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The role for Small Modular Reactors In A UK Low Carbon Economy

Low Carbon Technologies for the UK Energy System

Tuesday 7th November at the SCI, London

ETI10 TEN YEARS OF INNOVATION 2007 — 2017

Mike Middleton – Strategy Manager for Nuclear

Presentation Structure

Introduction to the ETI

- What is a Small Modular Reactor (SMR)?
- Benefits of deploying SMRs in the UK transition to a low carbon economy
- Understanding the steps towards potential deployment
- Update on Phase 1 of the UK SMR competition

Conclusions

Introduction to the ETI organisation

- The ETI is a public-private partnership between global energy and engineering companies and the UK Government.
- Targeted development, demonstration and de-risking of new technologies for affordable and secure energy
- Shared risk

ETI members

bp

CATERPILLAR®

EDF ENERGY

Rolls-Royce

Shell

Department for Business, Energy & Industrial Strategy

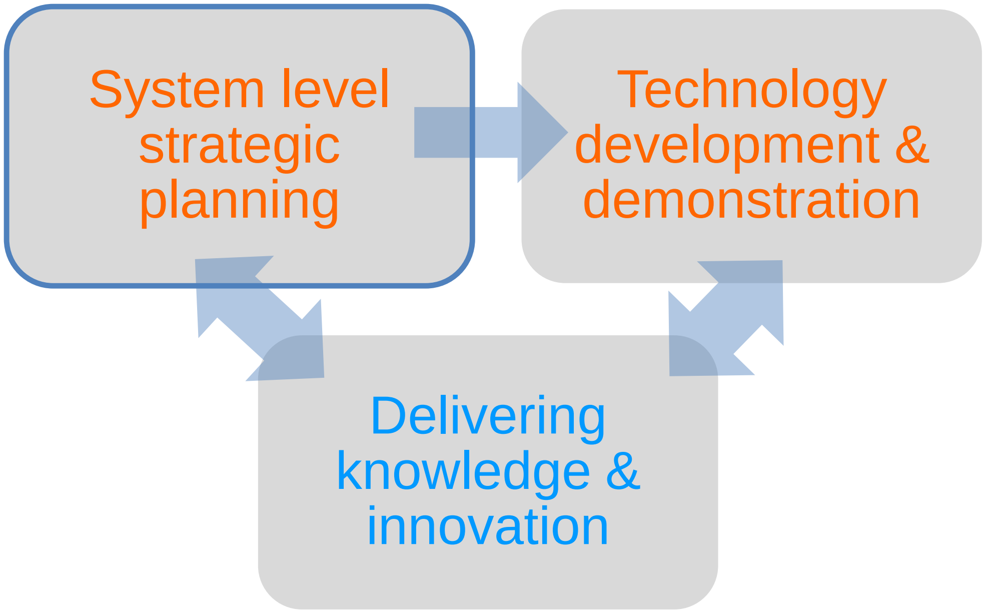
EPSRC Pioneering research and skills

Innovate UK Technology Strategy Board

ETI programme associate

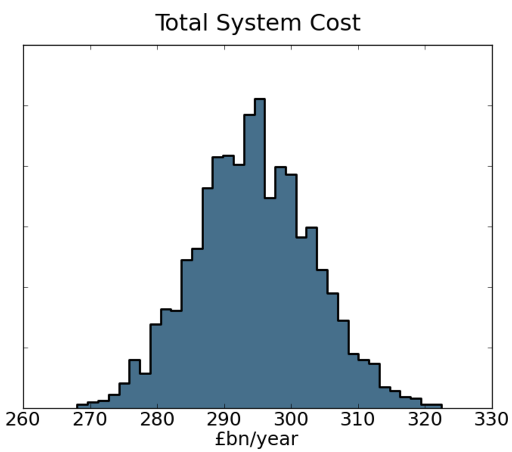
HITACHI Inspire the Next

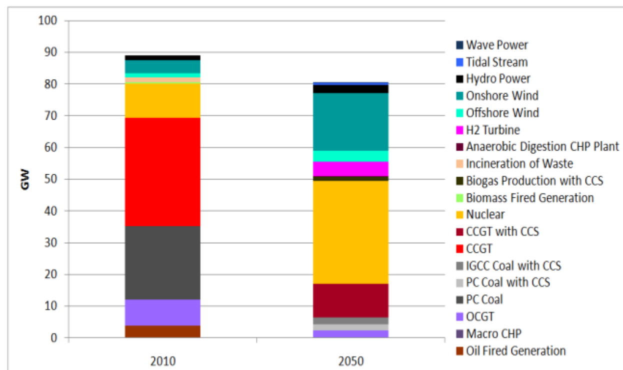
What does the ETI do?

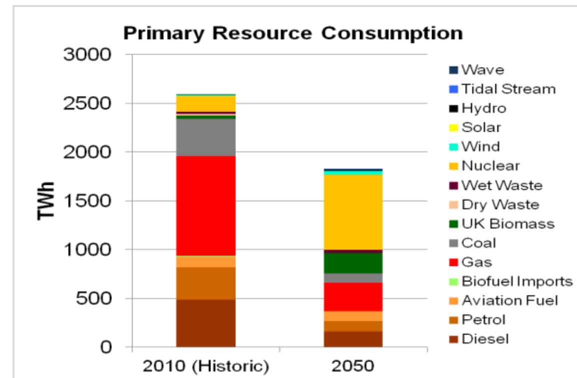


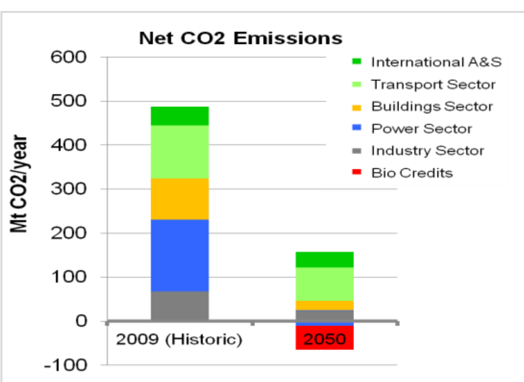
ESME – The ETI's system design tool

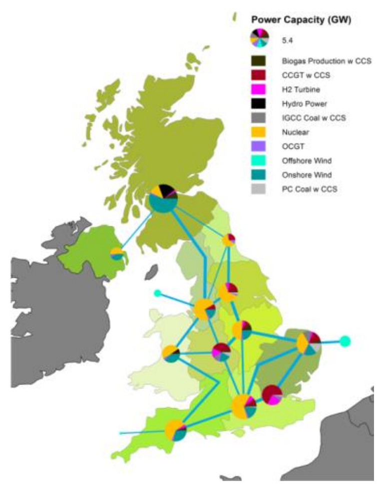
Integrating power, heat, transport and infrastructure providing national / regional system designs

