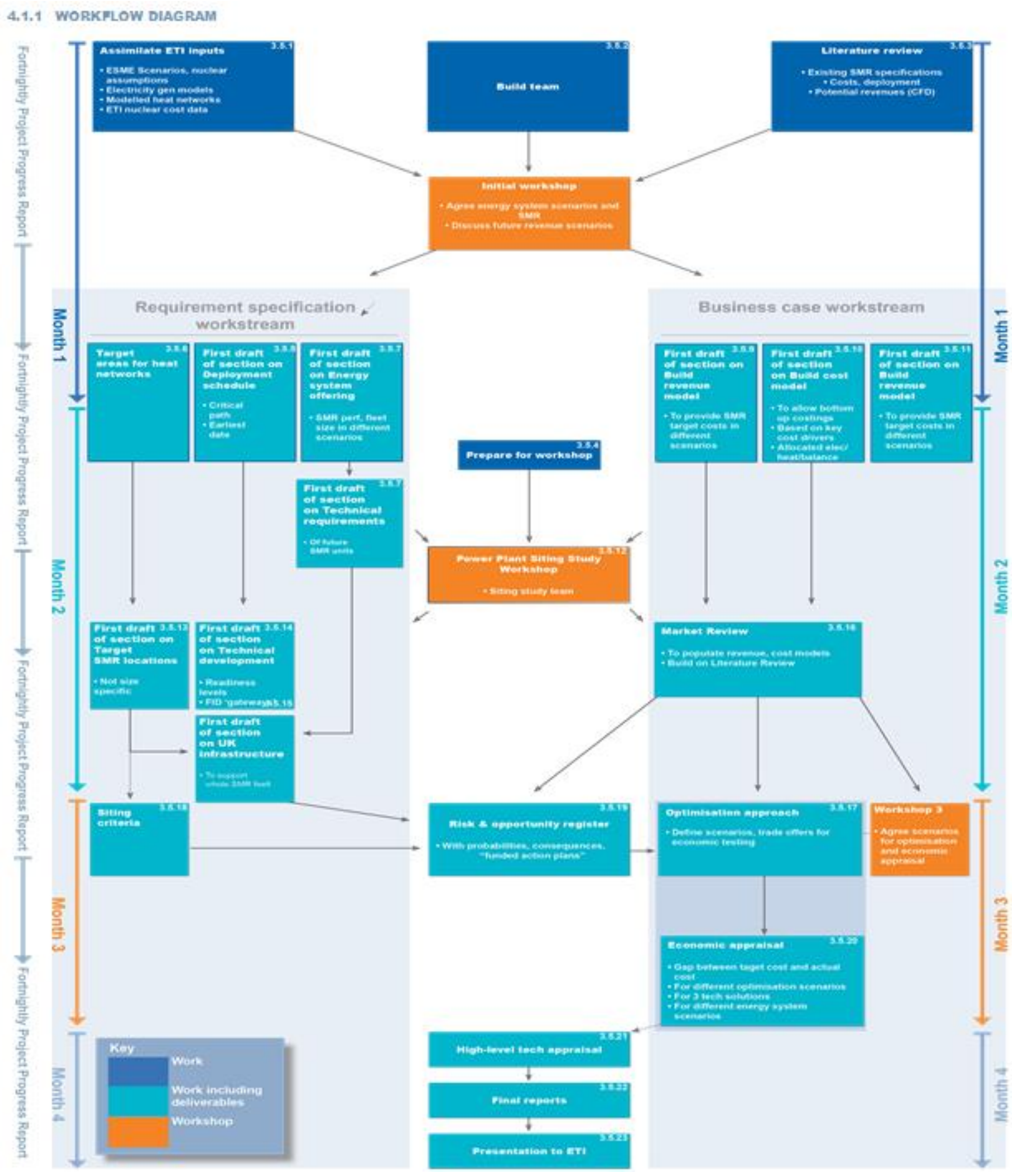
Scope - workstreams



- Aug 2014 – Aug 2015
- Two workstreams:
  - Functional Requirements
  - Economic Requirements
- 20+ tasks
- Integrated with Power Plant Siting Study (PPSS)
- Extensive peer review

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Scope - key parameters

- ✓ Requirements of a low carbon energy system
- ✓ Future looking, accepting the uncertainty involved
- ✓ Focus on LWR type technologies for some elements of work

- ✗ An assessment of individual SMR concepts
- ✗ An assessment of LWR vs alternative technologies
- ✗ An assessment of whether SMR technologies will actually deliver the identified requirements
- ✗ Investigate public perception / acceptability of SMRs

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Project Team

Mike Middleton – ETI lead

Guy Doyle – Chief economist
Bob Ashley – CHP & heat specialist
Sam Friggens – Project manager & economist
(plus engineering, power plant & consenting specialists)

David Dodd – Chief design engineer (civil nuclear)
Martin Goodfellow – Nuclear engineer

This presentation

1. Objective, Scope & Team

2. Introduction to SMRs

3. UK low carbon energy system

4. Functional requirements workstream

5. Economic requirements workstream

6. Key conclusions

7. Questions & Answers (20 minutes)

Focus on key findings

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An Introduction to SMRs

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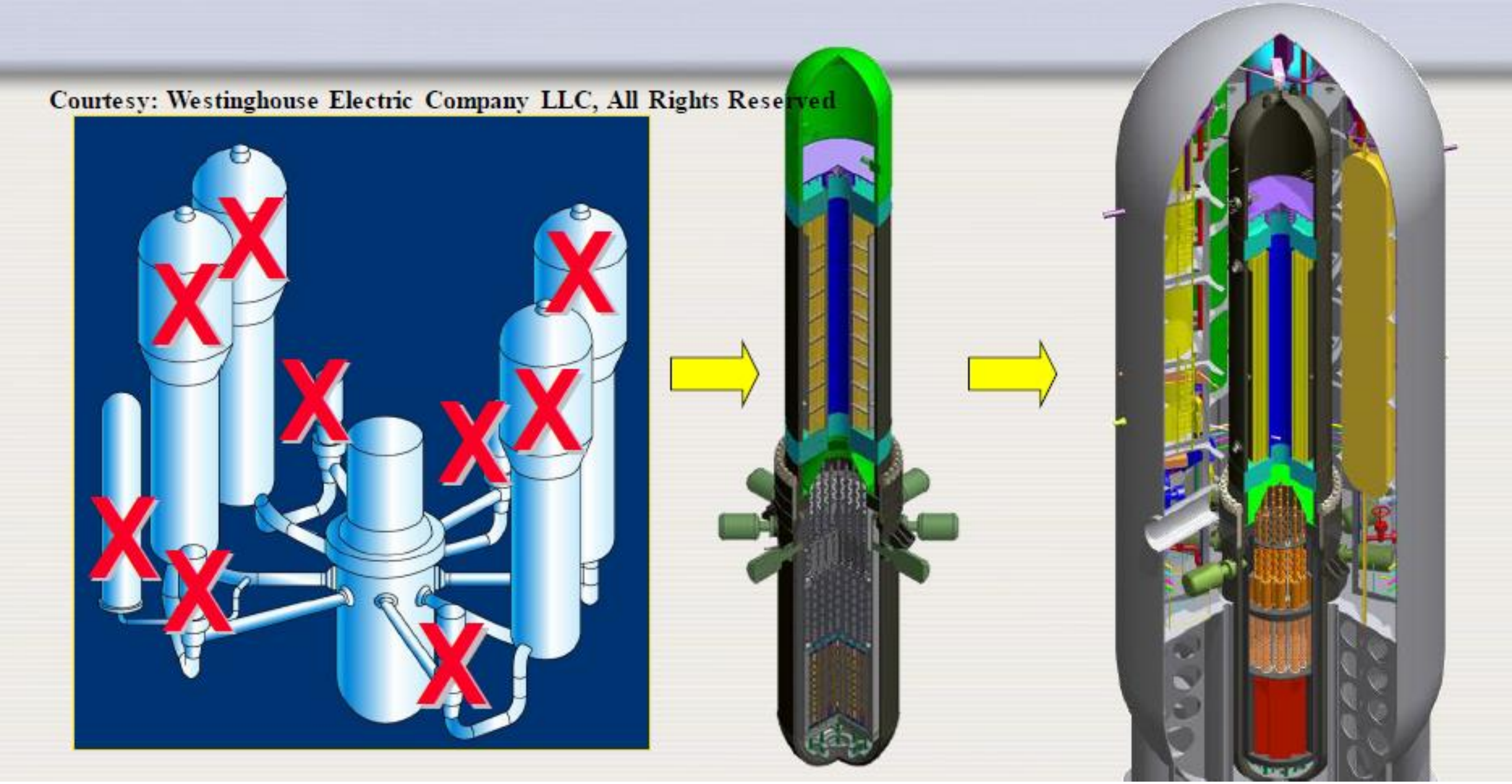
What is a Small Modular Reactor?

- <300MWe
- Modular
- Deployed in multiples
- Factory build
- Advanced manufacturing
- Transported to site

Integral design (passive safety)



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Proponents claim SMRs advantages

- Low carbon electricity, heat and flexibility
- Less water + less land = more sites
- Closer to demand
- Incremental deployment
- Lower total CAPEX, risk & financing costs
- Economies of multiples and factory production

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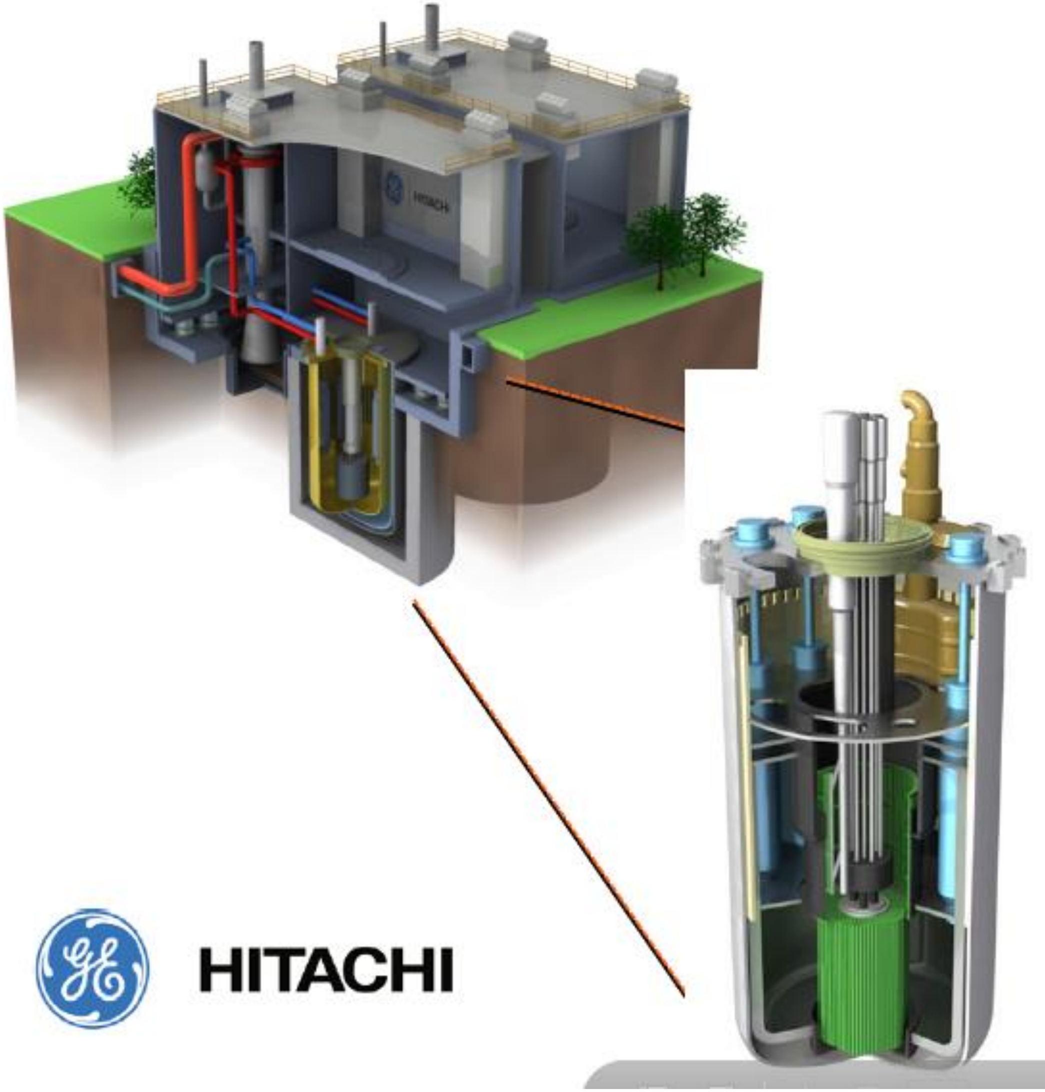
Technologies – from near term…

- ‘Near term’ PWR technologies:
  - mPower (180MWe)
  - NuScale (45MWe)
  - SMART (100MWe)
  - Etc.

- Chinese CNP-300 already operating
- KLT-40S in build

…to longer-term, revolutionary concepts



- For example:
- GE Hitachi PRISM 311MWe reactor
  - Liquid sodium-cooled fast-breed reactor
  - Fuelled using present day waste
- U-Battery 5-10MWe
  - Small transportable power batteries

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But…

- SMR concept around for decades
- No commercial deployment yet in the West
- Can we have confidence in vendor claims?
- Will the economics stack up?
- Can SMRs be competitive?

