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The role of nuclear in the transition to a UK low carbon economy

A talk for the Imperial College Energy Society 24th January 2018

Mike Middleton – Strategy and Programme Manager for Nuclear at the ETI

Presentation Structure

Introduction to the ETI

- Developing the role for nuclear in a UK transition
- What could be the role for SMRs in the UK energy system
- A credible plan for deployment of a UK SMR by 2030
- Cost competitiveness of nuclear as a low carbon technology

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

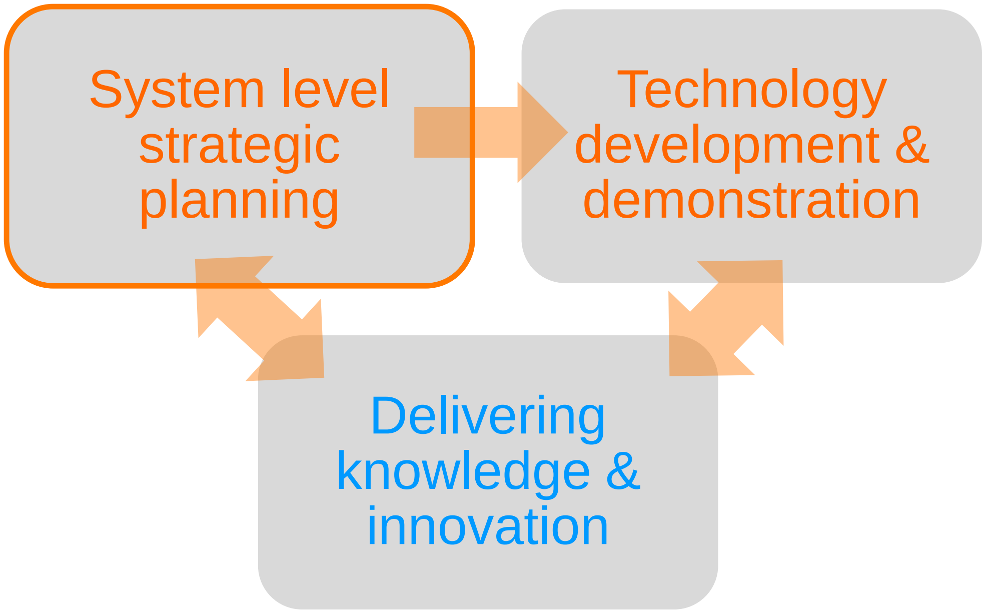
bp
CATERPILLAR®
EDF ENERGY
Rolls-Royce
Shell
Department for Business, Energy & Industrial Strategy
EPSRC Pioneering research and skills
Innovate UK Technology Strategy Board

ETI programme associate

HITACHI Inspire the Next

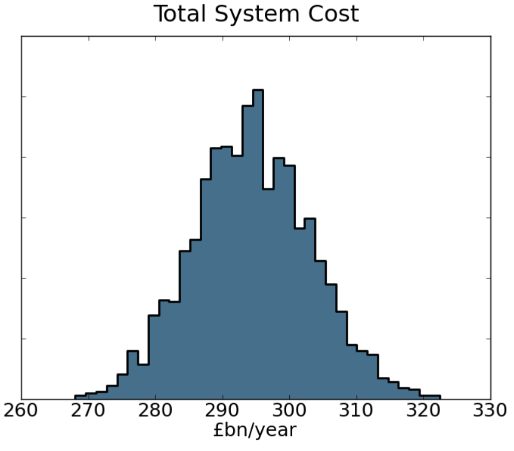
ESME Energy System Modelling Environment

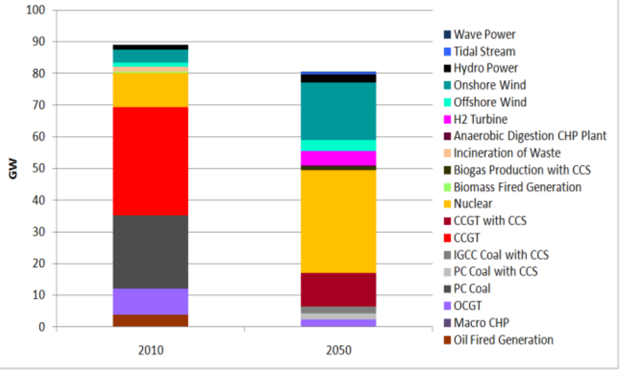
What does the ETI do?

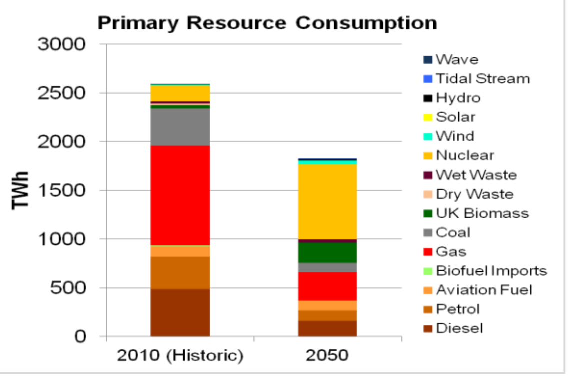


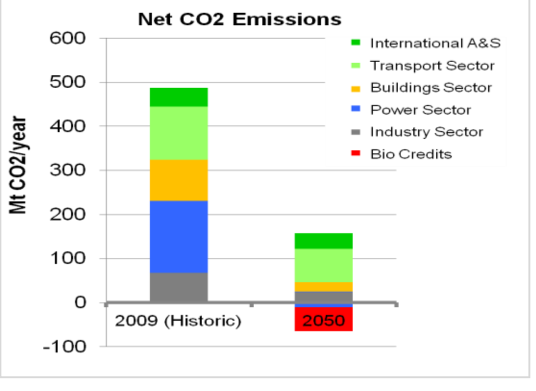
ESME – The ETI's system design tool

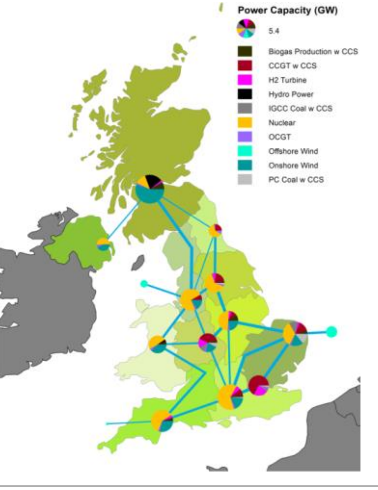
Integrating power, heat, transport and infrastructure
providing national / regional system designs