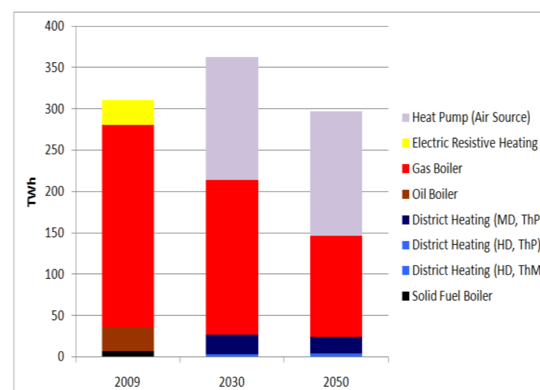








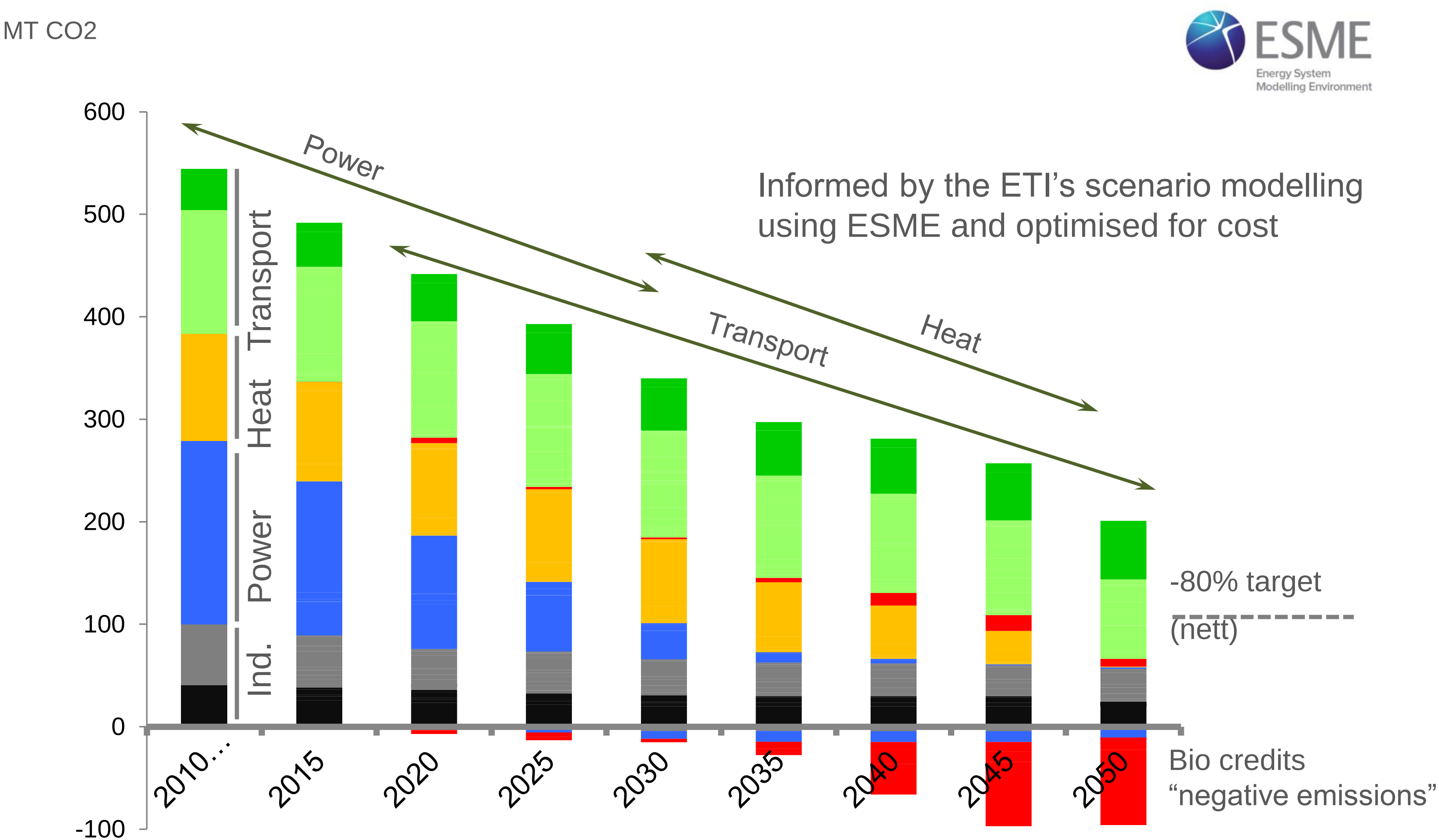




ESME example outputs

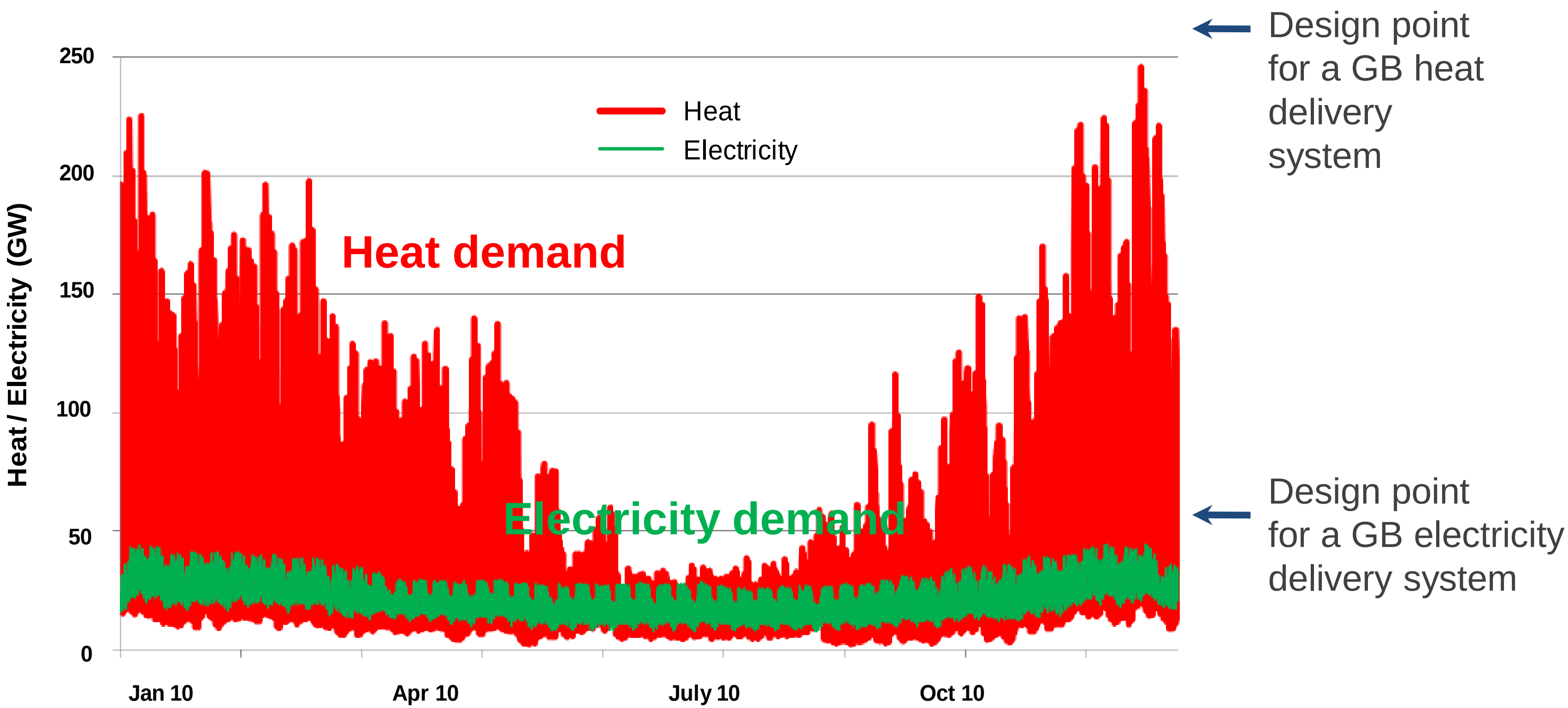
A UK emissions reduction plan

Power now, heat next, transport gradual – cost optimal



Decarbonising Heat Is Challenging

Heat demand variability in 2010 – Unattractive to electrify it all



GB 2010 heat and electricity hourly demand variability - commercial & domestic buildings
R. Sansom, Imperial College

Conclusions from published ETI insights (1) – role for nuclear in a low carbon energy system

10 YEARS TO PREPARE for a low carbon transition

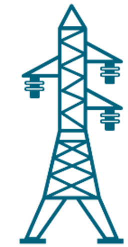
New nuclear plants can form a major part of an affordable low carbon transition

with potential roles for both large nuclear and small modular reactors (SMRs)

Large reactors are best suited for baseload electricity production

analysis indicates an **upper capacity limit** in England & Wales to 2050 from site availability of

35 GWe



Actual deployment will be influenced by a number of factors and could be lower. Alongside large nuclear, SMRs may be less cost effective for baseload electricity production

SMR's could fulfil an additional role in a UK low carbon energy system by delivering combined heat and power

a major contribution to the decarbonisation of energy use in buildings

but deployment depends on availability of district heating infrastructure

SMR's offer more flexibility with deployment locations that could deliver heat into cities via hot water pipelines up to

30 km in length

Assessed deployment capacity of at least

21 GWe

limit could be higher

Total nuclear contribution in the 2050 energy mix could be around 50 GWe; SMRs contributing nuclear capacity above 40 GWe will require flexibility in power delivery to aid balancing of the grid