UK low carbon energy system in 2050

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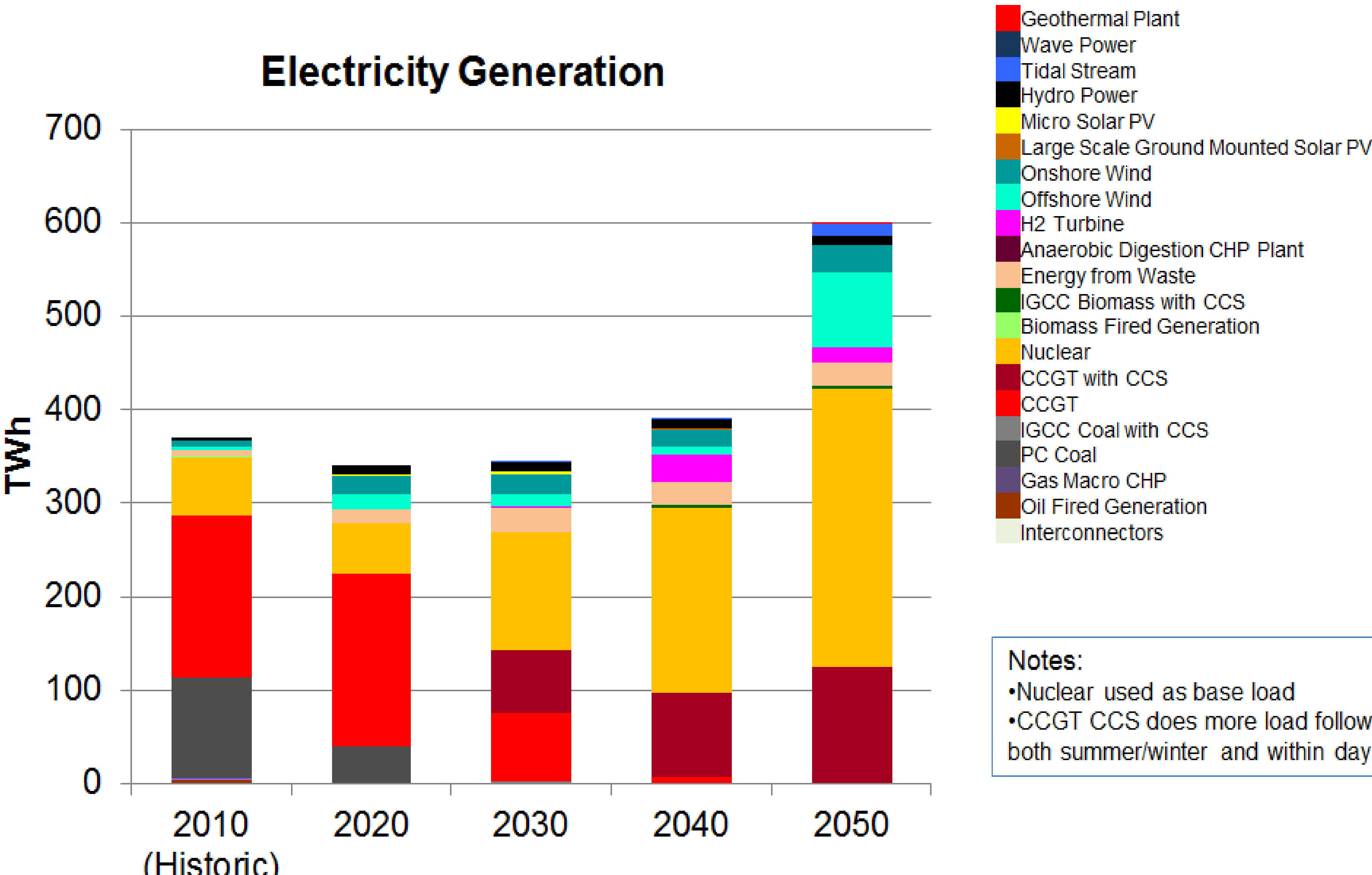
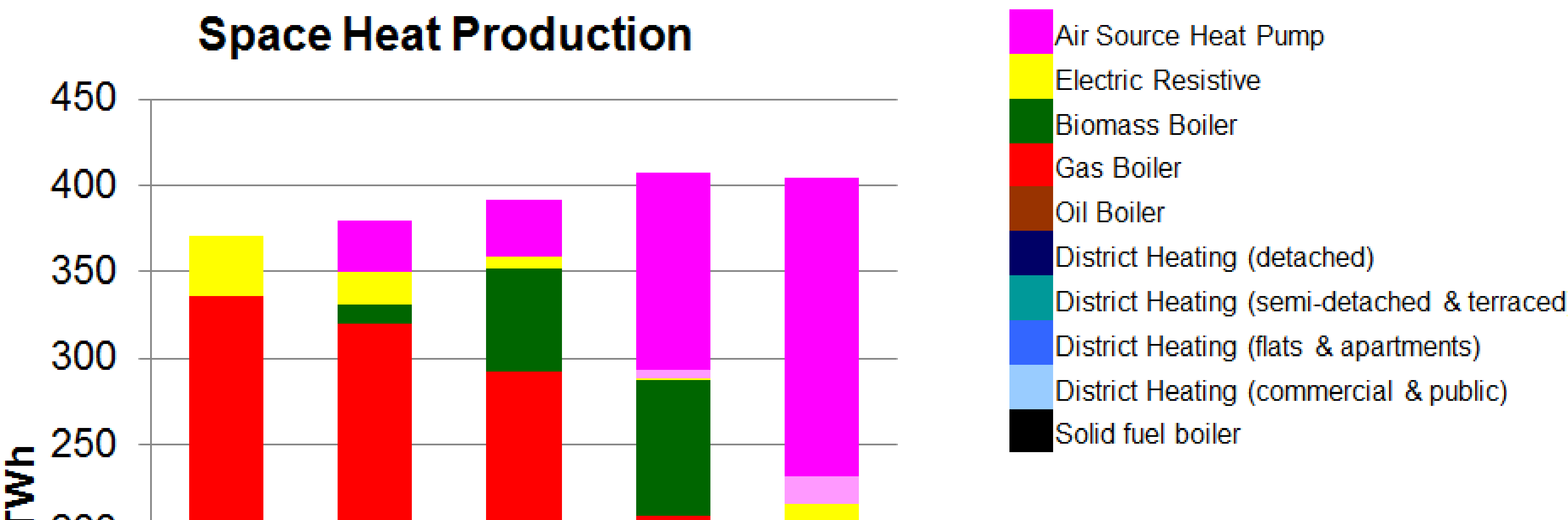


Notes:

- Nuclear used as base load
- CCGT CCS does more load following, both summer/winter and within day

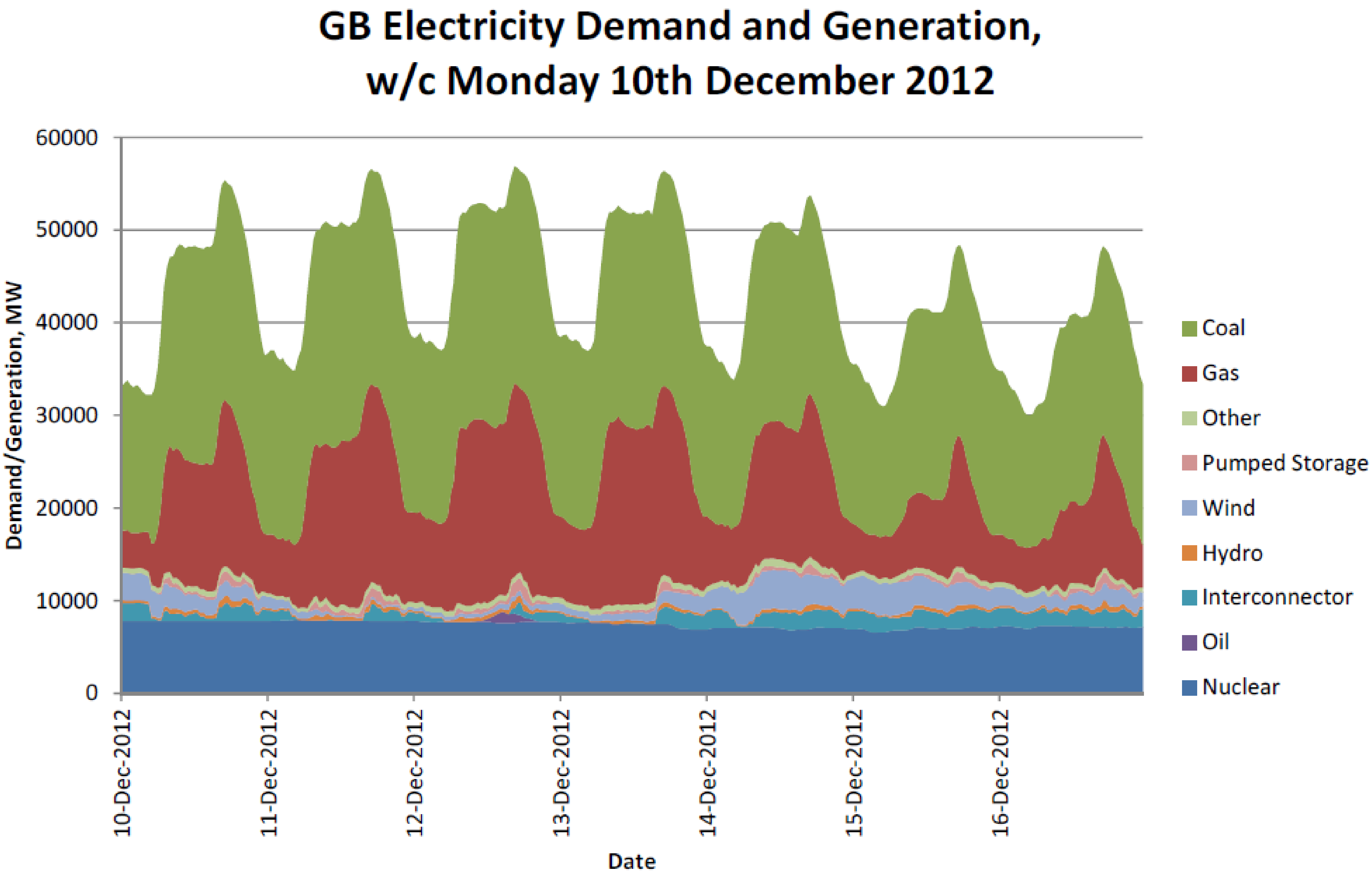
energy technologies institute



Notes:

- Significant role for both district heating and heat pumps, although some uncertainty over exact balance between the two
- First choice (i.e. least cost) heat for the DHN is usually heat from large power stations (see Sankey diagram). DHN is still selected even if this is not possible, but will instead get heat from marine heat pumps, geothermal and CHP.

Flexibility



Functional Requirements Workstream

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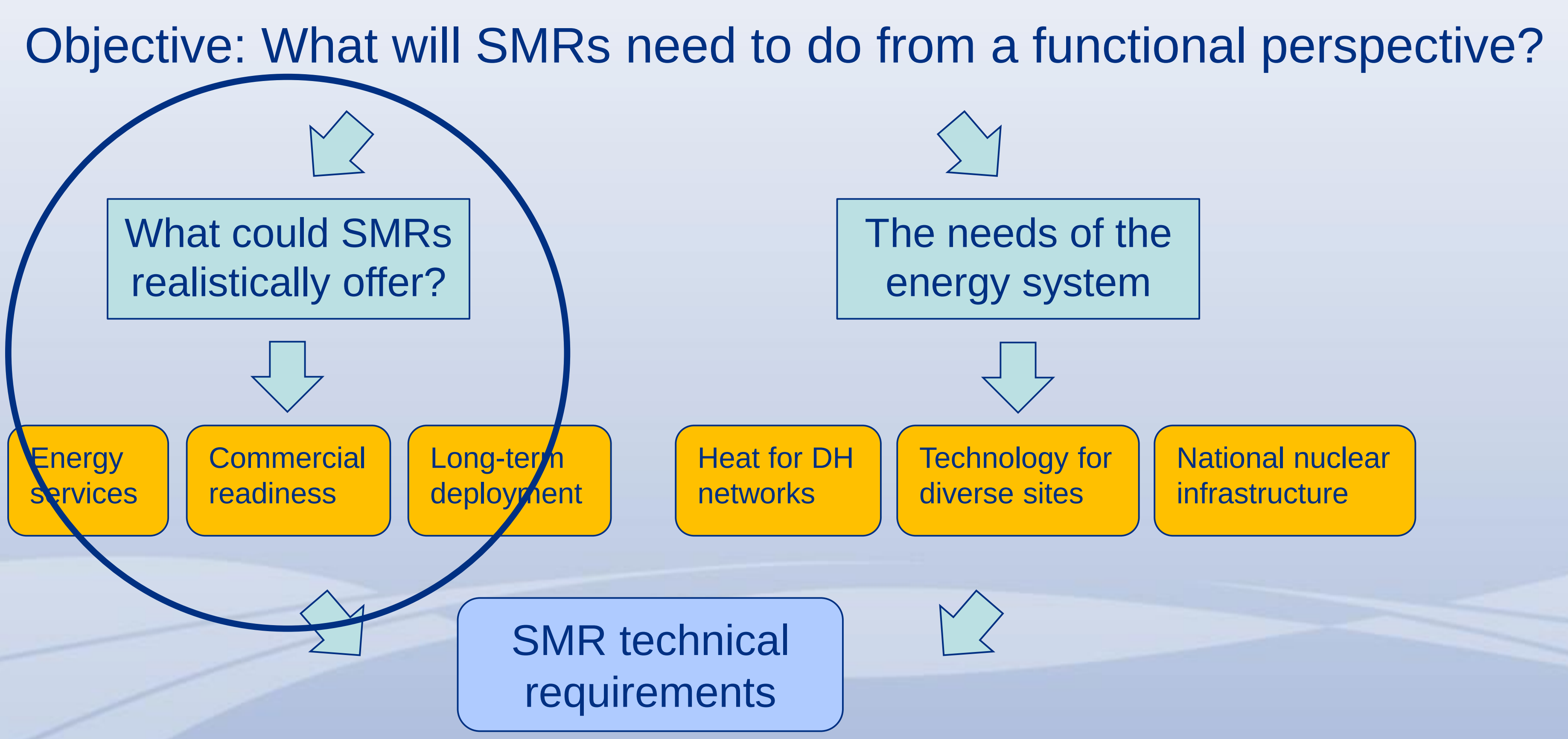
Approach



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What energy services could SMRs offer?

		Baseload	Flexible	"Extra-flex"
	Electricity only plant	Baseload power (runs continuously)	Load-following mode (reduces output at times)	Baseload power with extra storage & surge capacity
	Combined Heat & Power plant	As above but with heat	As above but with heat	As above but with heat