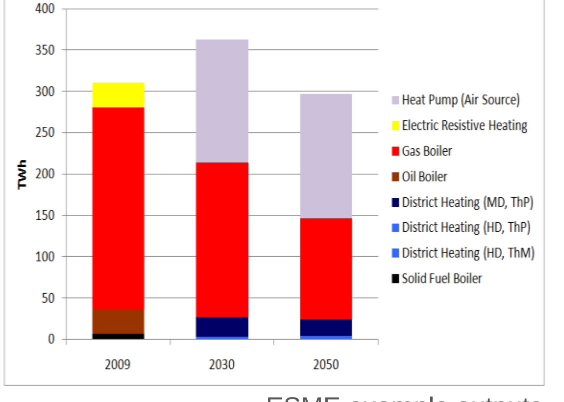








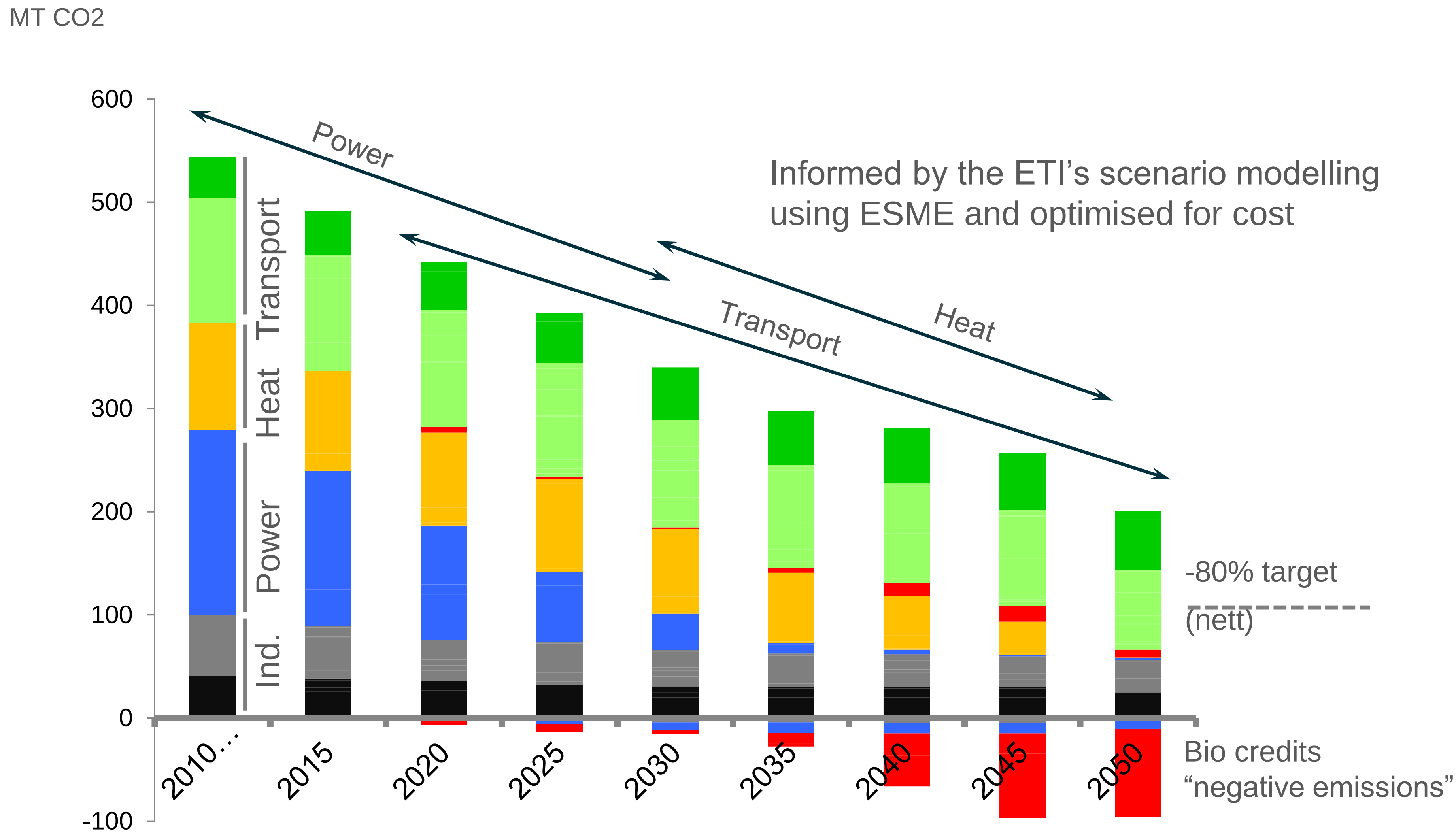




ESME example outputs

A UK emissions reduction plan

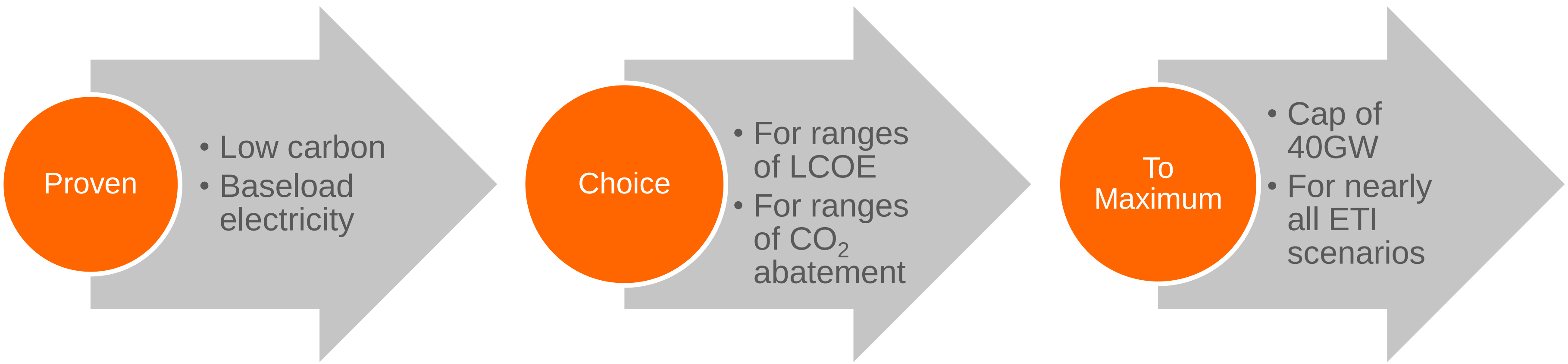
Power now, heat next, transport gradual – cost optimal



Legacy UK Nuclear Generation

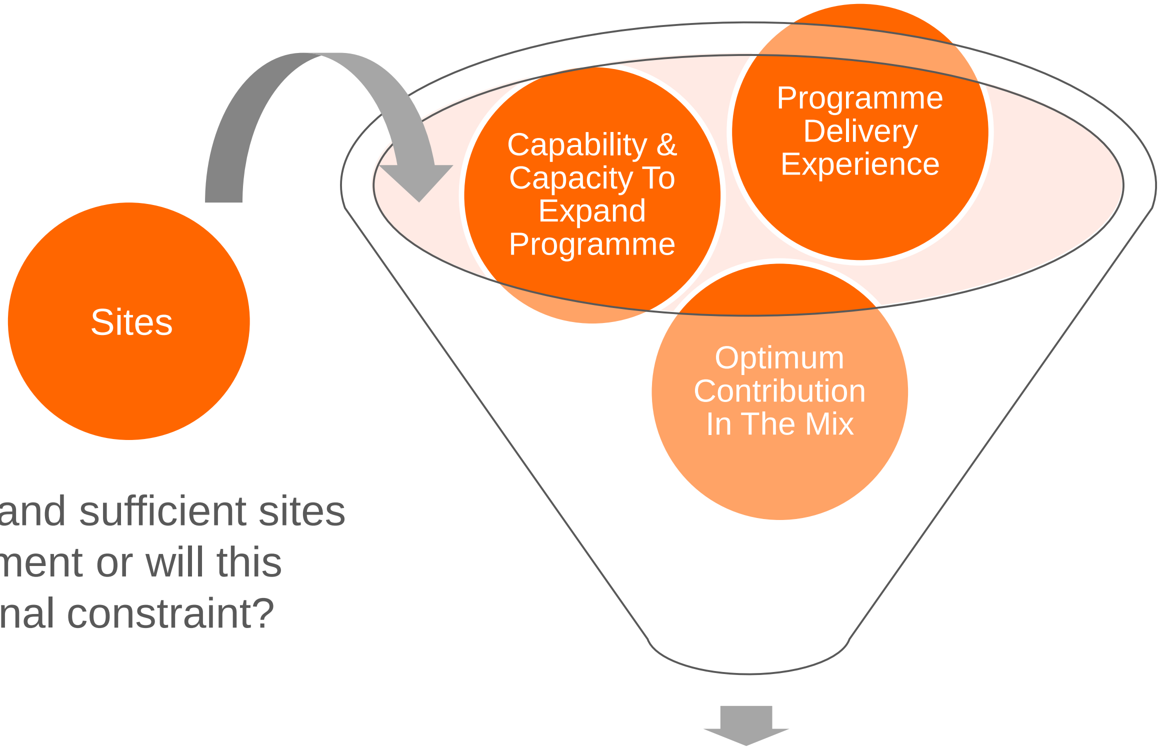
Plant Type	Capaity Installed GWe
Magnox	4.0
Advanced Gas Cooled Reactor	8.4
PWR Sizewell B	1.1
Total	13.5