Future nuclear technologies will only be deployed if there is a market need

and these technologies provide the most cost effective solution

A decision is required now

10 years

whether to begin 10 years of enabling activities leading to a final investment decision for a first commercially operated UK SMR

earliest operational date around

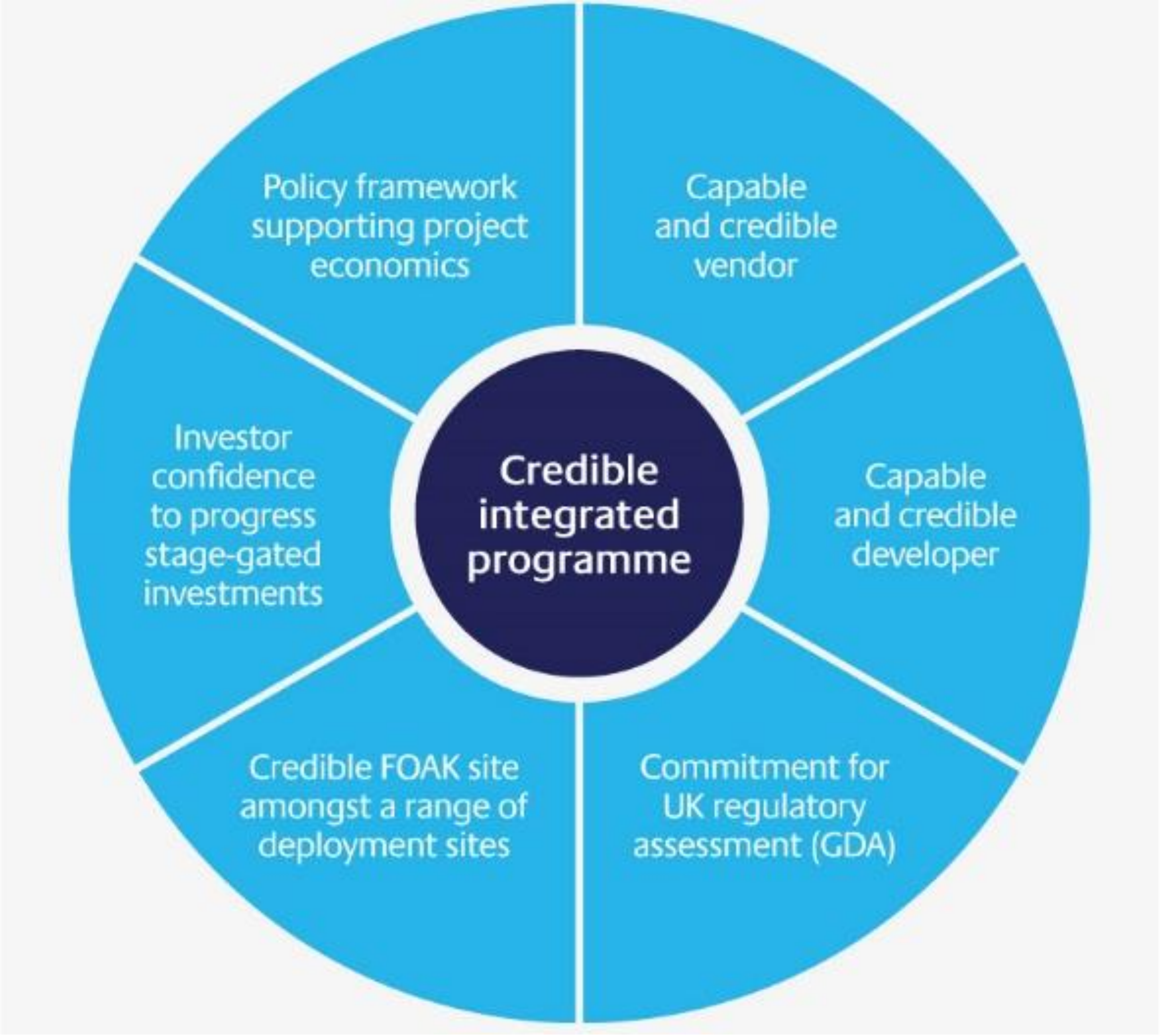
2030

A strategic approach to reactor siting together with public consultation

will be important in determining the extent of deployment of both large nuclear and SMR's

http://www.eti.co.uk/the-role-for-nuclear-within-a-low-carbon-energy-system/

Key Elements Of A UK SMR Development Programme



Small Modular Reactors - Definition

SMR is a small or medium reactor but not necessarily modular:

- Small - 10 to 300 MW (IAEA, DOE)
- Medium - 300 to 700 MW (IAEA)
- Excludes Large - 700 to 1700 MW (IAEA)

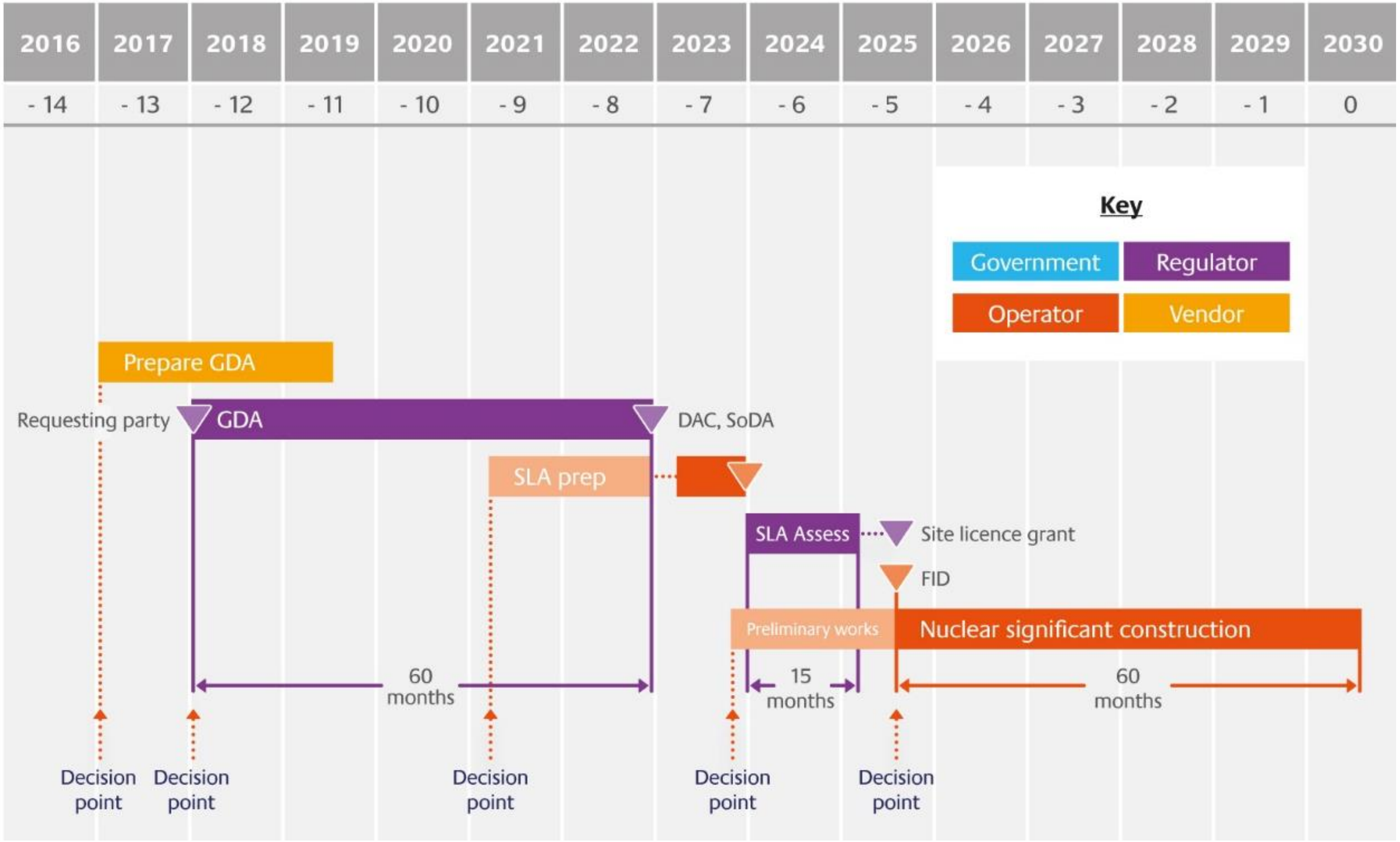
Modular in deployment:

- Modular – Multi-modular Nuclear Power Plant (NPP) on a common foundation base mat, with NPP modules added as needed
- Not power in a module to be returned to the factory for refuelling

Economic Advantage:

- Proponents aspire to use modern manufacturing and construction methods to reduce unit costs – the economies of multiples
- Innovation to overcome the dis-economies of scale of smaller units

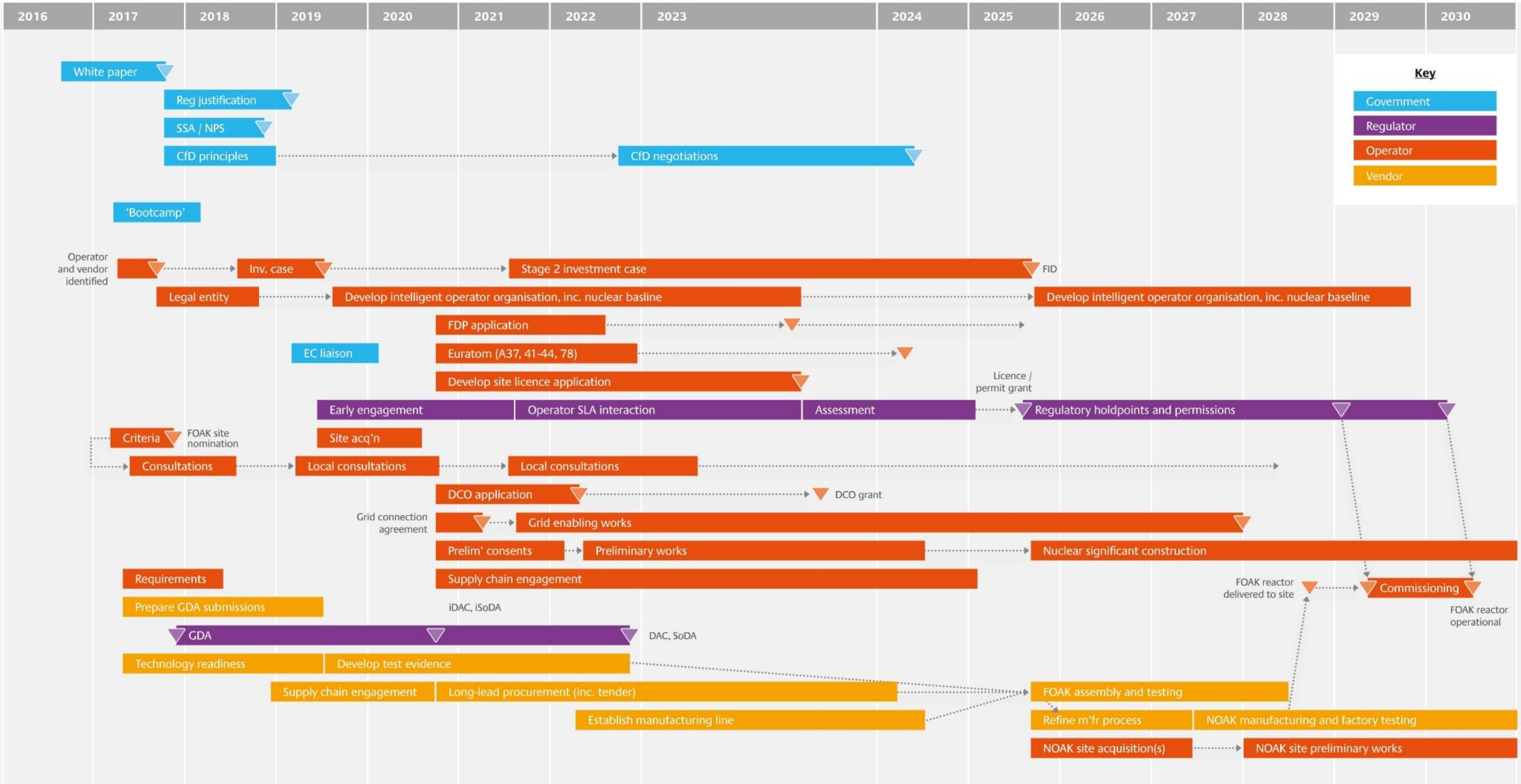
The Critical Path Of A 2030 Schedule



Key dates & assumptions (durations):

- GDA starts end 2017 (5 years)
- Site licensing preparations from early 2021 (4 and a half years)
- Site preliminary works from end 2023 (21 months)
- FID 2025 followed by nuclear construction and commissioning (5 years)

Integrated Schedule Leading To FOAK Operations By 2030



With UK Government Facilitation of enabling activities, vendor and developer activities can proceed in parallel - facilitation enables deployment acceleration

Conclusions - Preparing for deployment of a UK SMR by 2030

A credible integrated schedule for a UK SMR operating by 2030

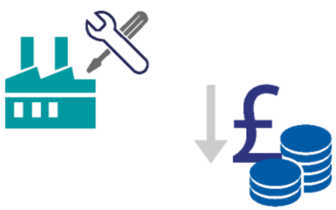
depends on early investor confidence

The Government has a crucial role to play

in delivering a policy framework which supports SMR deployment and encourages investor confidence

If SMRs are to become an integral part of a 2050 UK energy system, deployment should address future system requirements including

SMR factory production can accelerate cost reduction



UK SMRs designed and deployed as "CHP ready"

Extra costs are small and potential future revenue large

UK SMRs should be designed for a range of cooling systems

including air cooled condensers

There is economic benefit in deploying SMRs as CHP to energise district heating networks; this depends on district heating roll out

There is a range of sites suitable for early UK SMR deployment

Including options for the UK first of a kind site

http://www.eti.co.uk/insights/preparing-for-deployment-of-a-uk-small-modular-reactor-by-2030

UK SMR Competition Phase 1 - Update

NB The ETI is not a party to the BEIS UK SMR competition process

- Near term SMRs; economics and market applications
- Developing markets
- Developing technologies
- Reactor types and technology readiness
- Innovation support by Government since 2013