Six representative offerings

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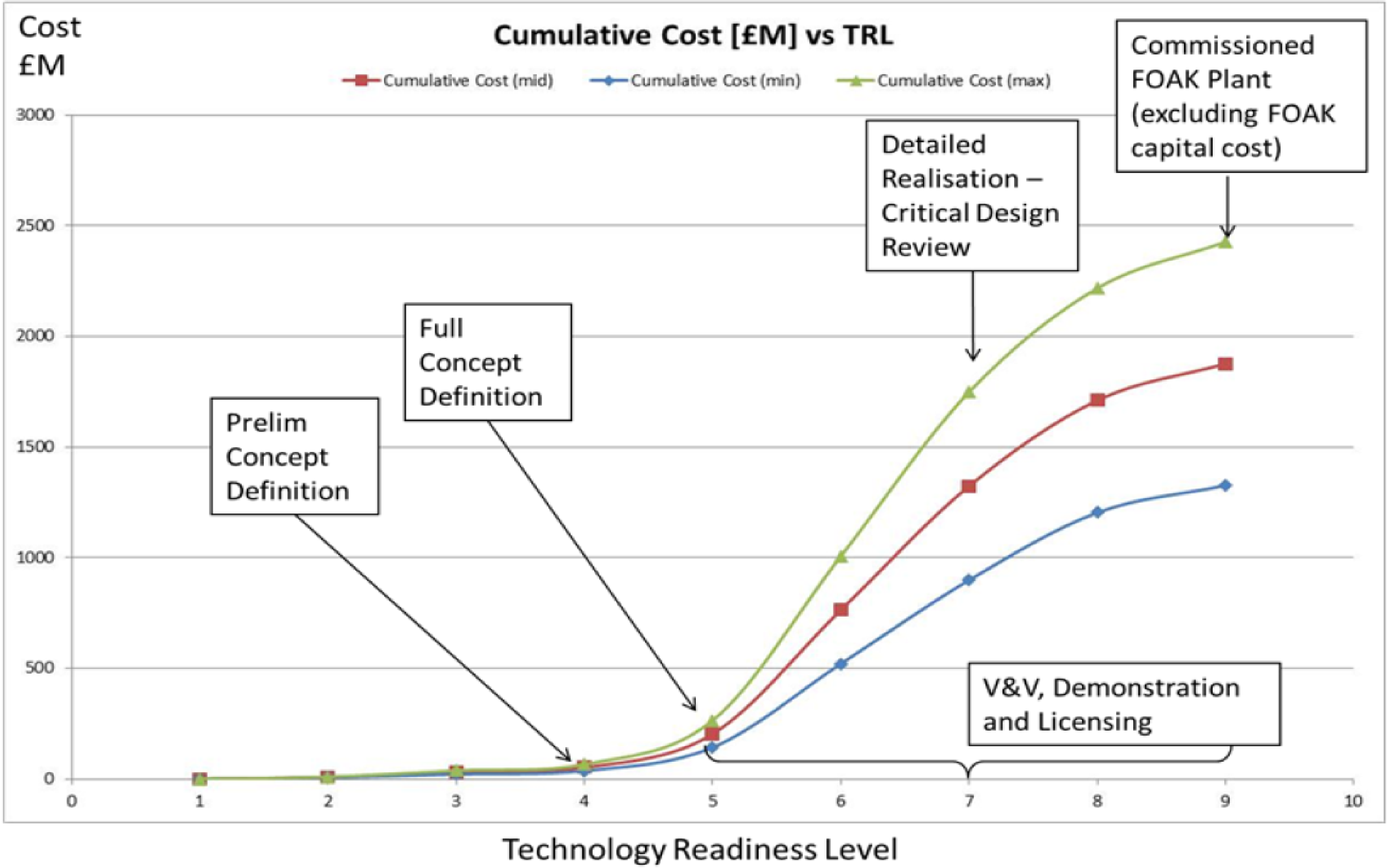
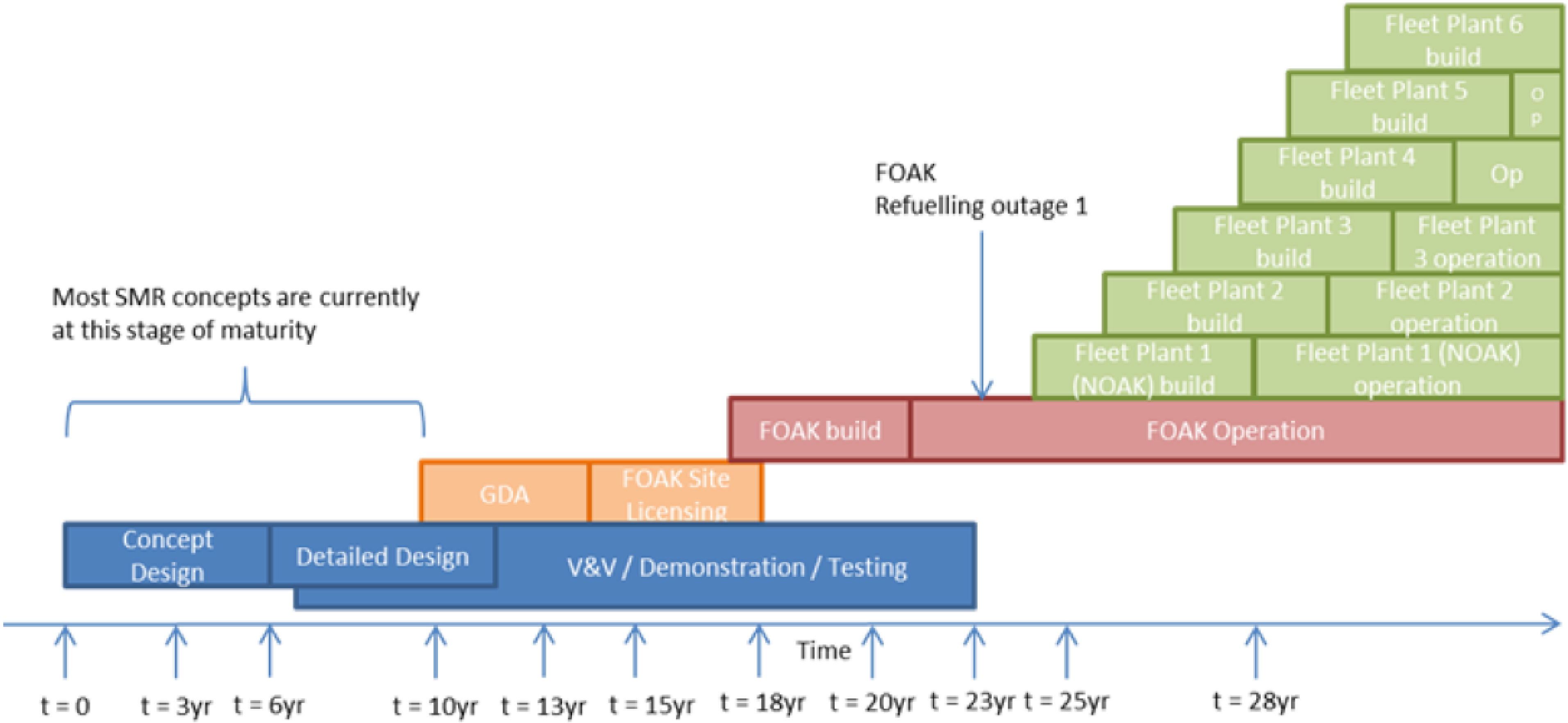
Costs of technology development



When will SMRs be ready for deployment?



Technology development timescales

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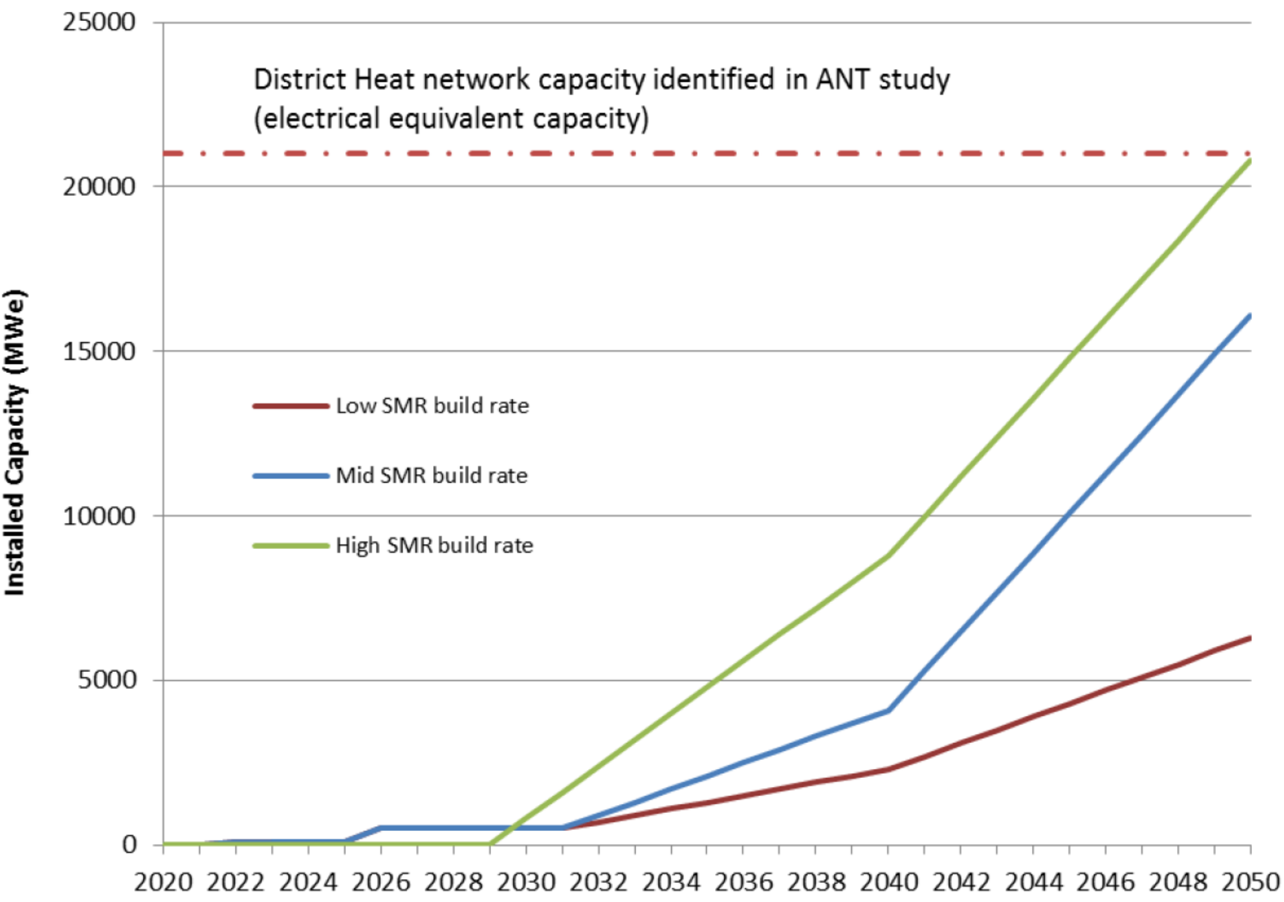
Deployment scenarios



Several drivers dominate:

- potential for module manufacturing at high volumes per year
- potential factory based learning
- constraints relating to on site deployment of completed modules
- constraints imposed by capital costs of increasing capacity and updating equipment

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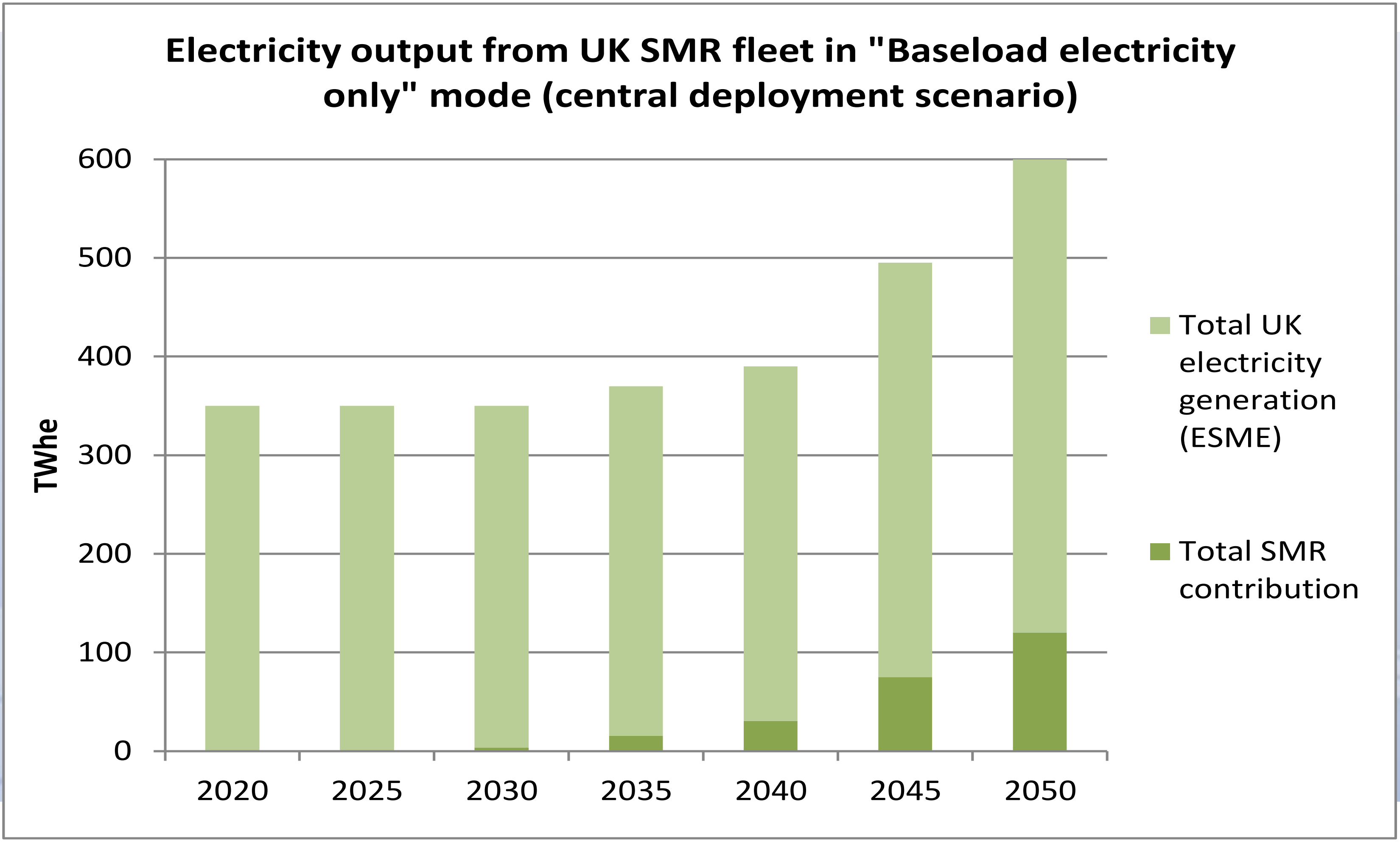
Electricity contribution to 2050