The Established Role For Nuclear At 2013



LCOE – Levelised Cost Of Energy

UK Constraints In The Deployment Of Nuclear

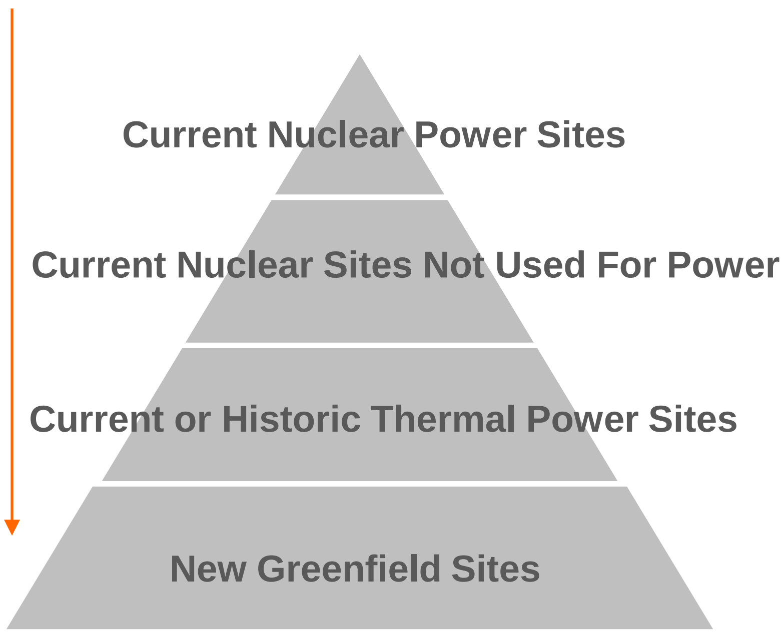


Are there suitable and sufficient sites for nuclear deployment or will this become an additional constraint?

Nuclear capacity in the 2050 energy system

Site Identification and Selection

Hierarchy Of Selection

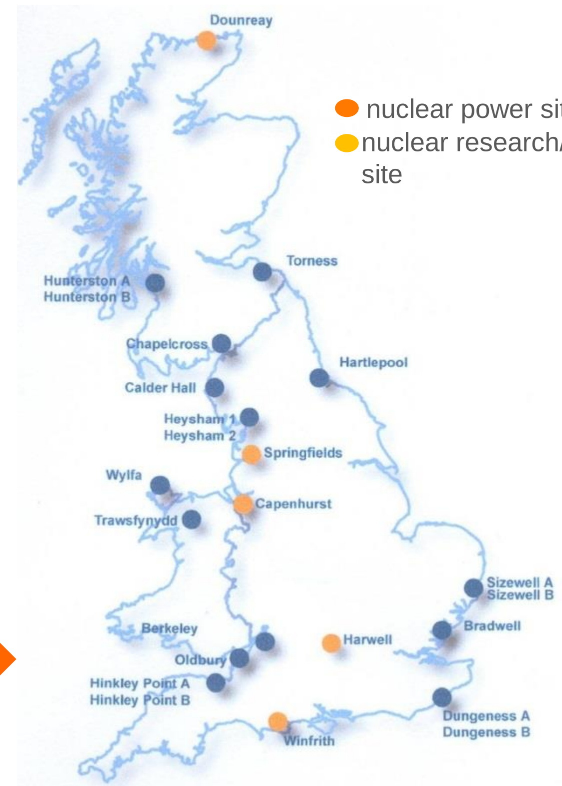


Site Capacity Required

Role For Nuclear	Installed Capacity	Site Capacity
Replacement	16 GW	☺
Expansion To Cap Applied In Most ETI Scenarios	40 GW	?
Expansion To Extreme Scenarios	75 GW	?

Up To 75 GW Nuclear Capacity?

Need to find sites for at least 25 of these, in this



- nuclear power site
- nuclear research/process site

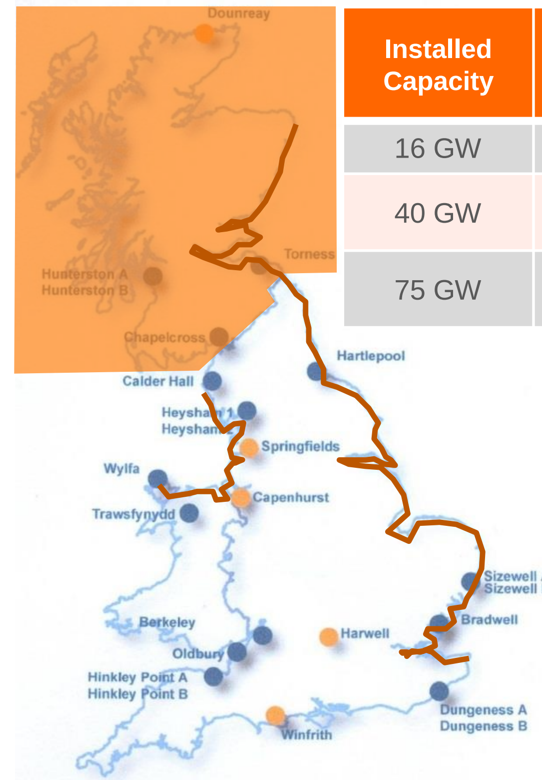
Policy Of Scottish Government Is To Not Support New Nuclear With Focus On Renewables Instead

Eliminates from consideration:

- existing nuclear sites in Scotland
- existing thermal power station sites in Scotland
- greenfield sites in Scotland otherwise suitable for new nuclear power stations

Potential For Competition For Sites Between Nuclear and New Thermal Plants With CCS

- CO_2 disposal sites in Irish and North Seas
- CO_2 storage and transport infrastructure expected to be located on the coast nearer the disposal sites
- New thermal plant requires CCS connection and access to suitable and sufficient cooling water



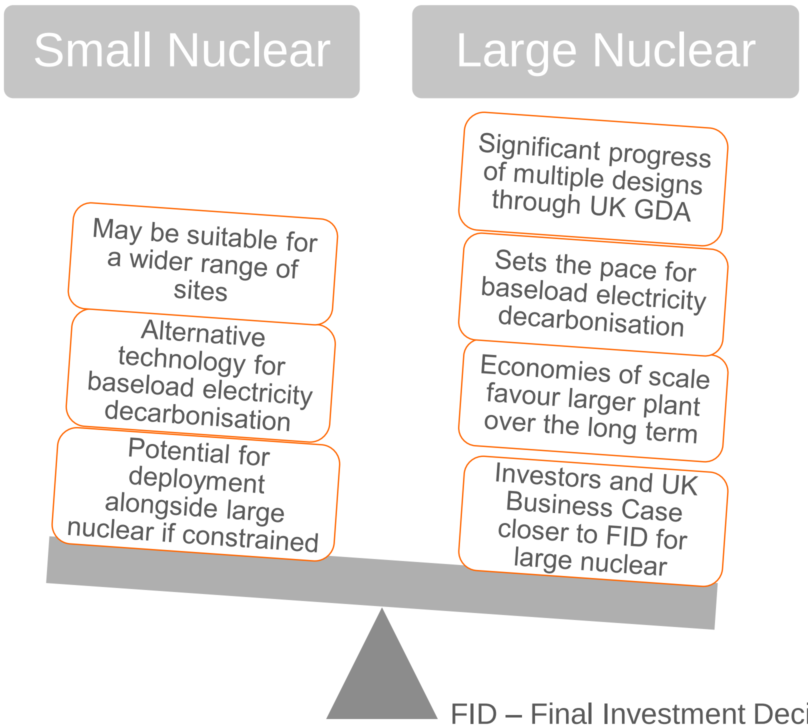
Installed Capacity	Site Capacity
16 GW	☺
40 GW	?
75 GW	?