Near Term SMRs
Economics & Market Applications

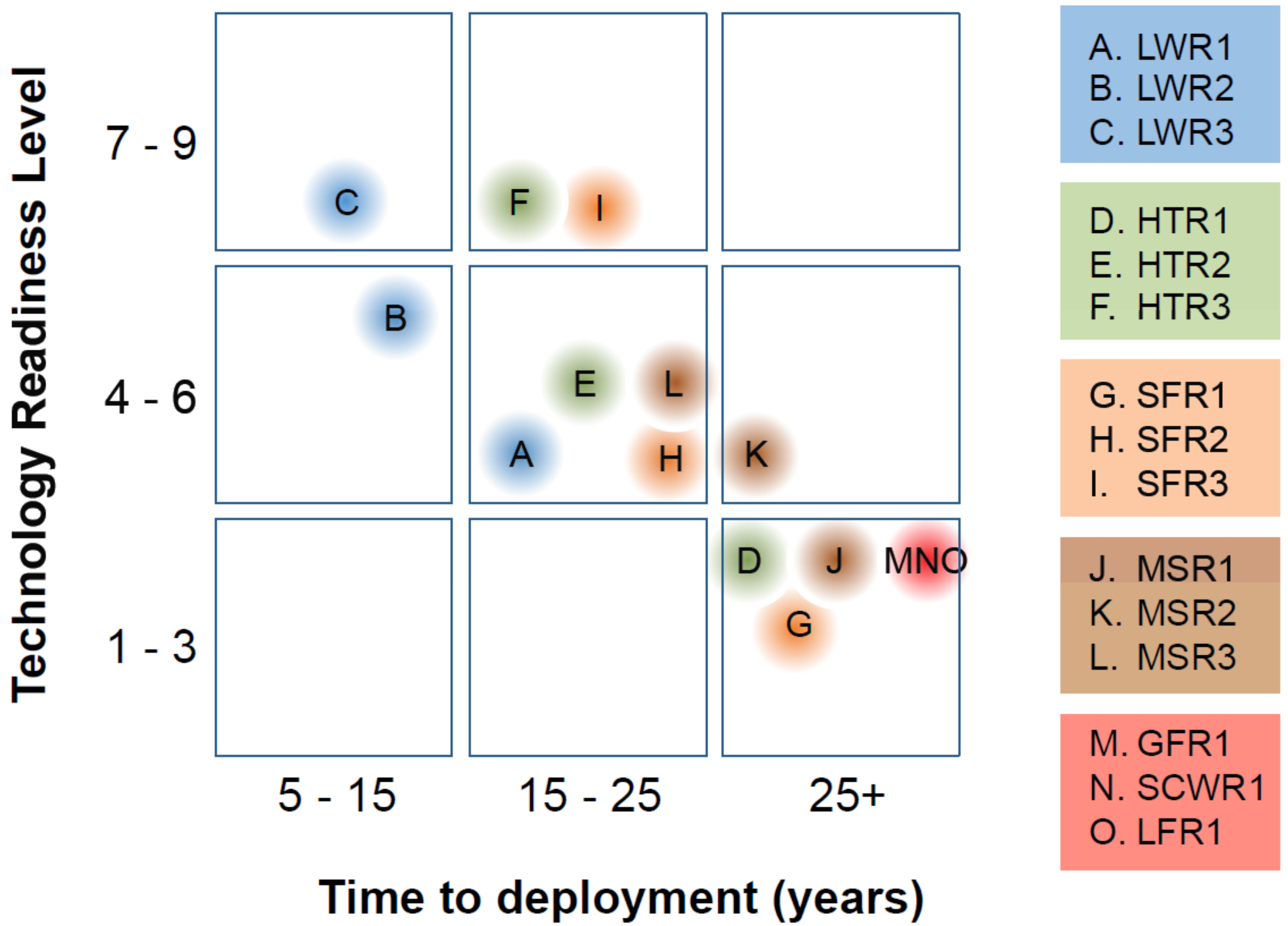
LCOE £/MWhr	Notes	Market Size
Low	Price lower than other low carbon alternatives with predictable project delivery.	Very large with potential for growth in nuclear share internationally driven by SMRs.
Competitive	A viable choice depending on policy considerations and viable projects.	Large with potential applications to complement large reactor deployment.
Not yet competitive	Cogeneration applications such as district heating supply or desalination improve project economic viability. Increase volume to reduce unit cost.	Small fraction of present international nuclear market.
High	Research and development plants. Remote communities off grid requiring heat and power.	Niche.

Developing Markets

Country	Technology	Notes
China	HTR – PM high temperature gas reactor	Construction start 2012 of demonstration plant at Shidaowan in Shandong province. Operations forecast 2017.
China	ACP100 integral PWR	IAEA safety review complete April 2017. Demonstration plant at Changjang. Commercial operations forecast 2021.
USA	NuScale integral PWR	Commenced NRC review Jan 2017. First potential customer UAMPs at site of Idaho Nuclear Laboratory. Commercial operations forecast 2025.
Canada	Open and technology neutral	Canadian Government and regulatory support for nuclear technology development at Canadian Nuclear Laboratories site at Chalk River with SMR demonstration by 2026.
UK	?	Announcements awaited.

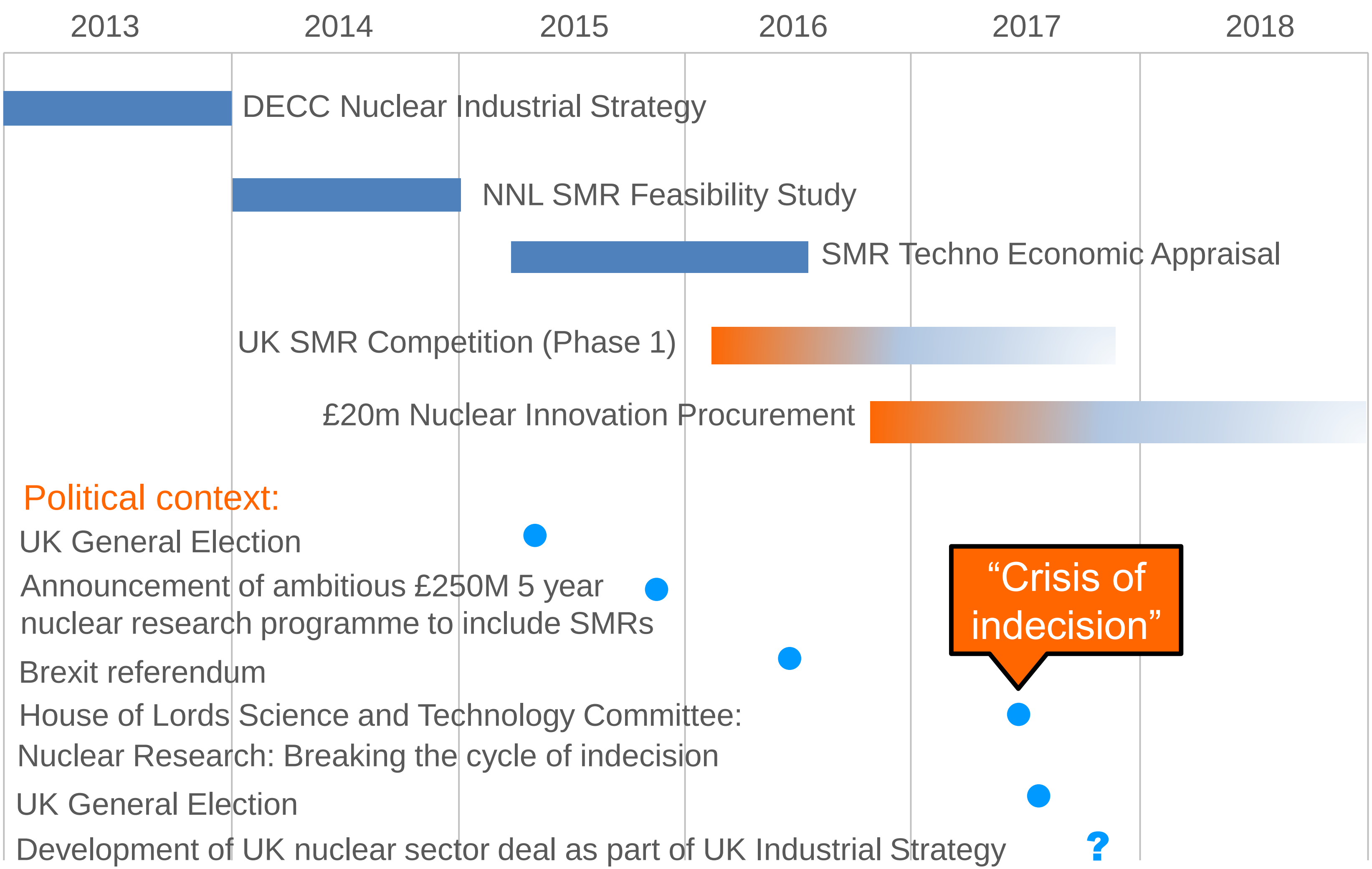
This table is illustrative; the list of markets and associated technologies is not exhaustive

NNL View In October 2016 of SMR Technology Readiness Levels



Source: NNL presentation at the London Nuclear Power Symposium 24th October 2016

Some Aspects Of Nuclear Innovation Support By Government Since 2013



Conclusions

- Cost optimised transition to a low carbon economy by 2050 summarised as:
  - Power first and substantially decarbonised by 2030
  - Heat to follow
  - Transition for transport is gradual and expected to include electrification
- Nuclear has a role to play depending on market needs and project economics (LCOE)
  - Large reactors for baseload and small flexible SMRs for potential CHP
- Economics of SMRs still relatively uncertain
  - Development schedule and cost
  - Capital cost and construction duration
  - Emergence of developers and operators prepared to invest in the UK
  - First adopter markets elsewhere advancing technology demonstration programmes
  - UK market alone unlikely to sustain a technology development/deployment programme
- Importance of UK Government policy:
  - Role of nuclear delivering UK energy security within the mix
  - Importance of Government facilitation for nuclear research, development & deployment
  - Plan for UK decarbonisation; heat and transport as well as electricity generation

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A showcase of a decade of research

ETI10 TEN YEARS OF INNOVATION 2007—2017

County Hall, London
21st and 22nd November

Register online at - www.eti.co.uk/10Years

ETI Projects – Nuclear Including SMRs

What are the siting opportunities and constraints for large reactors and SMRs in England and Wales? What is the range of locations suitable for early SMR deployment and is there an obvious front runner for a a First Of A Kind (FOAK) SMR site?