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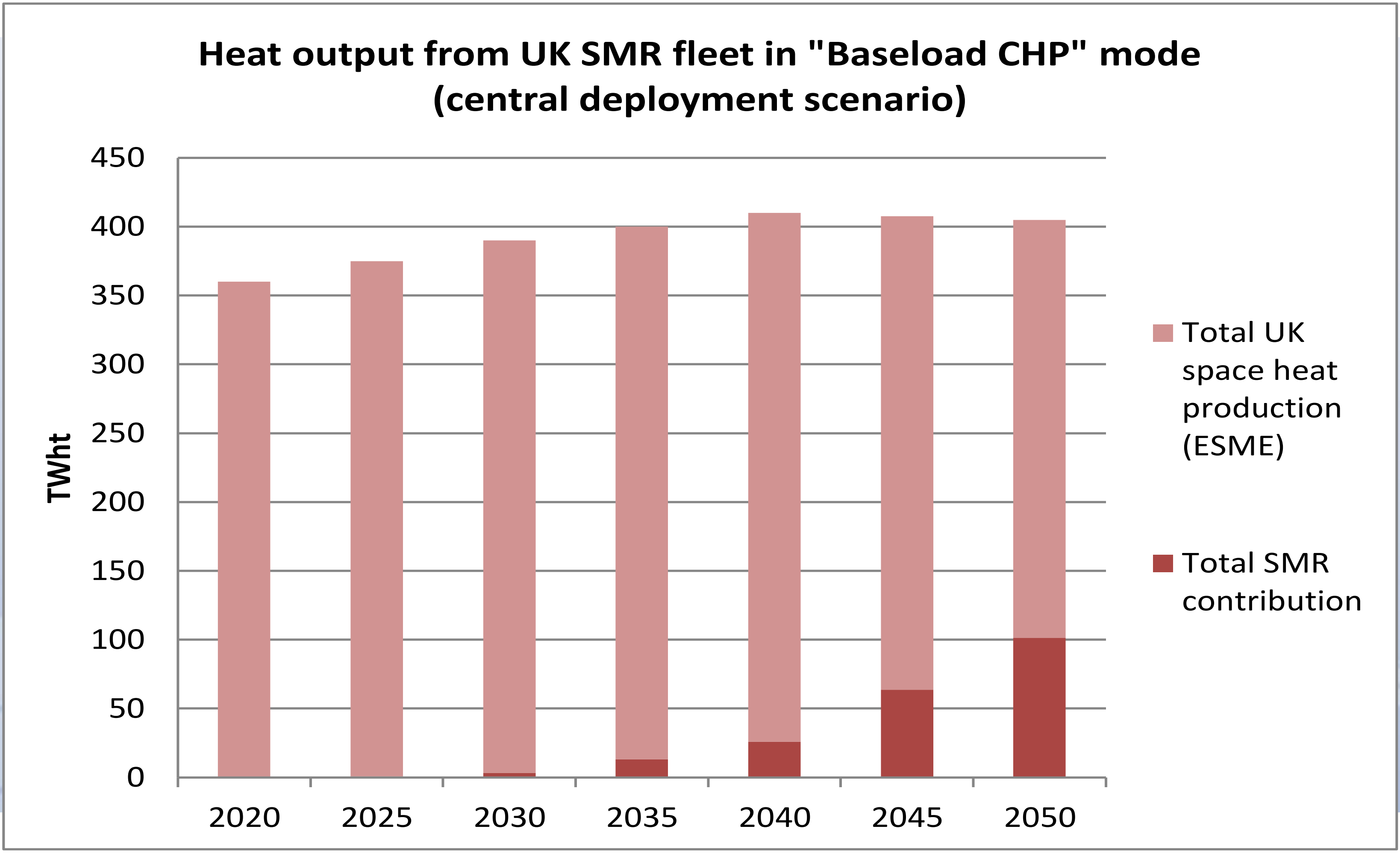
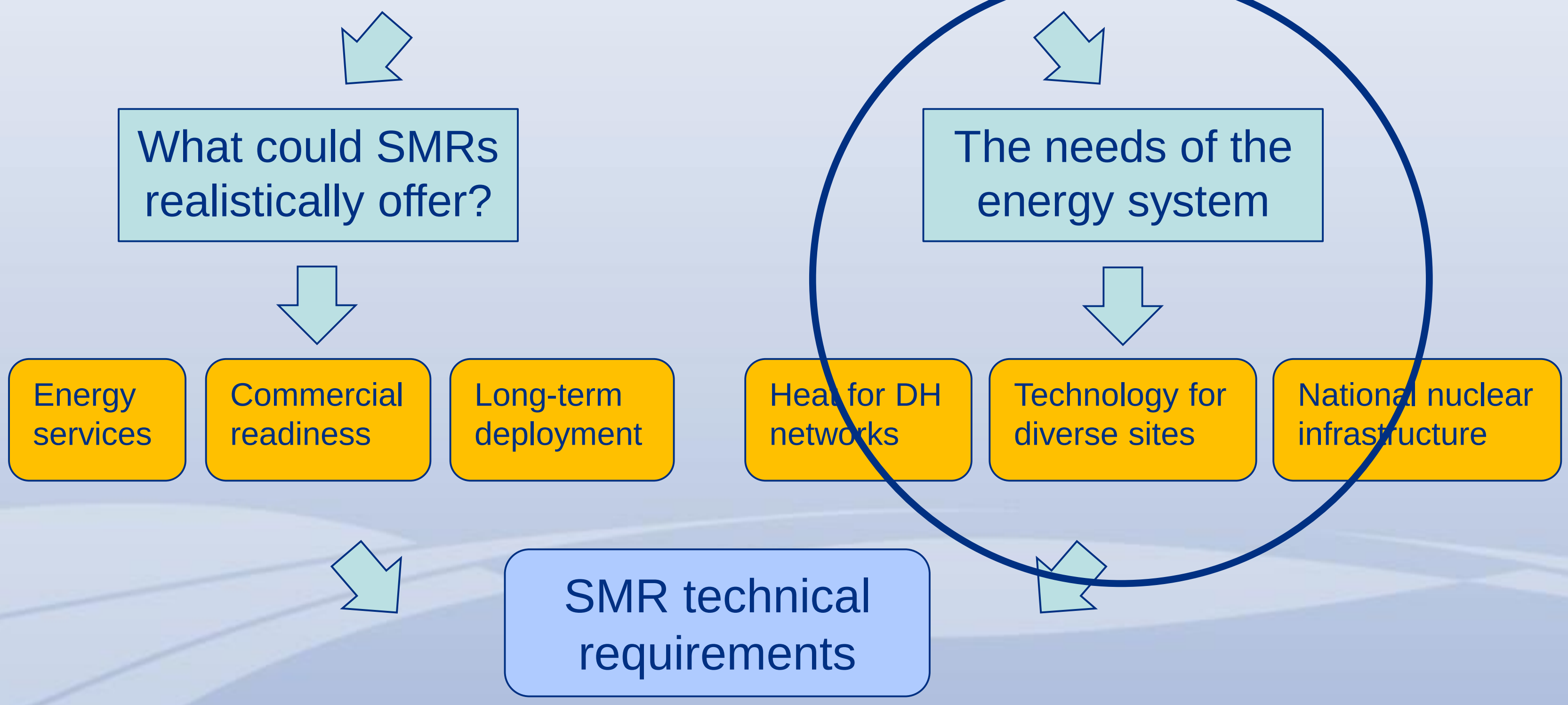
Heat contribution to 2050



Objective: what will SMRs need to do from a functional perspective?



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Demand for SMR heat?

A central proposition of the ANT project is that city-scale district heat (DH) networks will be rolled out in the future and that these will provide a market for SMR heat.

We tested this by:

- Analysing GB heat demand data to establish the location and size of potential city-scale DH networks
- Mapping the potential SMR sites locations identified in the PPSS - are they close enough? (<30km)

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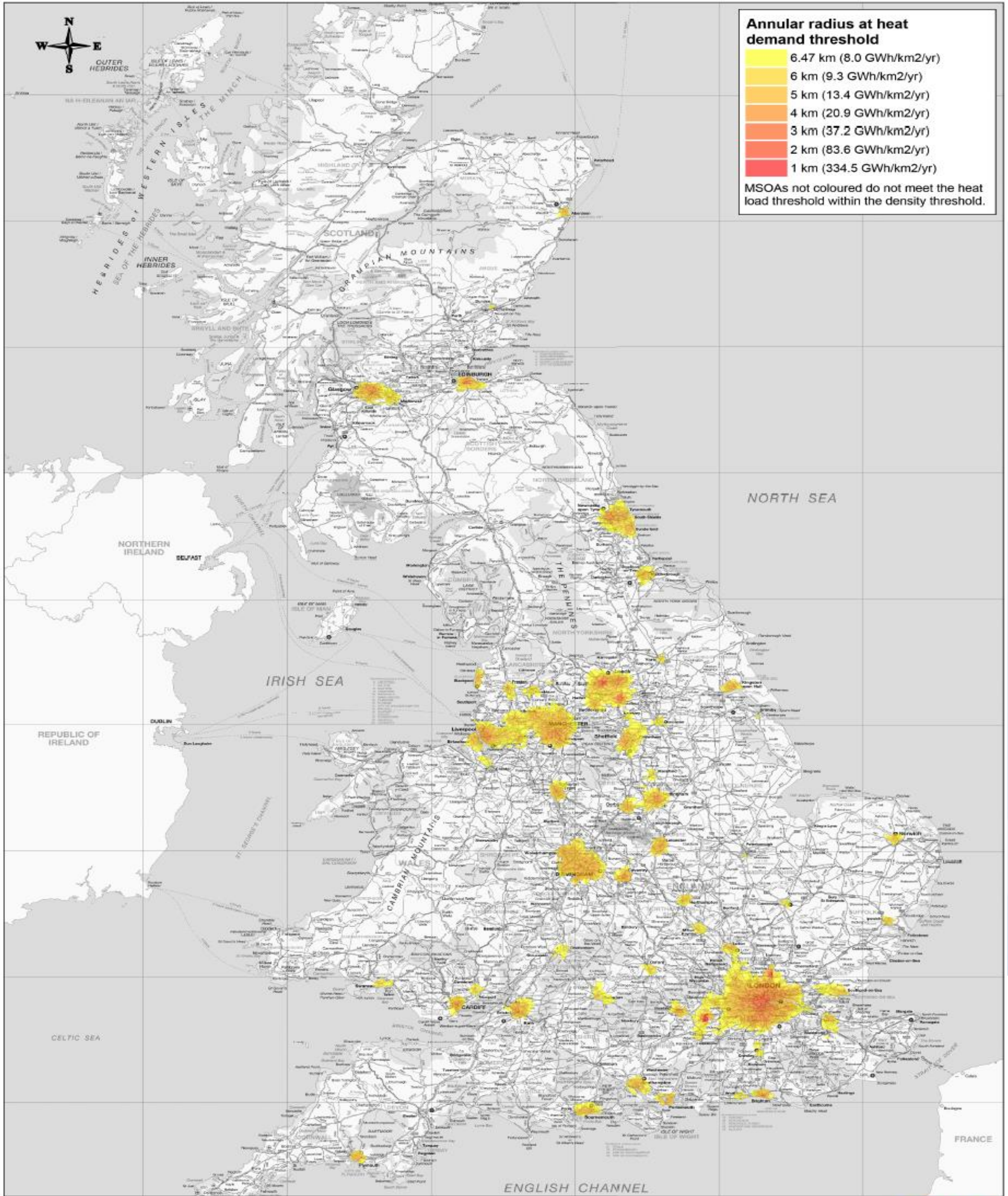

Almost 50 GB towns/cities could host DH networks of sufficient size and density

Theoretically requires 22.3GWe / 40.1GWth CHP SMR capacity

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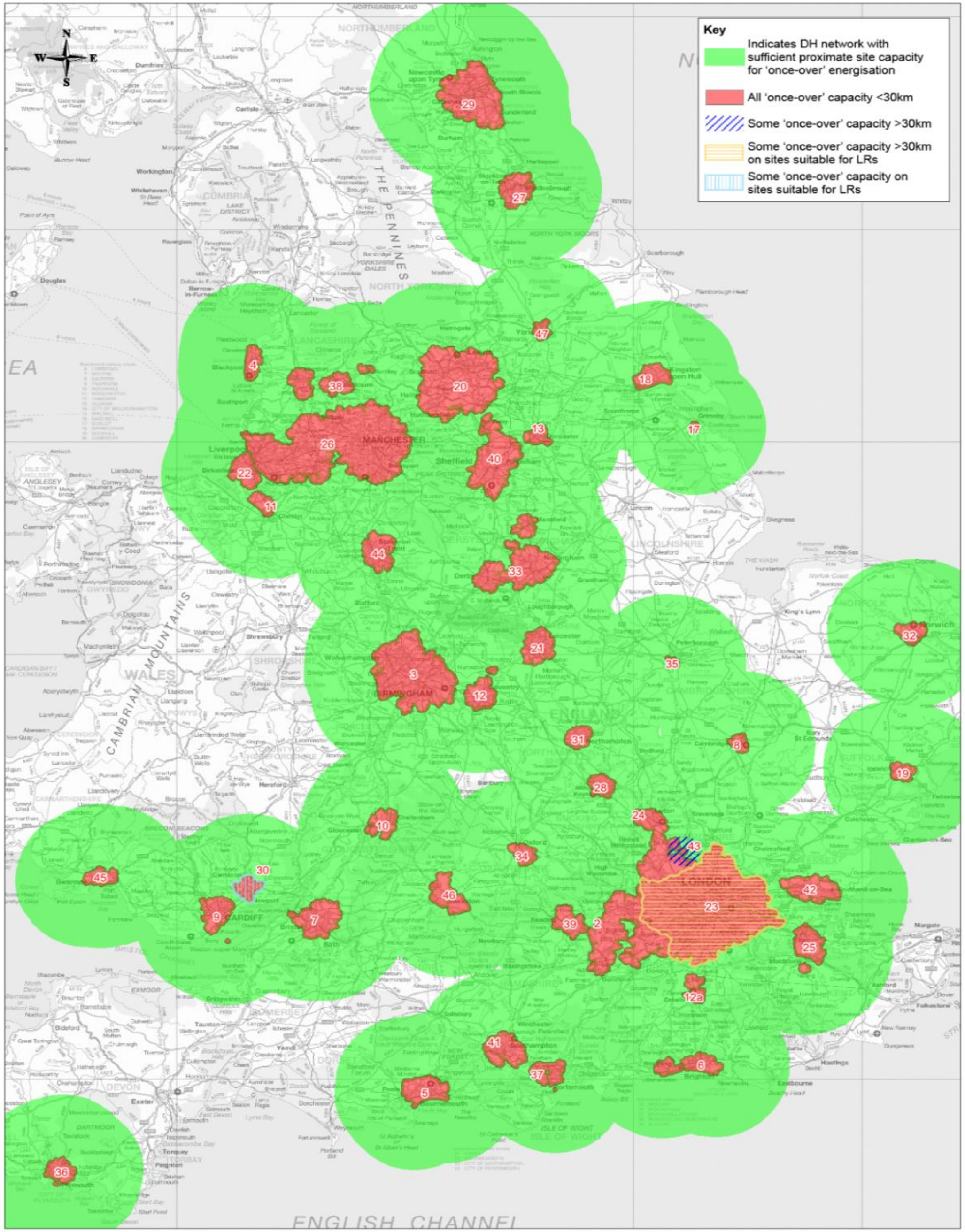
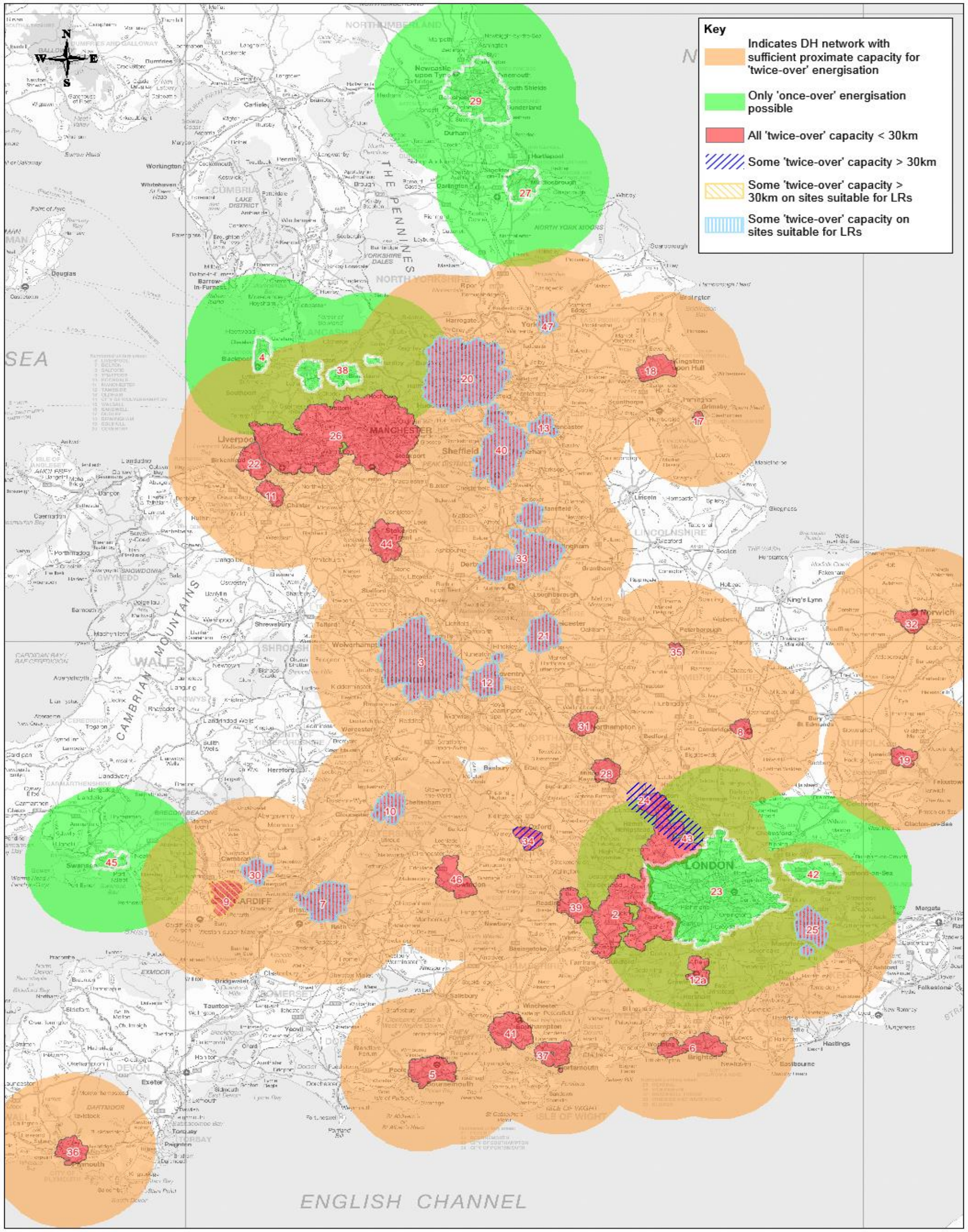