Potential coastal locations to access CCS transport and disposal infrastructure

Can Small Nuclear Build A Niche Within The UK Energy System?

For SMRs to be deployed in UK:

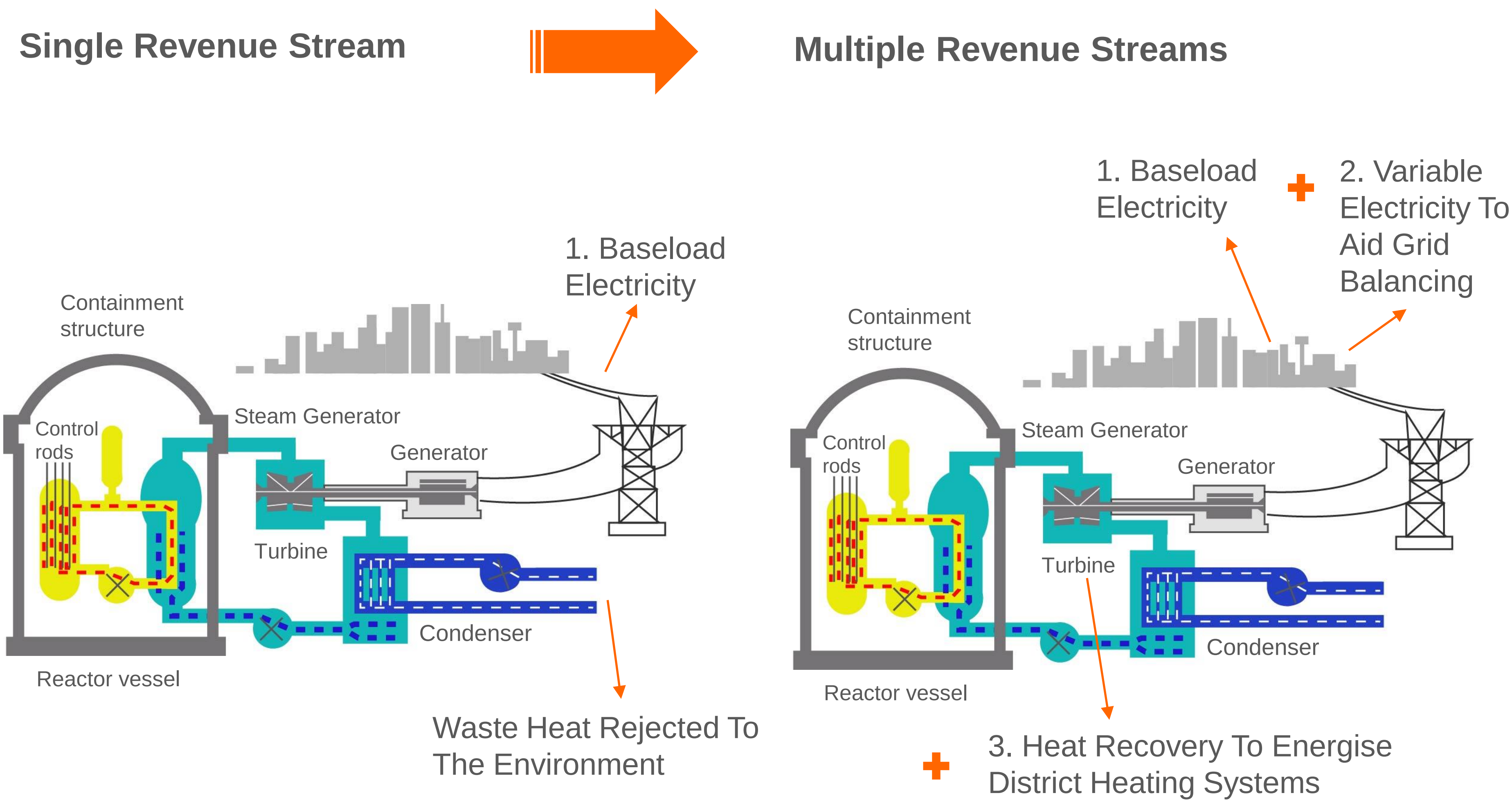
- technology development to be completed
- range of approvals and consents to be secured
- sufficient public acceptance of technology deployment at expected locations against either knowledge or ignorance of alternatives
- deployment economically attractive to
  - reactor vendors
  - utilities and investors
  - consumers & taxpayers



FID – Final Investment Decision

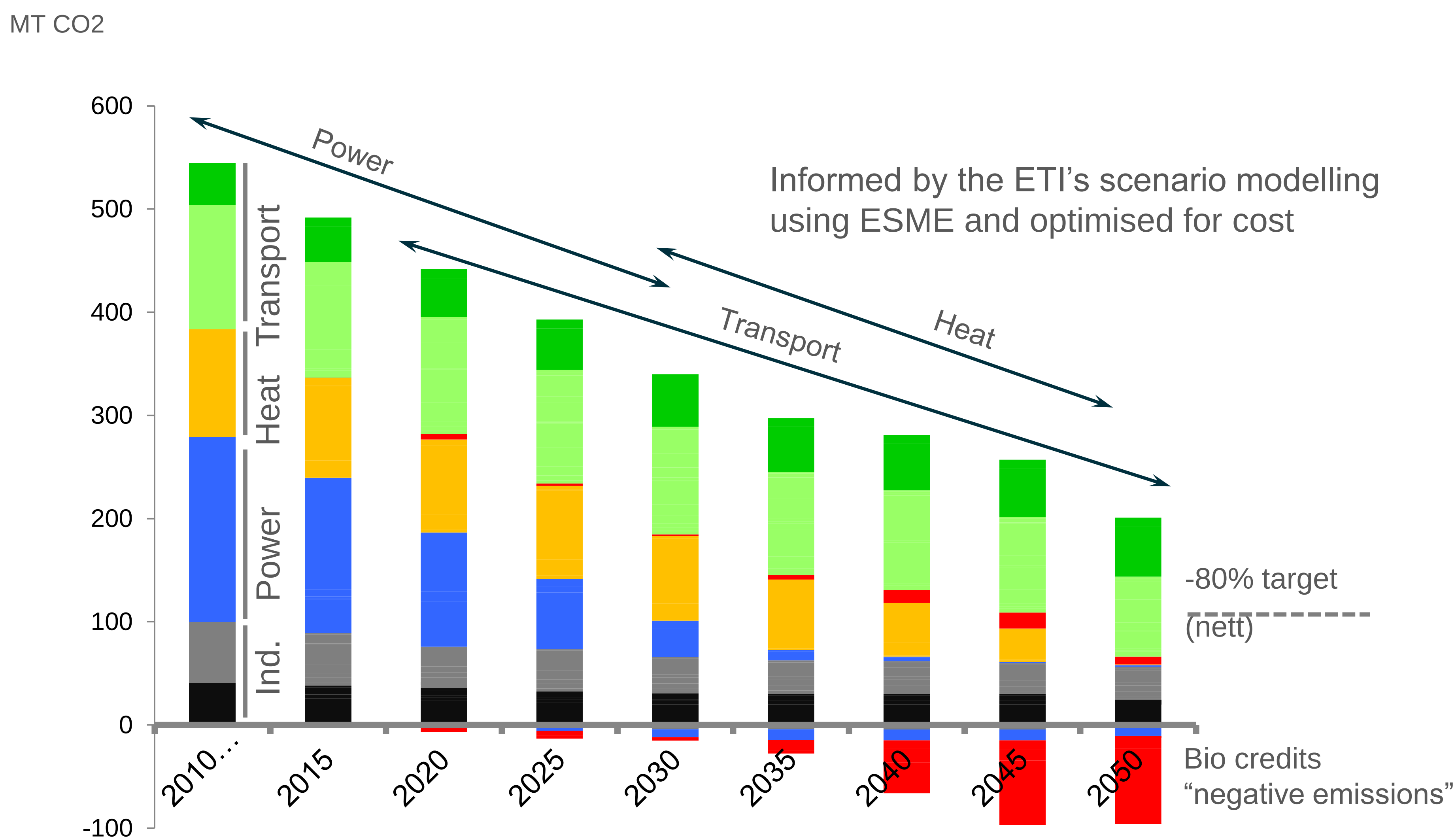
Realistic objective for SMRs to be economically attractive to all stakeholders

Niche For Small Nuclear In The UK?