- Power Plant Siting Study Phases 1, 2 and 3

What services and characteristics would be attractive from the perspectives of a cost optimised low carbon energy system? Could SMR technology be a credible provider of some of these services? What are the cost and operational implications of committing to a plant which is CHP ready when built? What are the potential cooling system choices and economic impacts if unconstrained access to cooling water becomes more difficult?

- System Requirements For Alternative Nuclear Technologies Project Phases 1,2 and 3

What are the enabling activities in the first five years of an SMR programme necessary to support potential operations of a first UK SMR by 2030?

- SMR Deployment Enablers Project

Services Required From A UK SMR

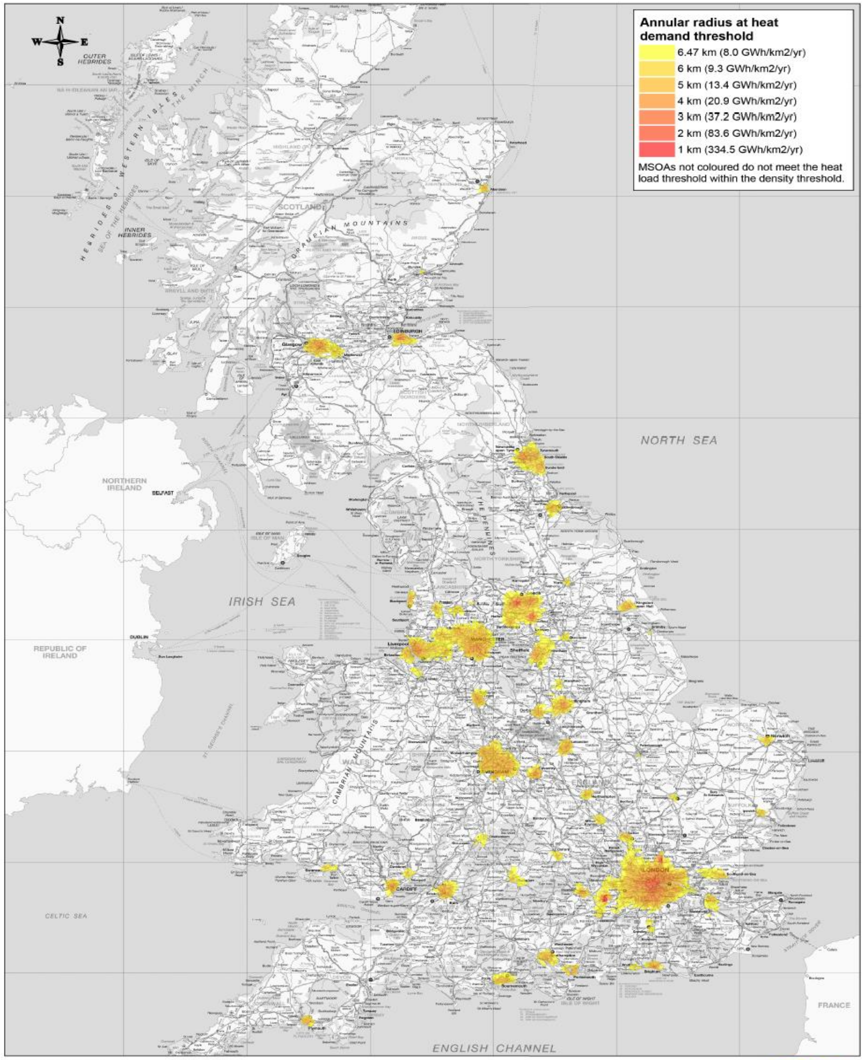
Large reactors optimal here

		Baseload	Flexible	Extra-flex
	Electricity only SMR power plant	Baseload power (continuous full power operation between outages)	Operated with daily shaped power profile when required to help balance the grid	(Slightly) reduced baseload power with extra storage & surge capacity
	Combined Heat & Power (CHP) plant	As above but with heat	As above but with heat	As above but with heat