“Once-over” energisation:

There are enough potential SMR sites to energise <u>all</u> of the identified DH networks (i.e. <30km)

Heat market = economic advantage for SMRs



"Twice-over" energisation:

There are enough potential SMR sites to energise <u>many</u> of the identified DH networks two times over

Allows for site attrition

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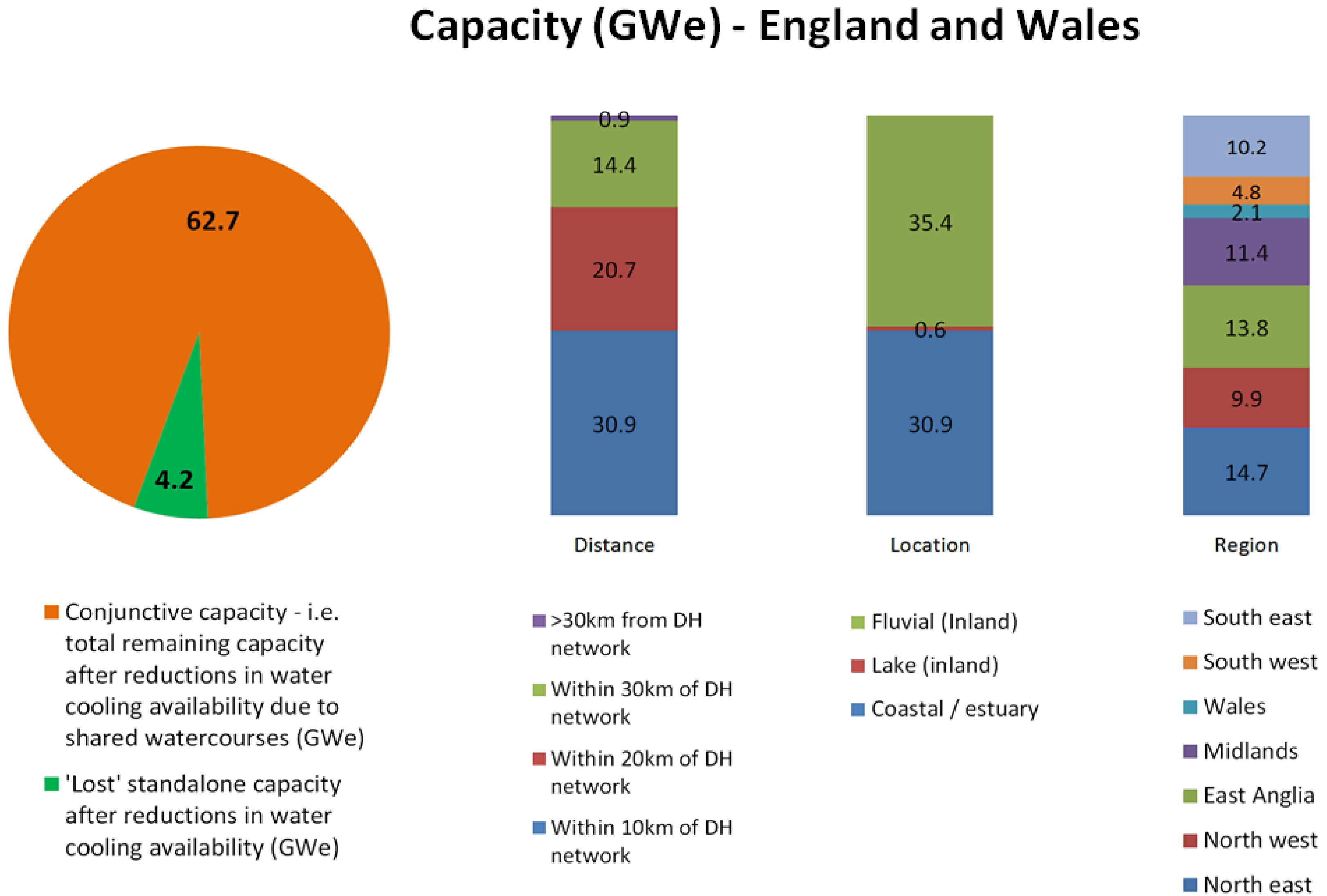
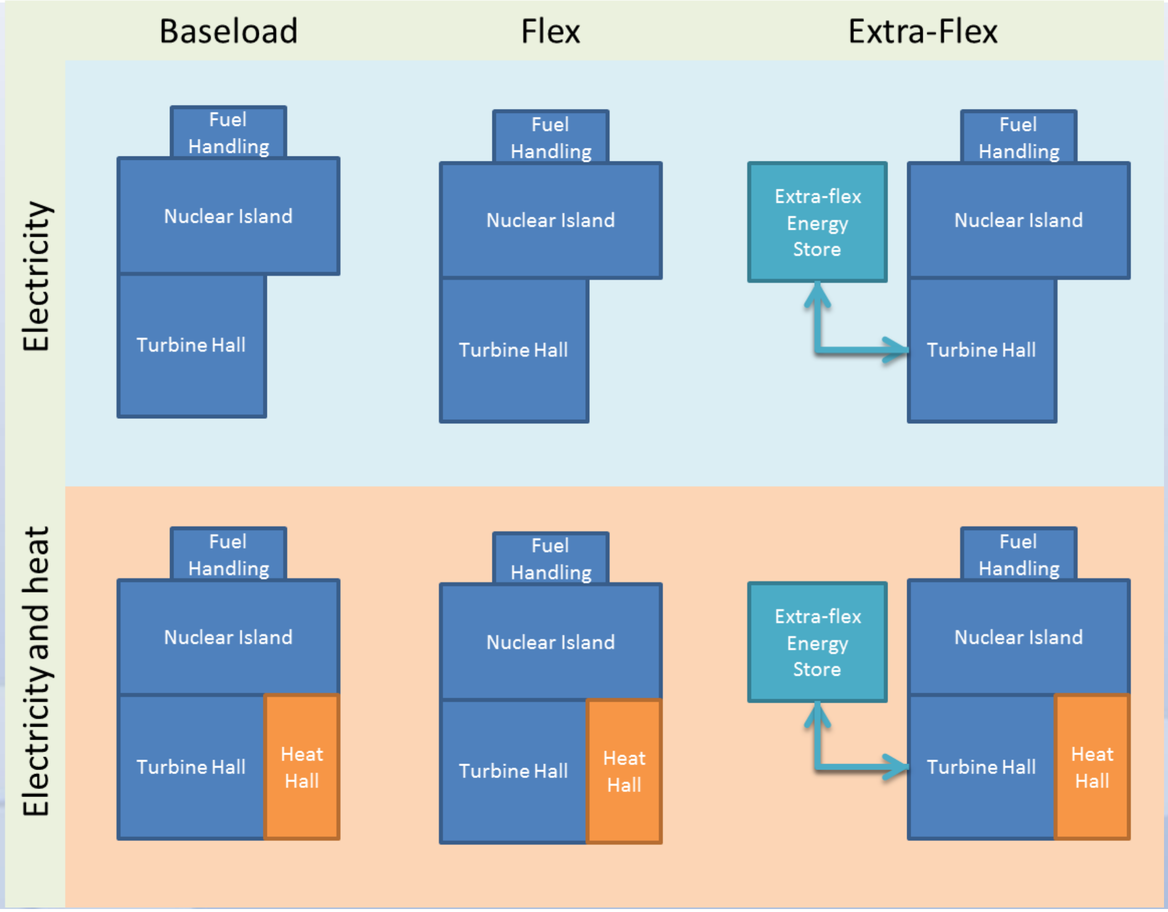
Breakdown of SMR site capacity



One standardised plant with plug-ins



Potential route forward to address multiple service offerings within a standardised system arrangement

Challenges associated with:

- Licensing
- Operations
- Skills and capability

Multiple operating modes

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National nuclear infrastructure

What impact would SMR deployment have on the UK's 'back-end' (fuel cycle) nuclear infrastructure?

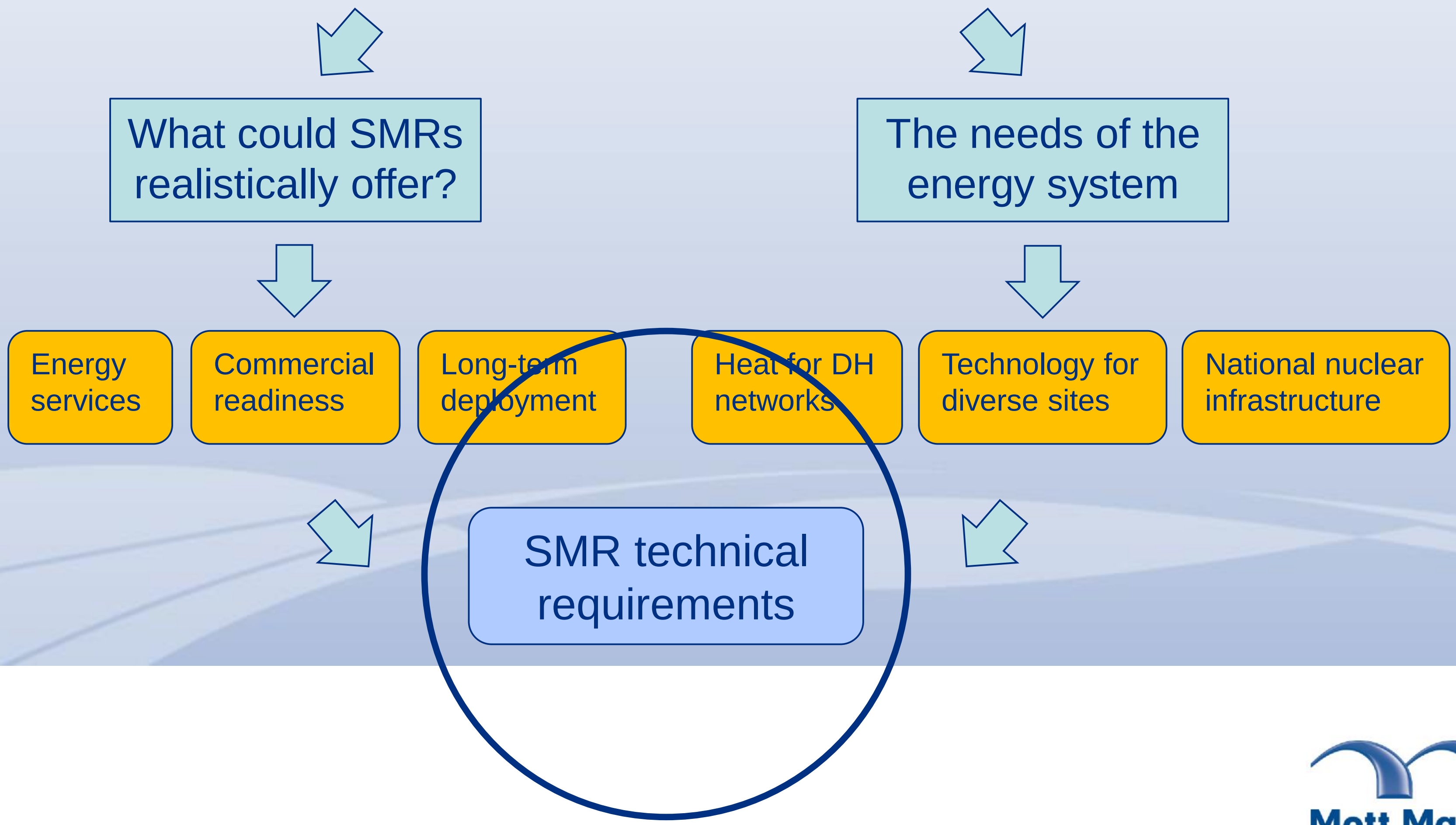
Our review:

- Acknowledged UK's existing infrastructure & plans
- Considered aggregate impacts of a fleet of SMRs

Key conclusions:

- Type of SMR technology could be important
- LWR technologies more compatible with lower cost impact
- Alternative fuel cycles and reactor types could encounter policy uncertainty

Objective: what will SMRs need to do from a functional perspective?



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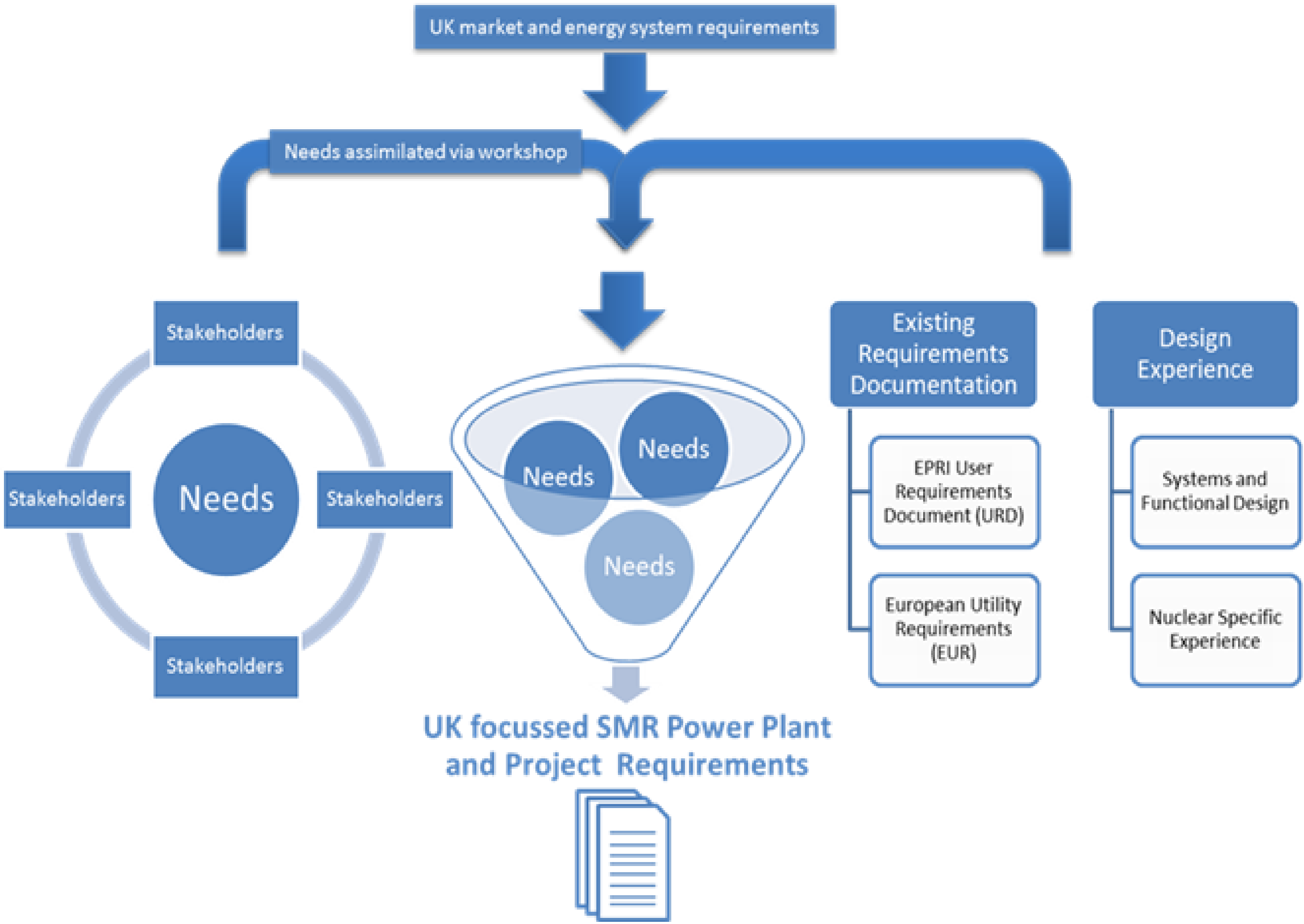
UK market and energy system requirements
Needs assimilated via workshop
Stakeholders
Stakeholders
Needs
Stakeholders
Stakeholders
Needs
Needs
Needs
Existing Requirements Documentation
EPRI User Requirements Document (URD)
European Utility Requirements (EUR)
Design Experience
Systems and Functional Design
Nuclear Specific Experience
UK focussed SMR Power Plant and Project Requirements

SMR technical requirements

Ref.	Key technical requirements (out of 100)
CO02	Designed on a modular basis with maximum possible amount of factory construction and assembly
CO05	Compatible with existing transport infrastructure routes
OM02	Safe installation of additional modules whilst existing modules are under operation
OM03	Safe refuelling of modules whilst other modules are under operation
PE01	Capable of providing flexible electricity / diurnal load following mode (30-100% nominal power with minimum 0.5% per minute ramp rate)
PE02	Capable of providing electricity *and* heat
SA06	Safe in the event of normal or abnormal operation irrespective of operator presence or intervention

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Economic Requirements Workstream

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Economic appraisal

Objective: What will SMRs need to do from an economic perspective?