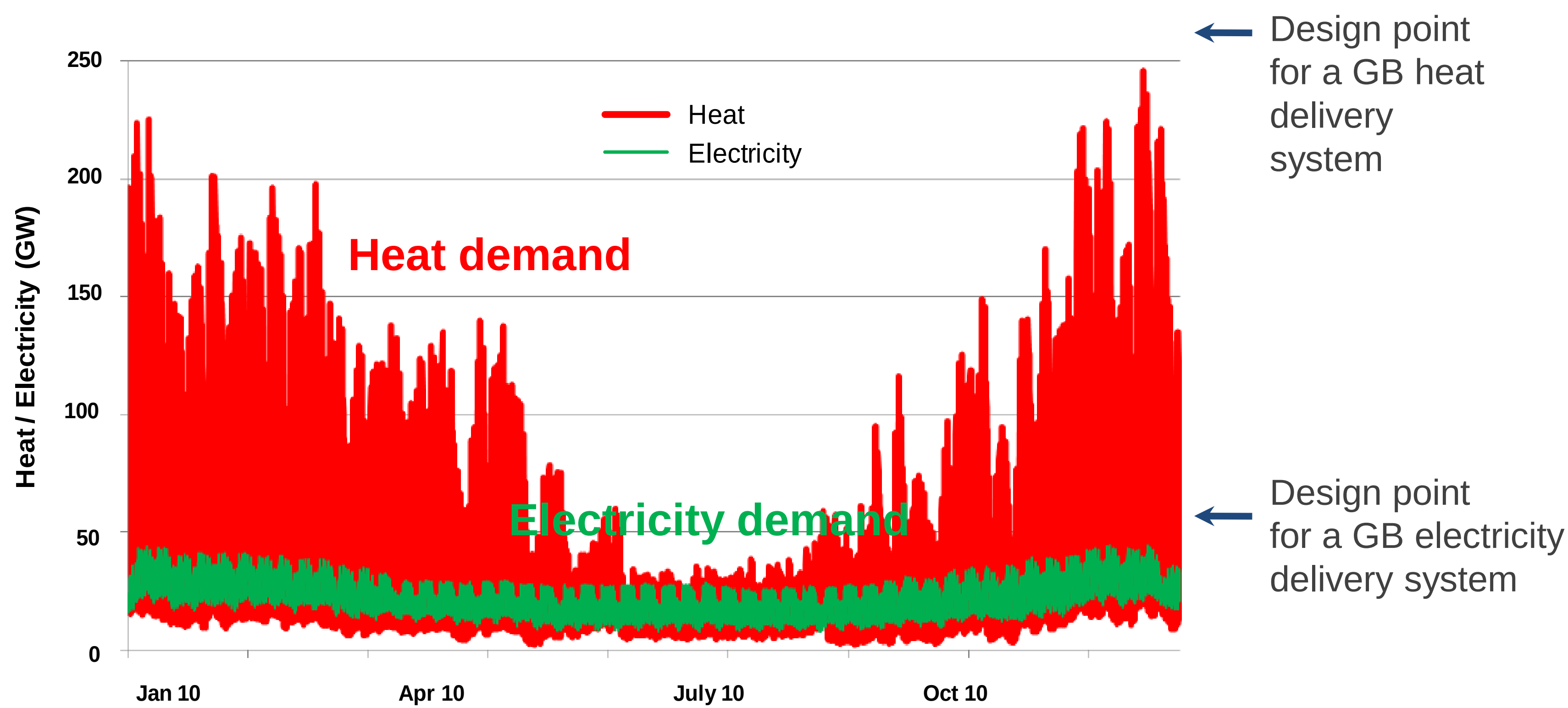
A UK emissions reduction plan

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

ETI Projects Delivered (2015)

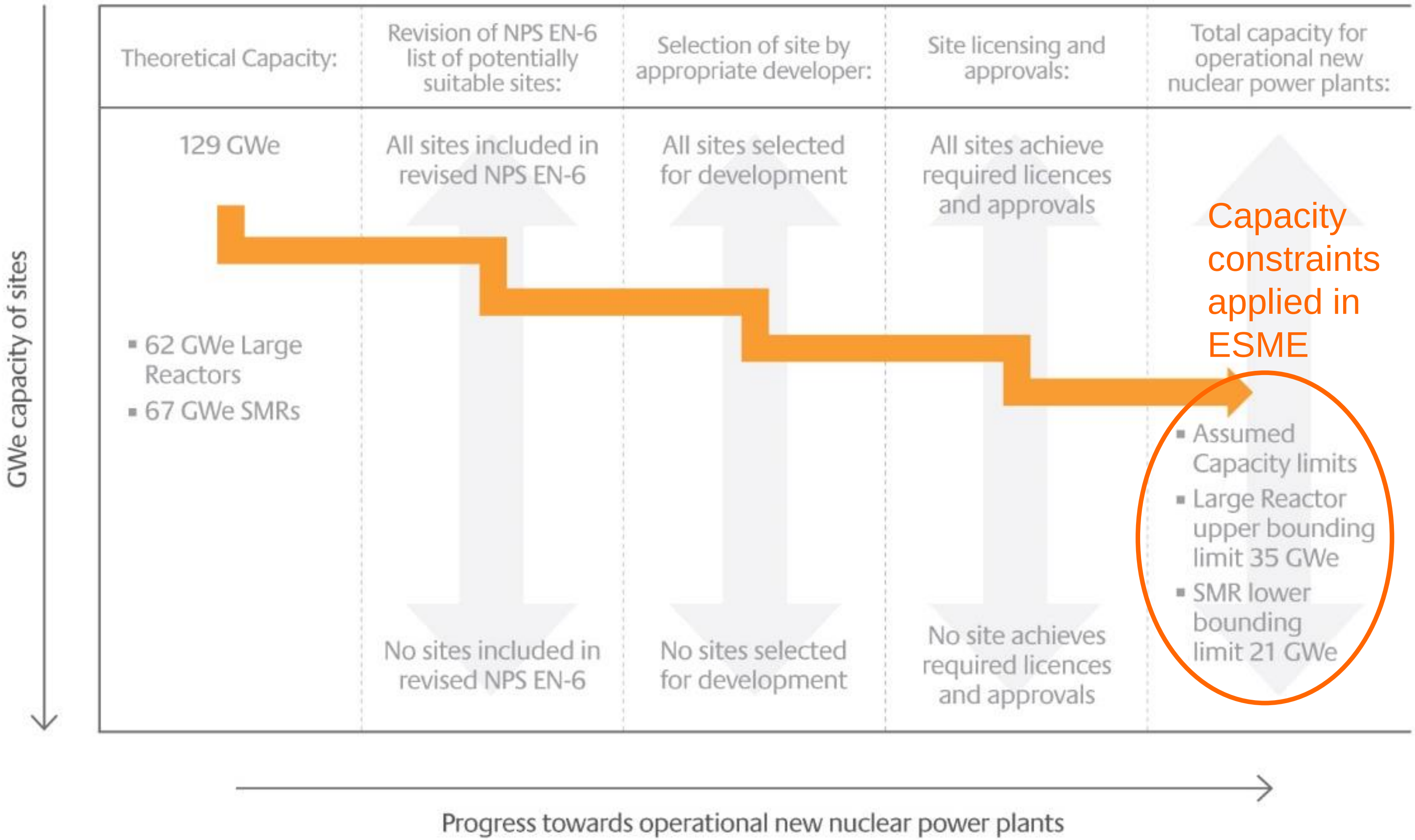
Power Plant Siting Study	System Requirements For Alternative Nuclear Technologies

• Explore UK capacity for new nuclear based on siting constraints
• Consider competition for development sites between nuclear and thermal with CCS
• Undertake a range of related sensitivity studies
• Identify potential capacity for small nuclear based on existing constraints and using sites unsuitable for large nuclear
• Project schedule June 2014 to Aug 2015
• Delivered by Atkins for ETI following competitive open procurement process
	• Develop a high level functional requirement specification for a “black box” power plant for
	  – baseload electricity
	  – heat to energise district heating systems, and
	  – further flexible electricity to aid grid balancing
	• Develop high level business case with development costs, unit costs and unit revenues necessary for deployment to be attractive to utilities and investors
	• Project schedule August 2014 to Aug 2015
	• Delivered by Mott MacDonald for ETI following competitive open procurement process
	• Outputs to be used in ETI scenario analysis to determine attractiveness of such a “black box” power plant to the UK low carbon energy system

So What Did We Learn In 2015?