Power, heat and flexibility

SMRs optimal here

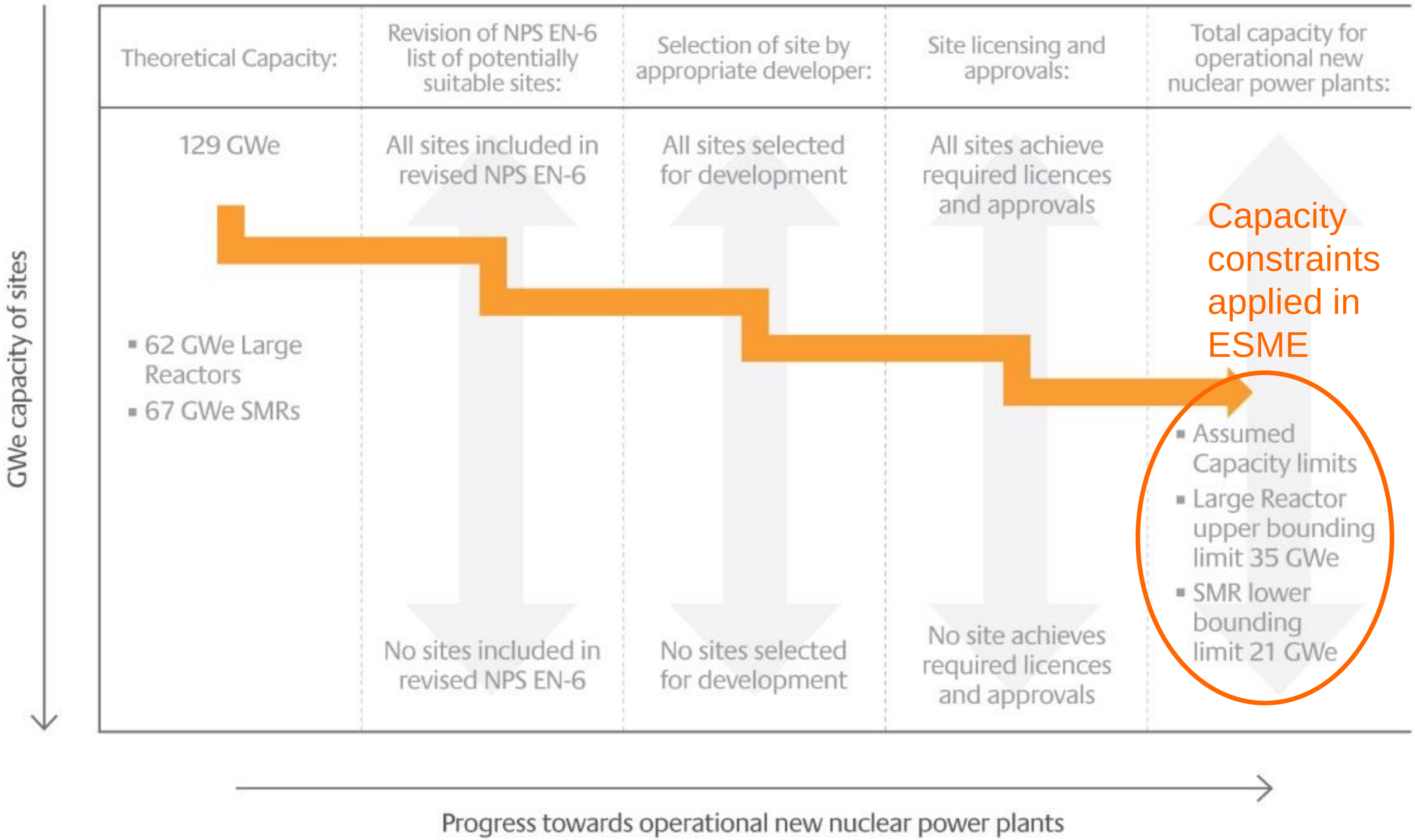
Future Heat Networks



Mott MacDonald

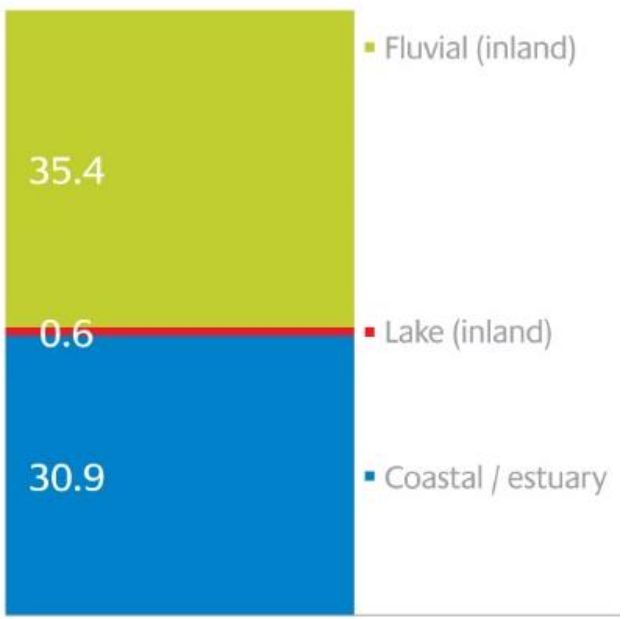
- Almost 50 GB urban conurbations with sufficient heat load to support SMR energised heat networks
- Would theoretically require 22 GWe CHP SMR capacity

Siting Data Applied In ESME

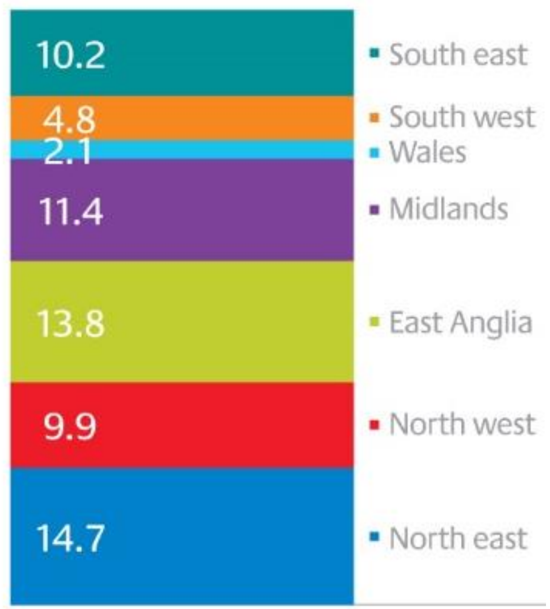


Distribution Of SMR Site Capacity

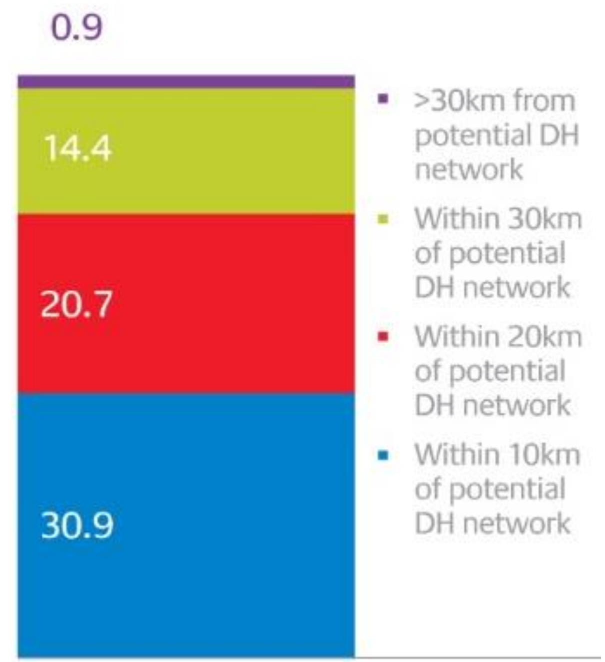
SMR site capacity from the Power Plant Siting Study -
Further potential locations likely to be found; the limit has not been explored



SMR Capacity (GWe) By Cooling Water Source



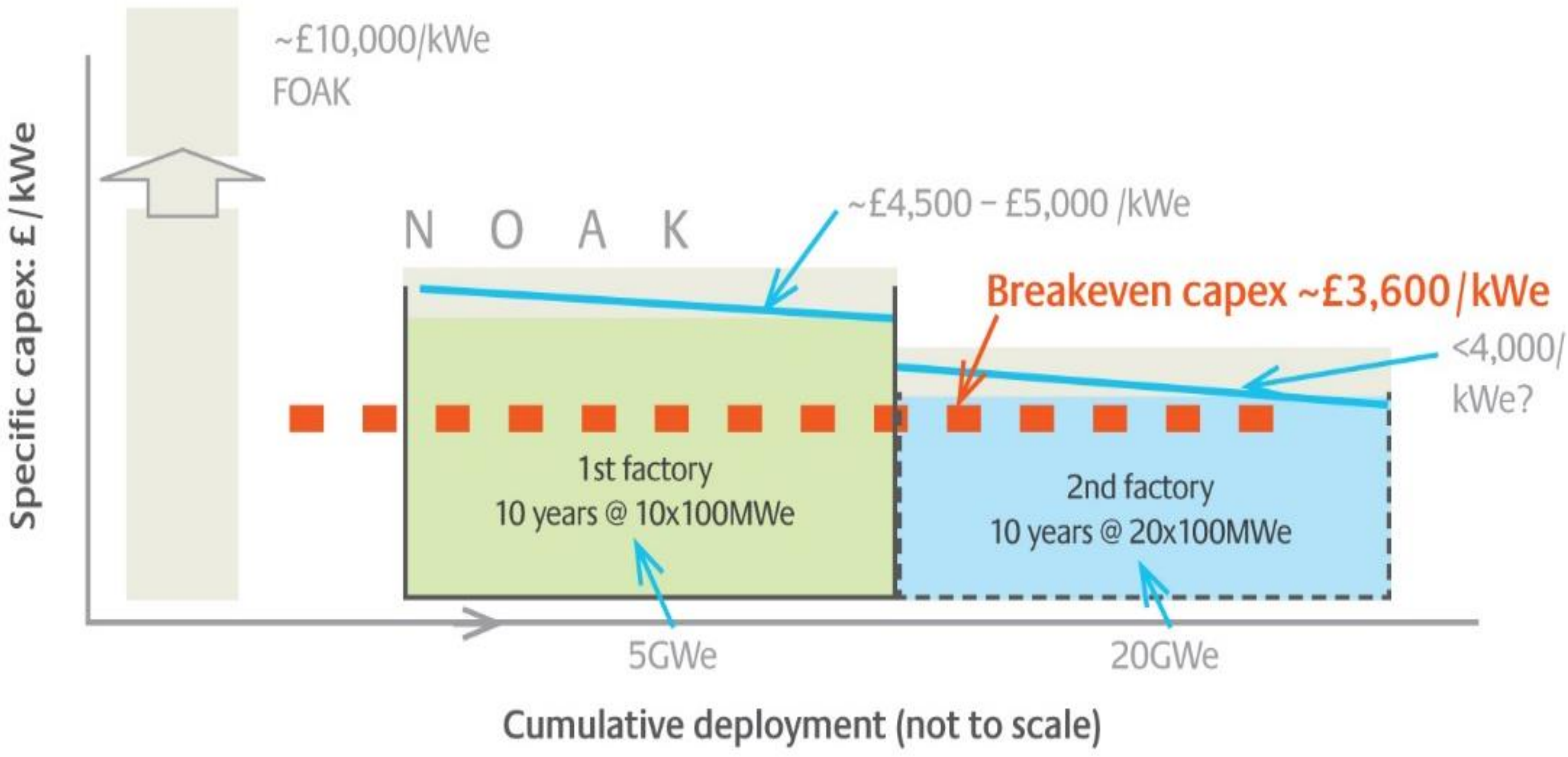
SMR Capacity (GWe) By Regional Location To Meet Demand