1. Target SMR costs

vs

2. SMR cost estimates

What is the maximum an SMR plant could cost whilst delivering commercial rates of return under future market conditions?

“Target” = breakeven point

Explored one possible cost scenario. Others are possible.

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Caveat

- High uncertainty
- Many assumptions
- Multi-decadal timescale
- Treat results with caution
- Indicative only

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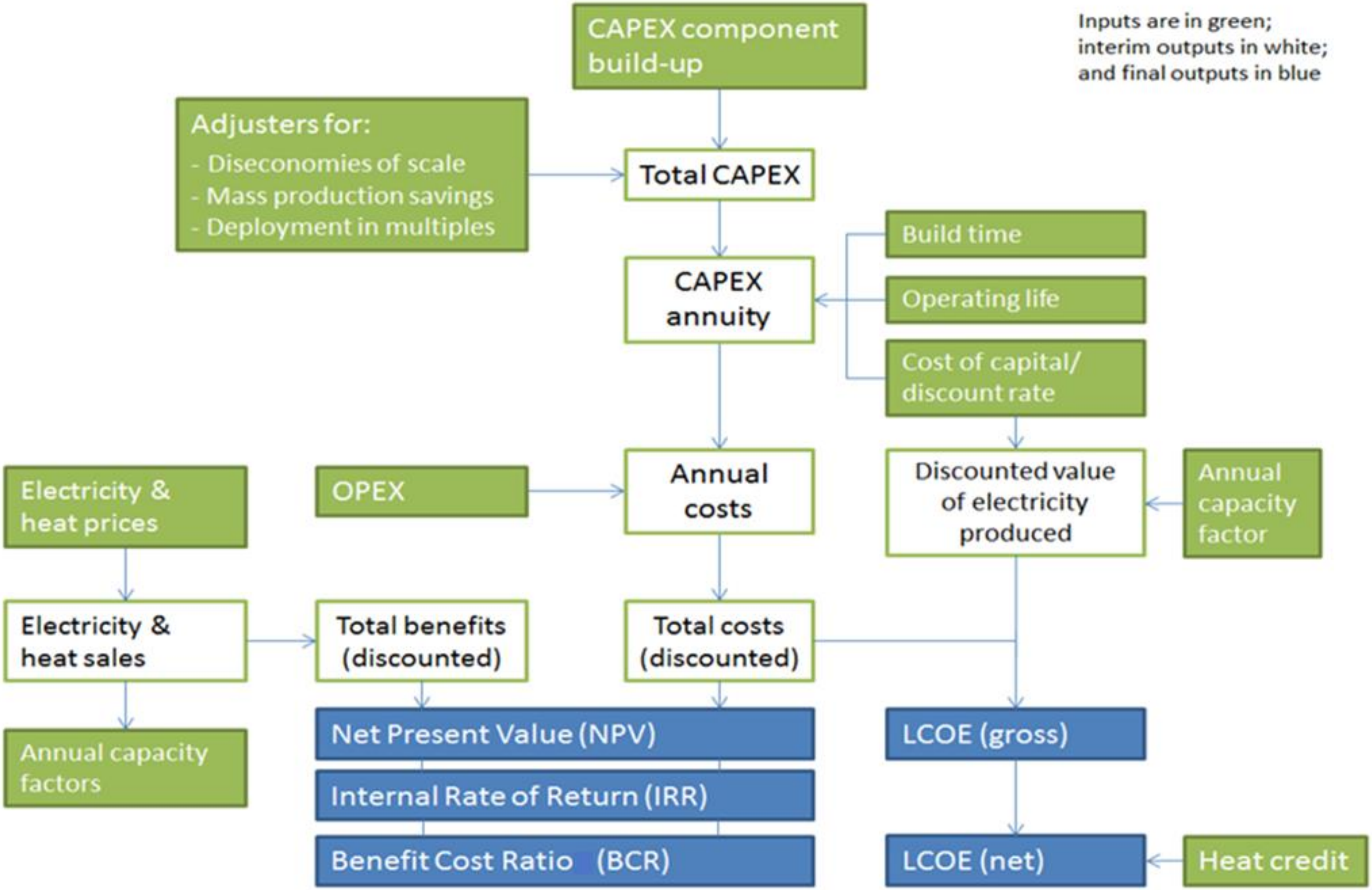
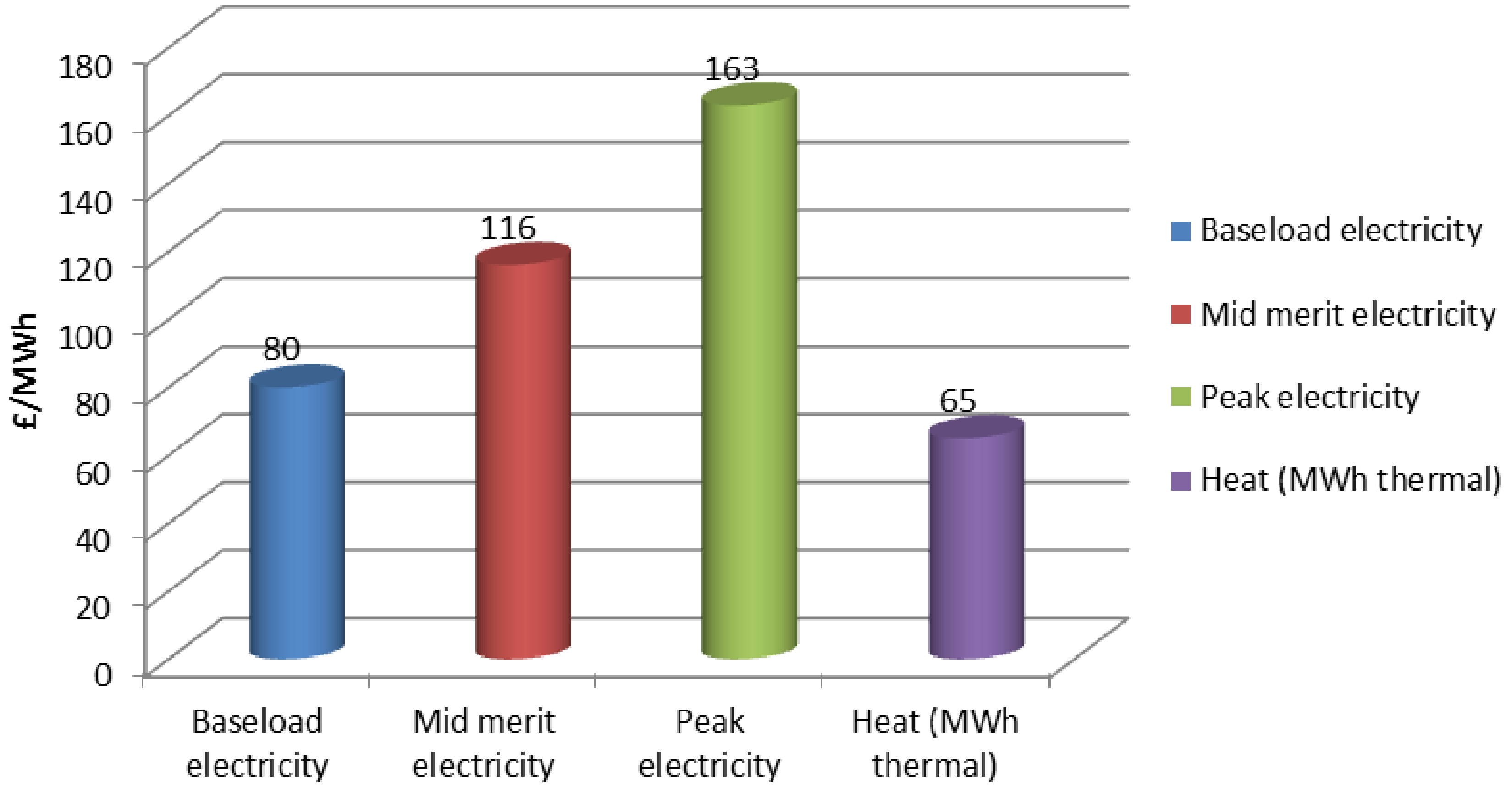
Economic model



Assumptions: Prices



Prices available to generators

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Assumptions: Other

	Assumption
Electricity Annual Capacity Factor	85% for electricity only SMR 75% for CHP SMR
Heat Annual Capacity Factor	40% for CHP SMRs
Discount rate	10% (12% for FOAK)
Construction period	4 years
Project life	60 years
CfD term	35 years
Fuel cycle cost	£50/kW p/a (NOAK)
Total OPEX	£165/kW p/a (NOAK)

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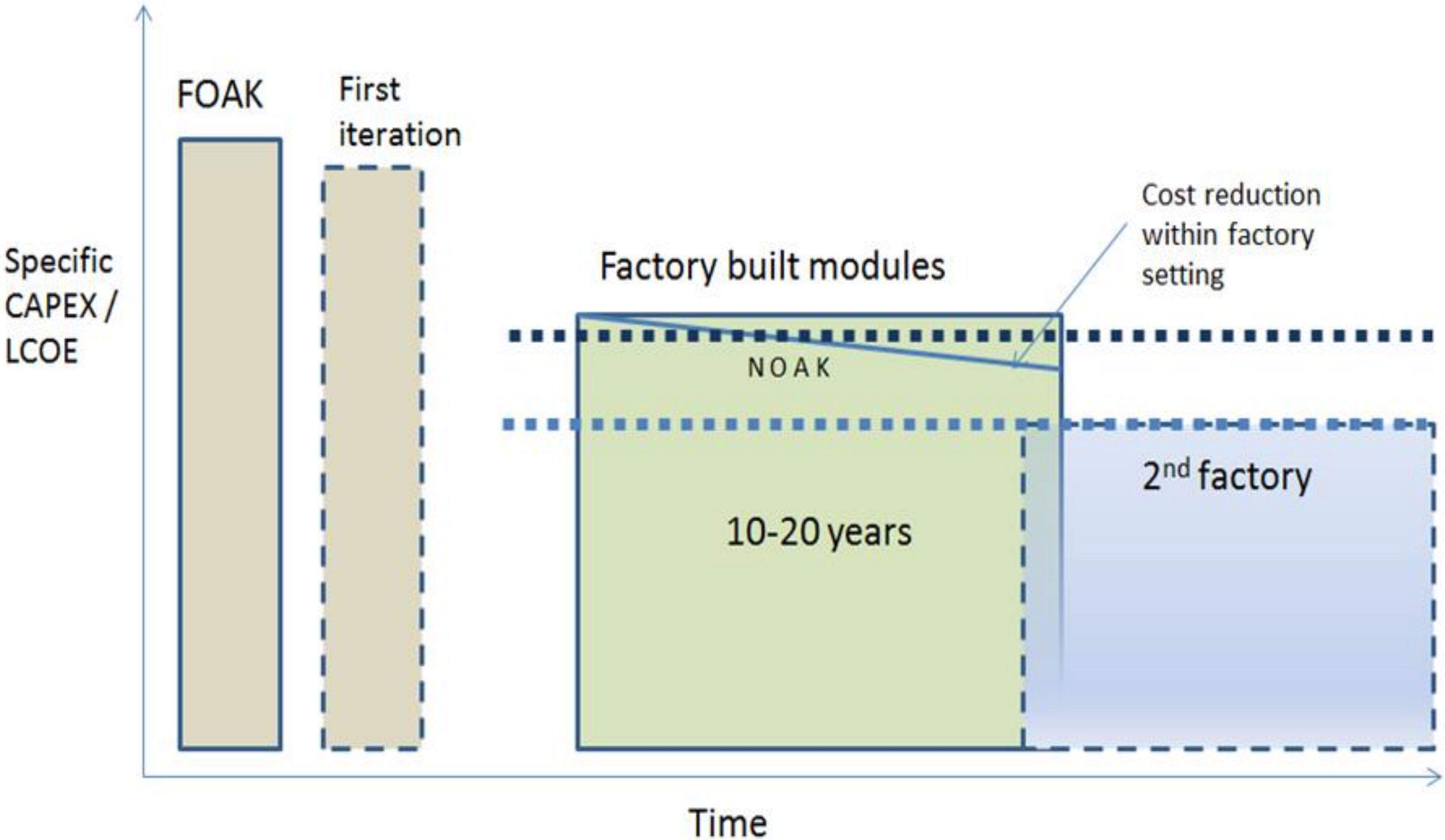
Stepped cost reduction pathway



Target costs: Results

	NOAK plant (base case)	NOAK plant (sensitivity)
Electricity-only SMR (baseload)	<£3,600/kWe <£80/MWh LCOE	Increases to <£3,900/kWe with more optimistic assumptions
CHP SMR	<£6,500/kWe	Reduces to <£5,000/kWe with more pessimistic assumptions
Extra-flex SMR	*Incremental* specific CAPEX of <£415/kWe (11% uplift)	