- Power Plant Siting Study
- System Requirements For Alternative Nuclear Technologies
- ETI ESME Scenario and Sensitivity Studies For Nuclear

Siting Data Applied In ESME



Services Required From A UK SMR

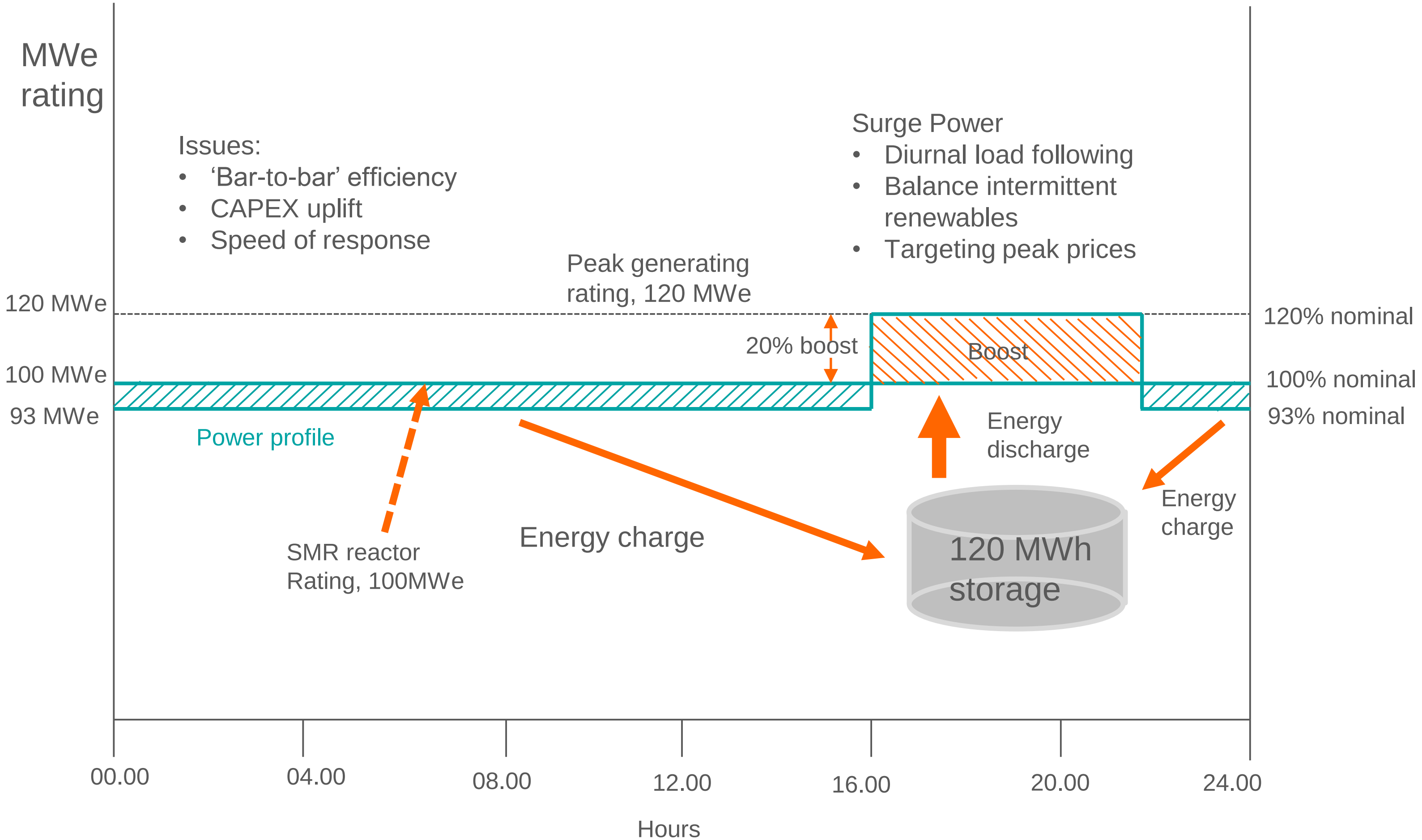
Large reactors optimal here

		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

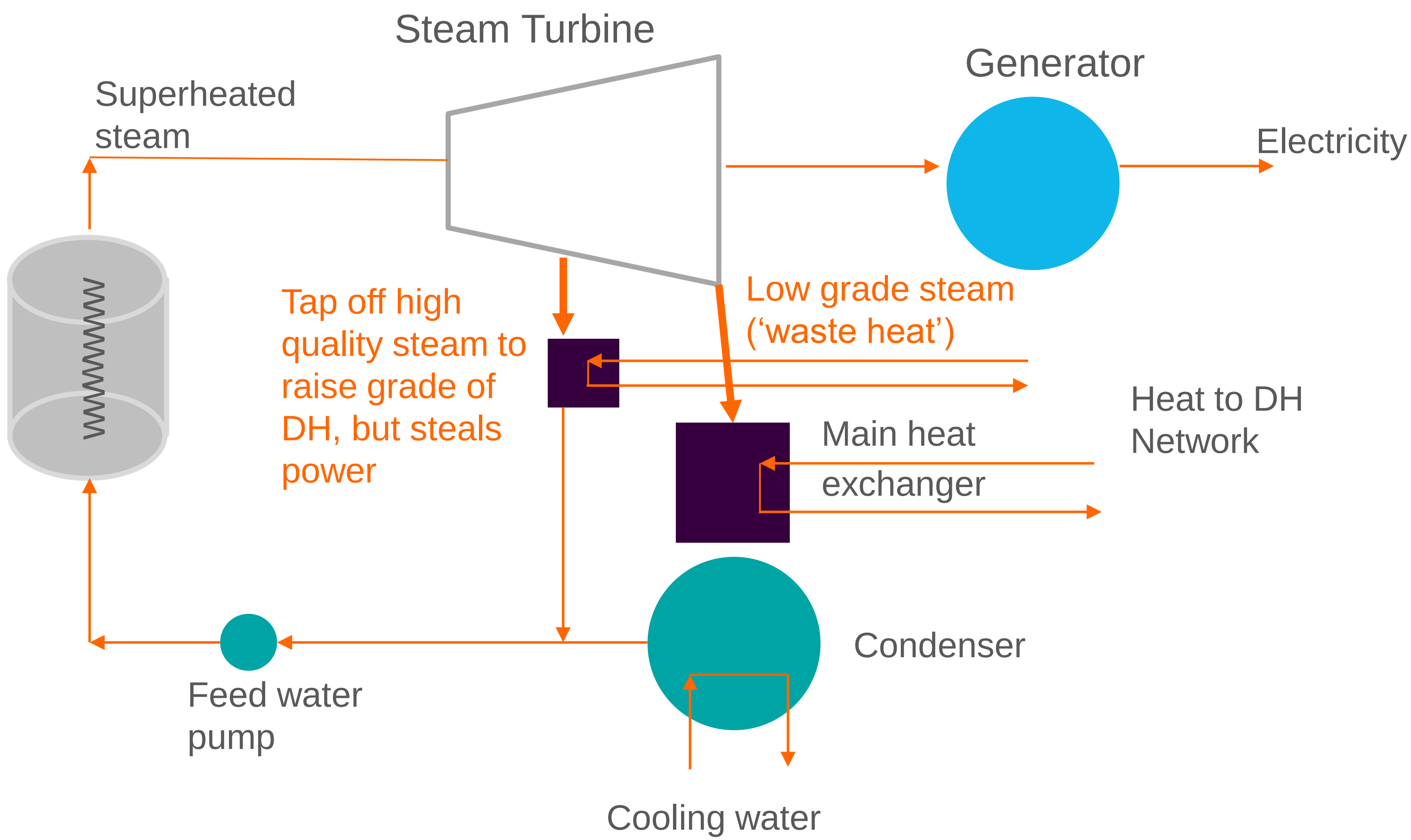
Power, heat and flexibility

SMRs optimal here

Extra-flex example (30% boost)