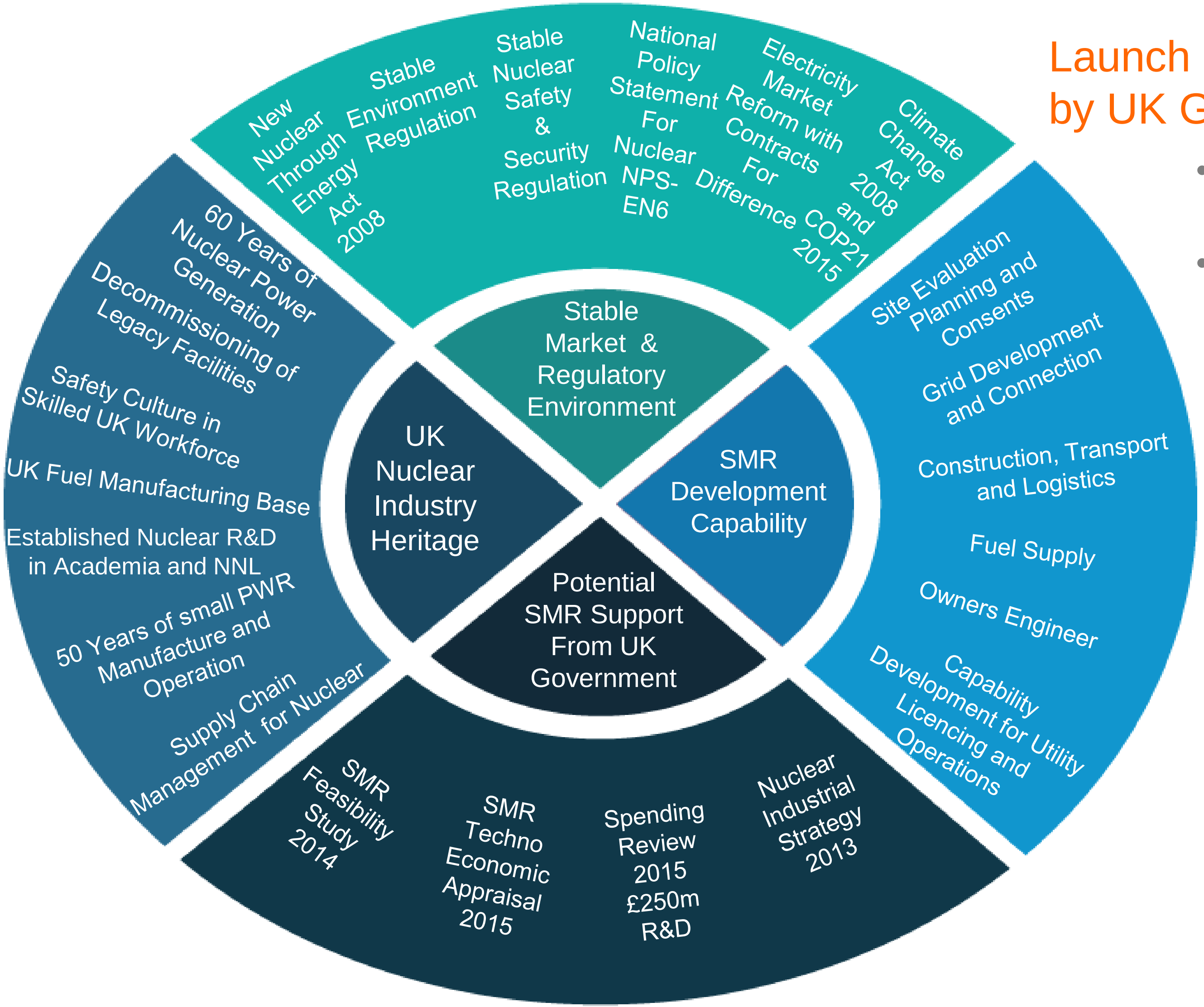
SMR Capacity (GWe) By Distance From Potential District Heating Network

Cost Reduction Model - Factory & Learner

Target CAPEX for a first fleet of SMRs providing baseload electricity is challenging



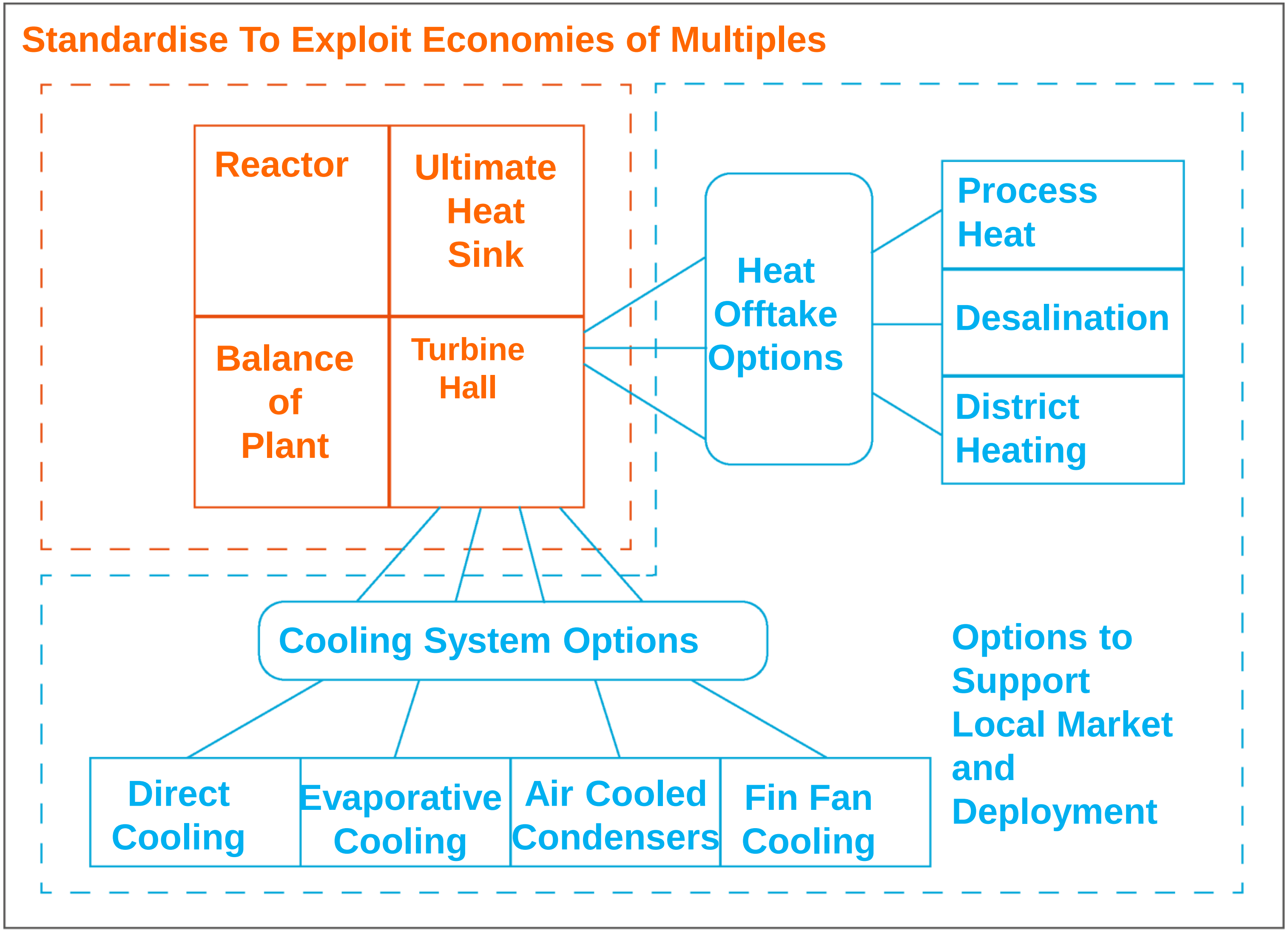
UK capability to support SMR deployment



Launch of SMR competition by UK Government:

- Expressions of interest until 6th May
- Phase 1 dialogue late May until autumn 2016

Exploiting The Economies Of Multiples – UK GDA and Coping With Variants



Scope of Design To Be Assessed Through Generic Design Assessment

Generation IV Advanced Reactor Types

Technology Group	Abbreviation	Neutron Spectrum
Very high temperature gas reactors	VHTR	Thermal
Molten salt reactor	MSR	Thermal
Supercritical water cooled reactors	SCWR	Thermal
Gas cooled fast reactor	GFR	Fast
Sodium cooled fast reactors	SFR	Fast
Lead cooled fast reactors	LFR	Fast

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