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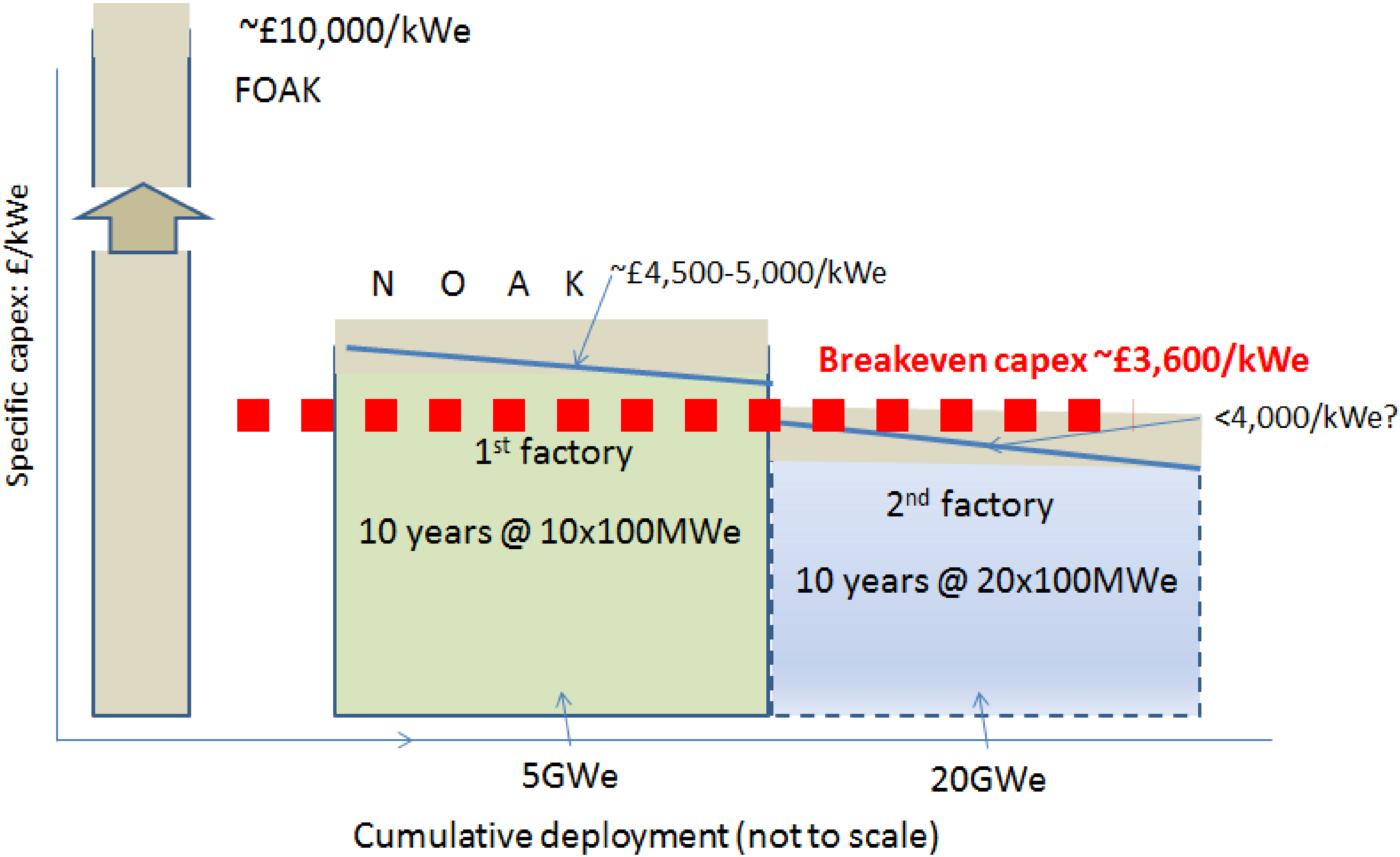
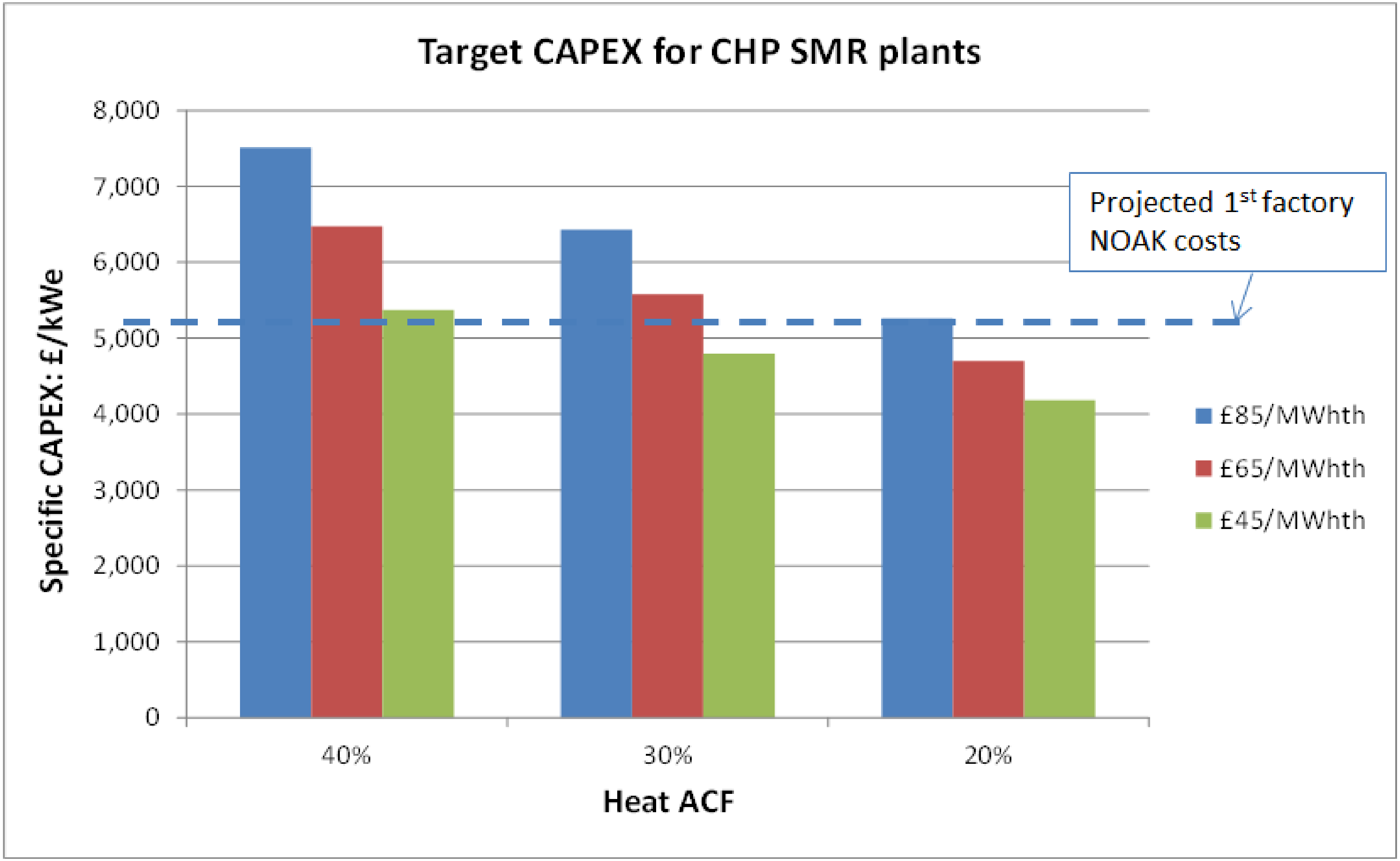
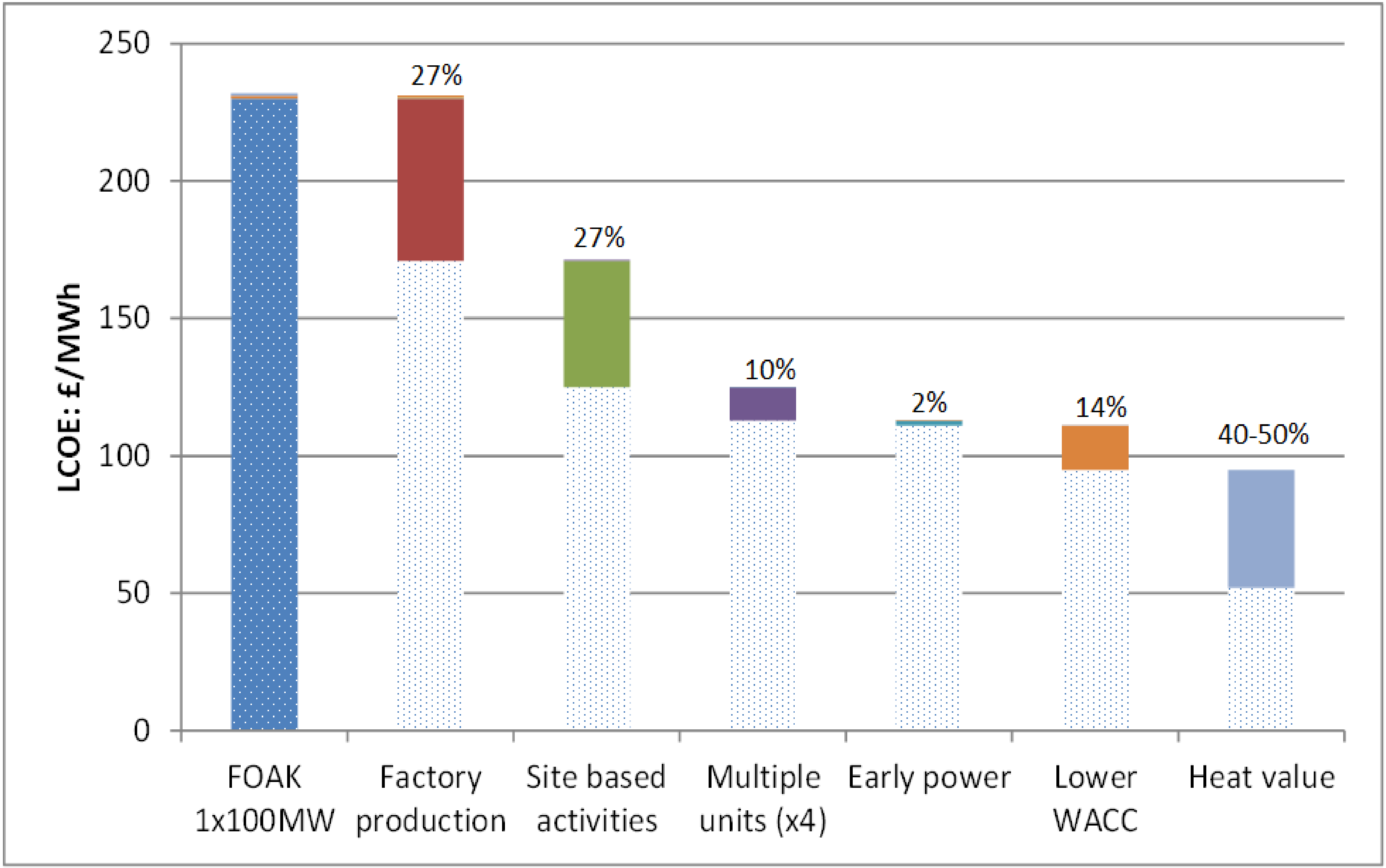
Target vs estimate: Electricity-only SMR



Target vs estimate: CHP SMR



Cost reduction drivers



Timeline for deployment

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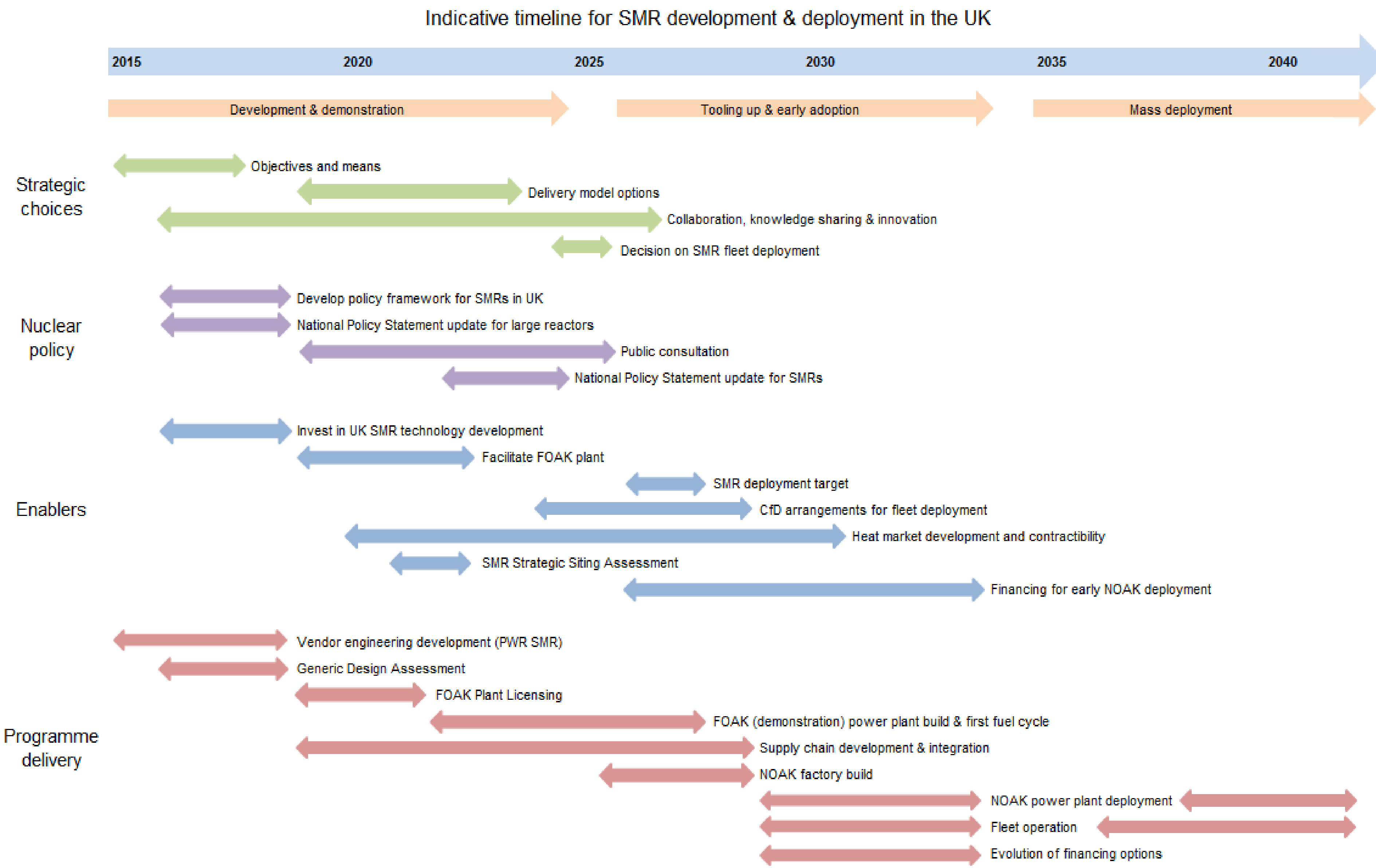
Enabling activities



Conclusions

Headline conclusions

1	Role	If SMRs do what proponents claim, SMRs could play a significant role in the UK's future energy system
2	Requirements	SMRs will need to achieve a number of functional and economic energy systems requirements e.g. costs
3	Heat	Heat provision to DH networks could be a major benefit to the UK energy system and SMR plant economics
4	Timeframes	Widespread deployment likely only from 2030 onwards
5	Role of Government	Deploying a fleet of UK SMRs is likely to require Government co-ordination and intervention

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Questions?