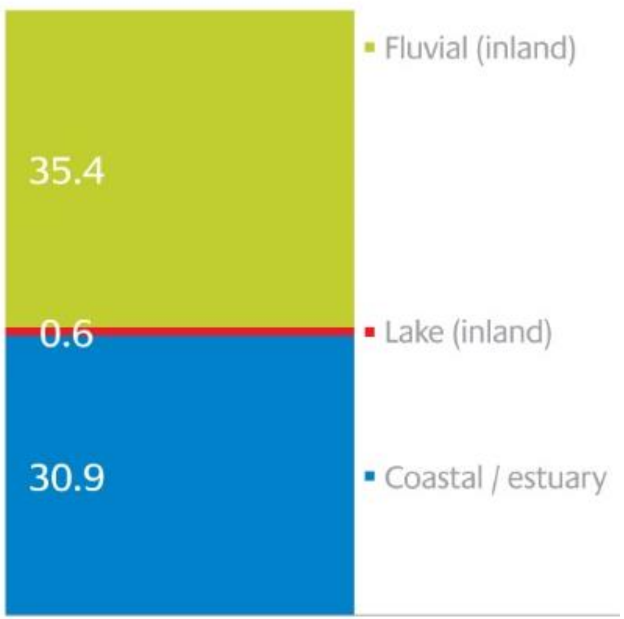


CHP – mostly waste heat

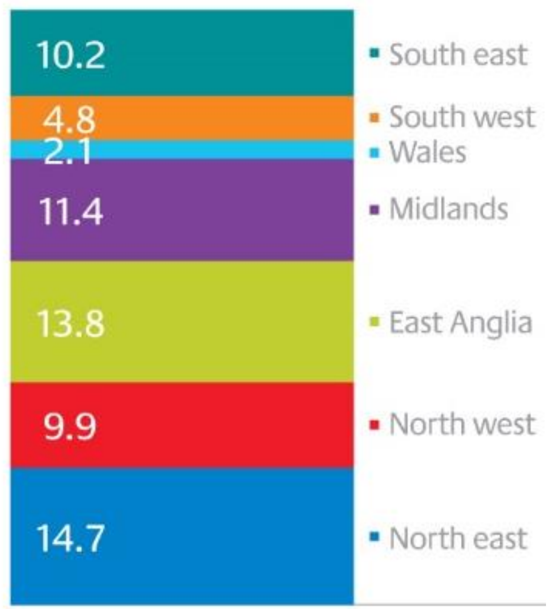


Distribution Of SMR Site Capacity

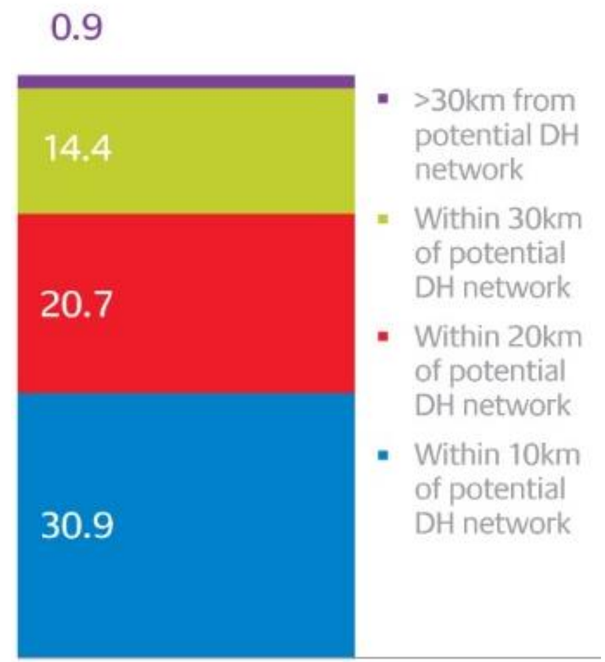
Site capacity from the Power Plant Siting Study -
Further potential locations likely to be found; the limit has not been explored



SMR Capacity (GWe) By Cooling Water Source



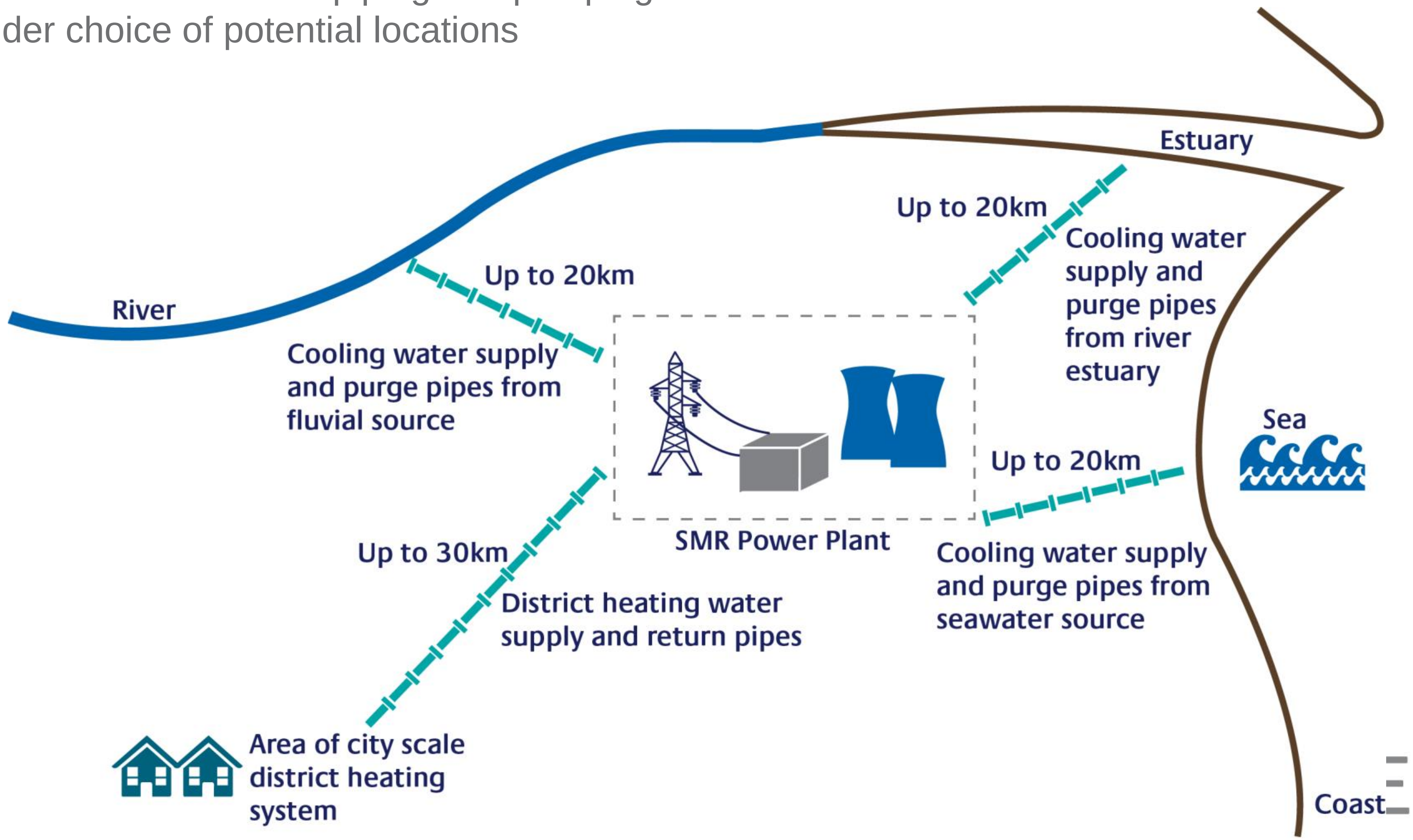
SMR Capacity (GWe) By Regional Location To Meet Demand