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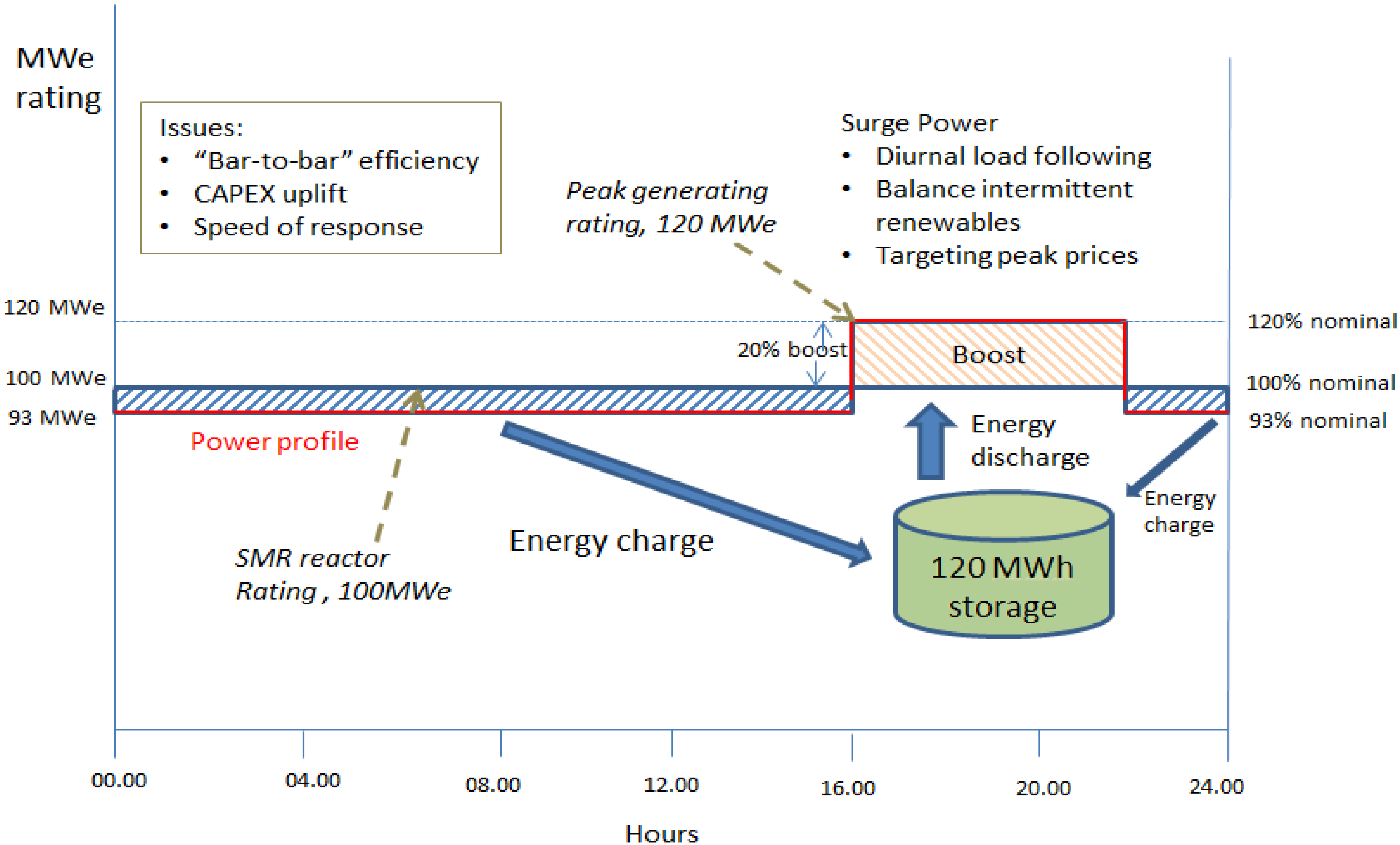
Back-up slides

What energy services could SMRs offer?



Extra-flex concept

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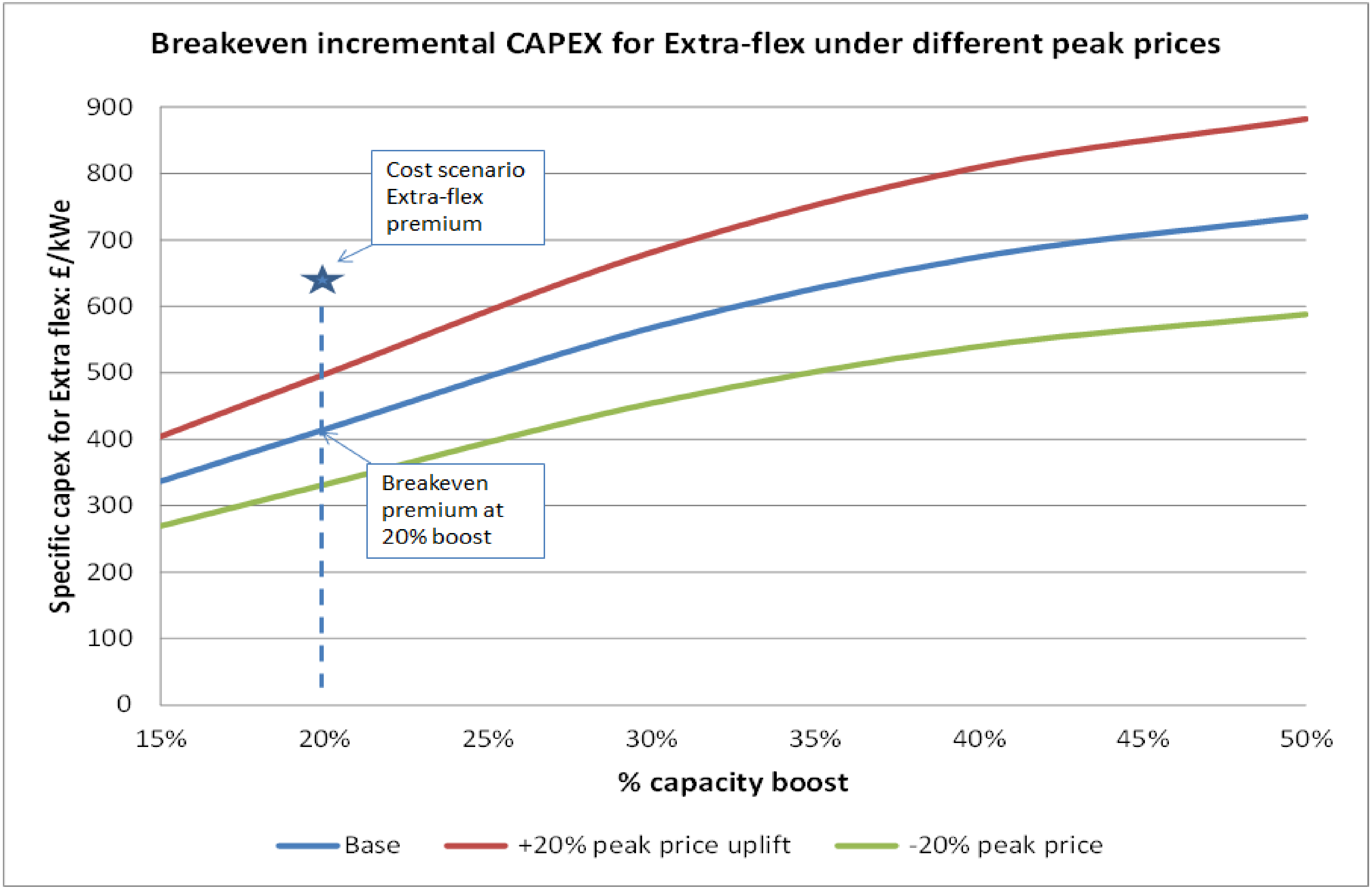
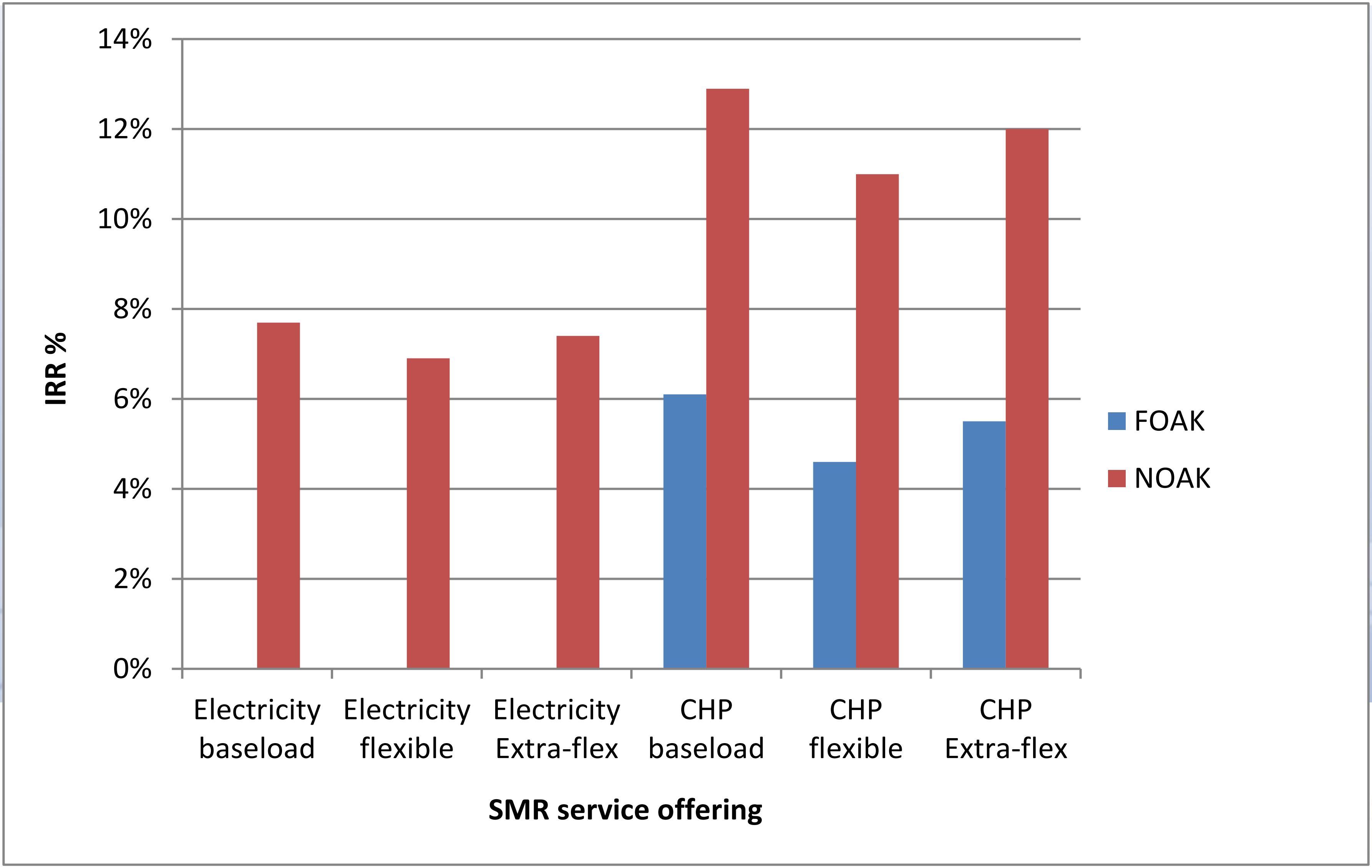
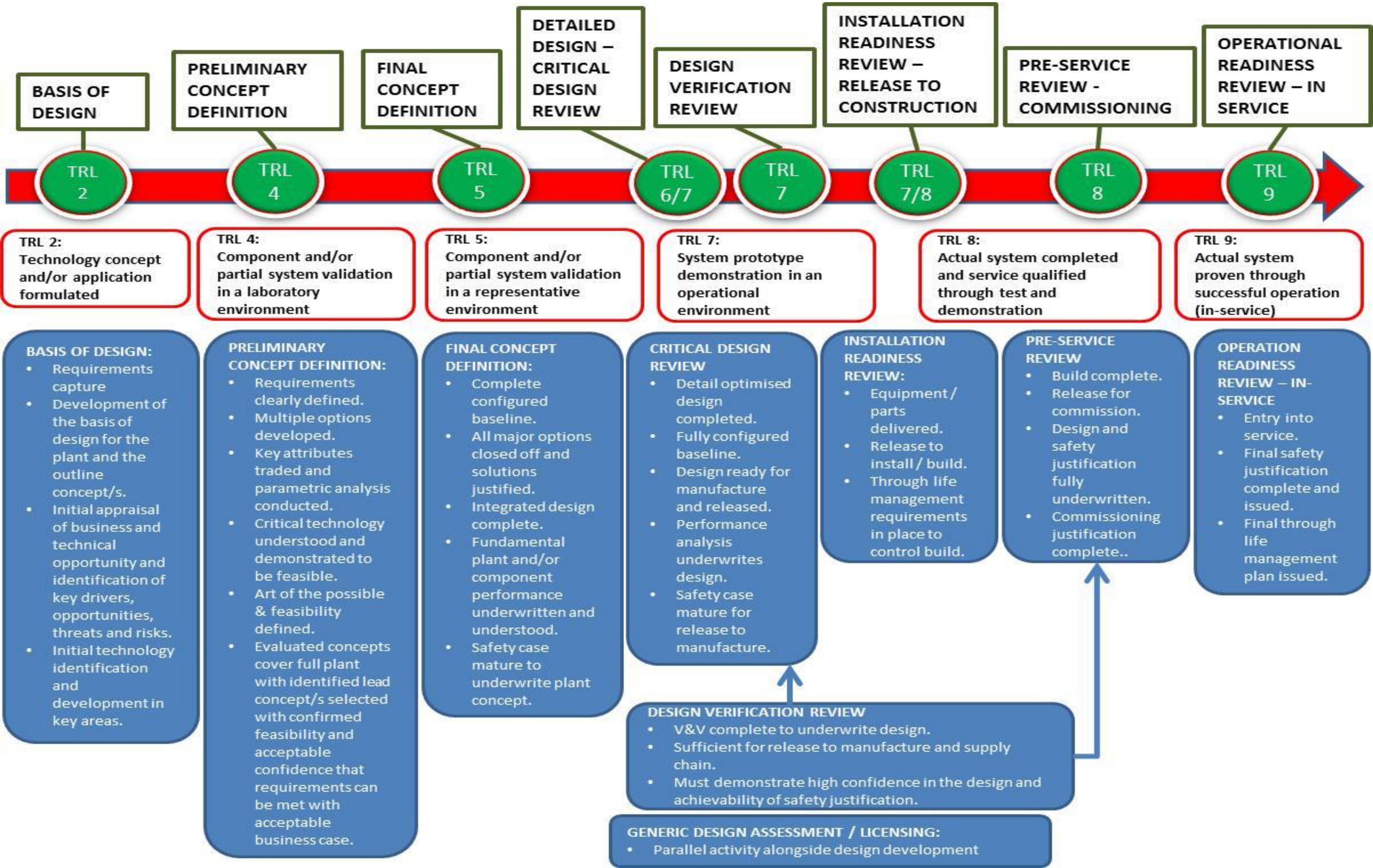
Target vs estimate: Extra-flex



IRRs based on estimated CAPEX



Technical development assessment framework



Non-kWh services

- Reserve and response of different types
- Equivalent to ~2% of energy sales value
  - Mainly procured through Balancing Mechanism (BM)
- Expectation that Ancillary Services (AS) need will increase
- But limited role for (conventional) nuclear
  - As not suited to active participation in BM
  - Strong competition from flexible generation, smart demand and storage
  - Extra flex may offer greater scope

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