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

Extension Of Water Source Distance to 20 km

- More cost effective for piping and pumping
- Wider choice of potential locations

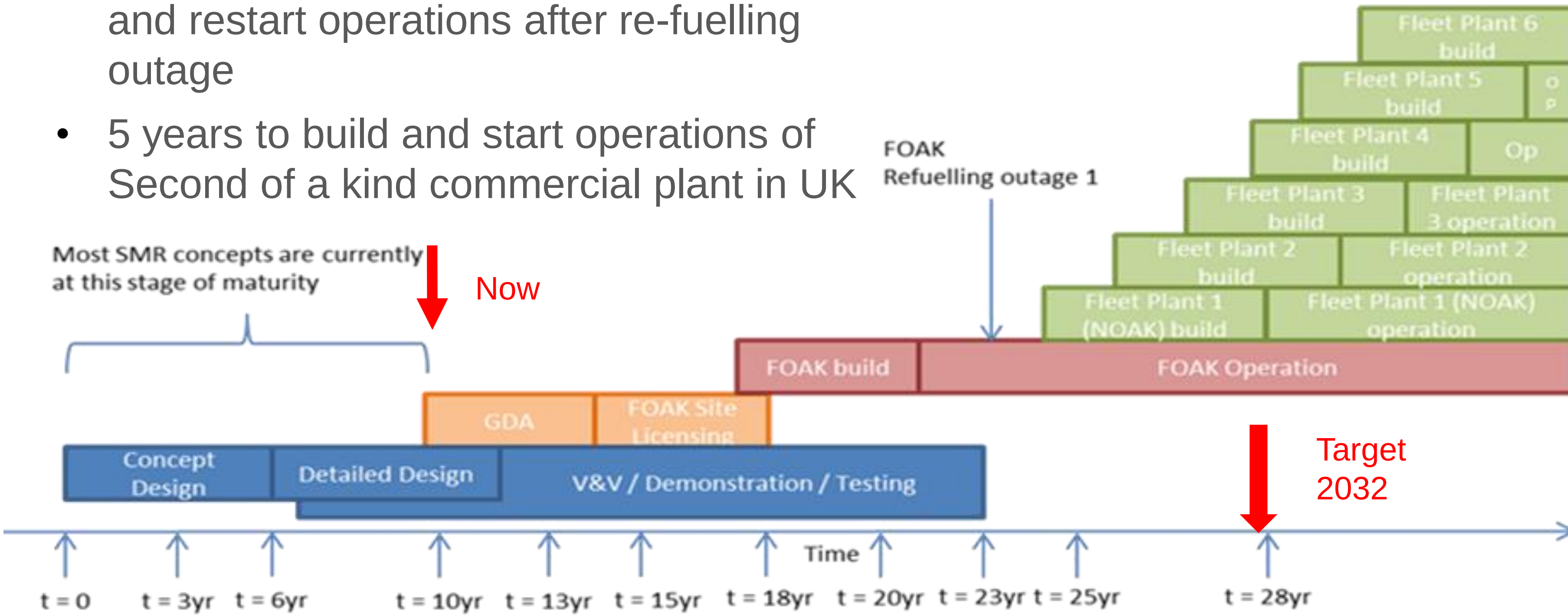


The Timeline Challenge

GDA start to Second Of A Kind Plant Operating in UK Assuming LWR technology

Broadly 17 years:

- 5 years GDA
- 7 year to build FOAK anywhere in world and restart operations after re-fuelling outage
- 5 years to build and start operations of Second of a kind commercial plant in UK

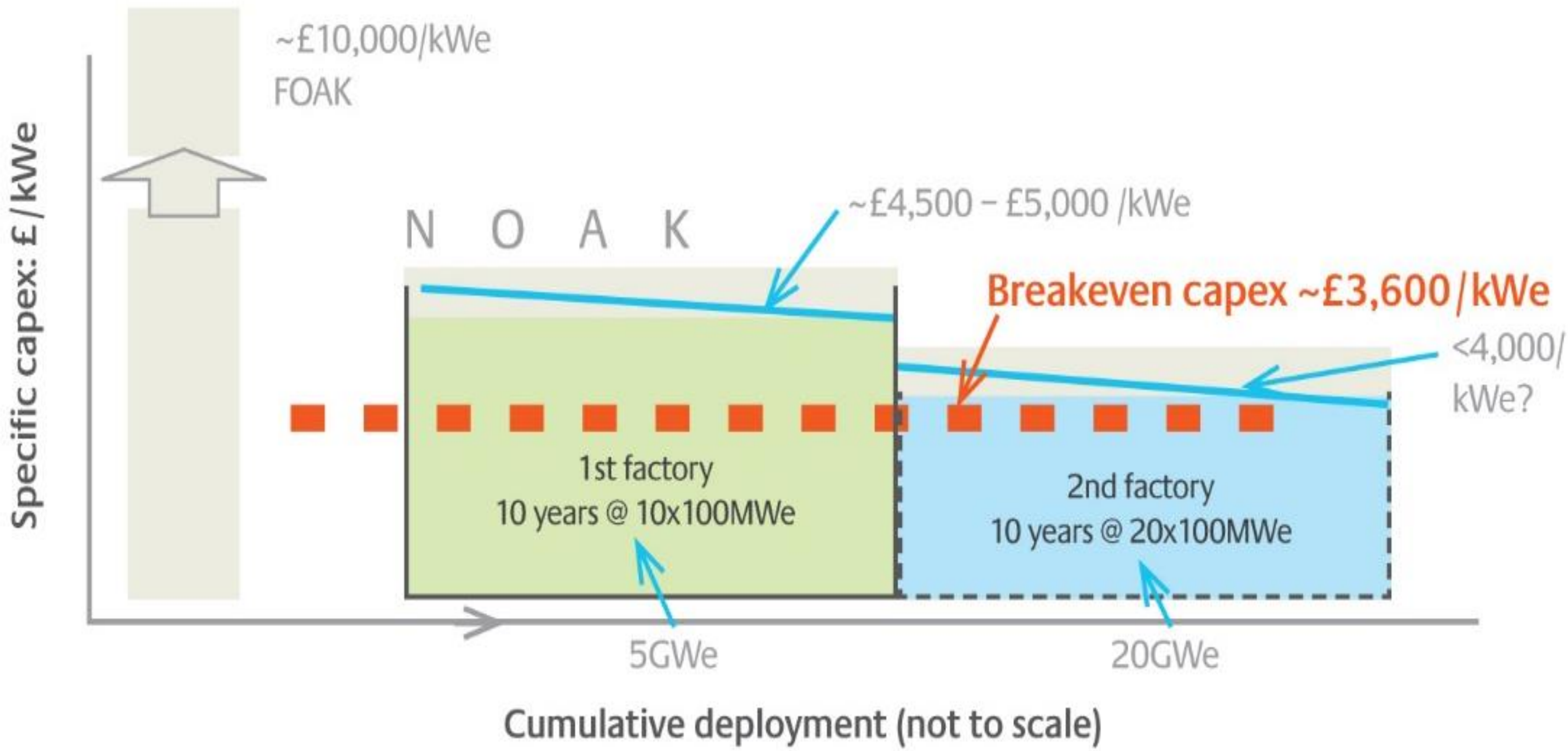


Caveat

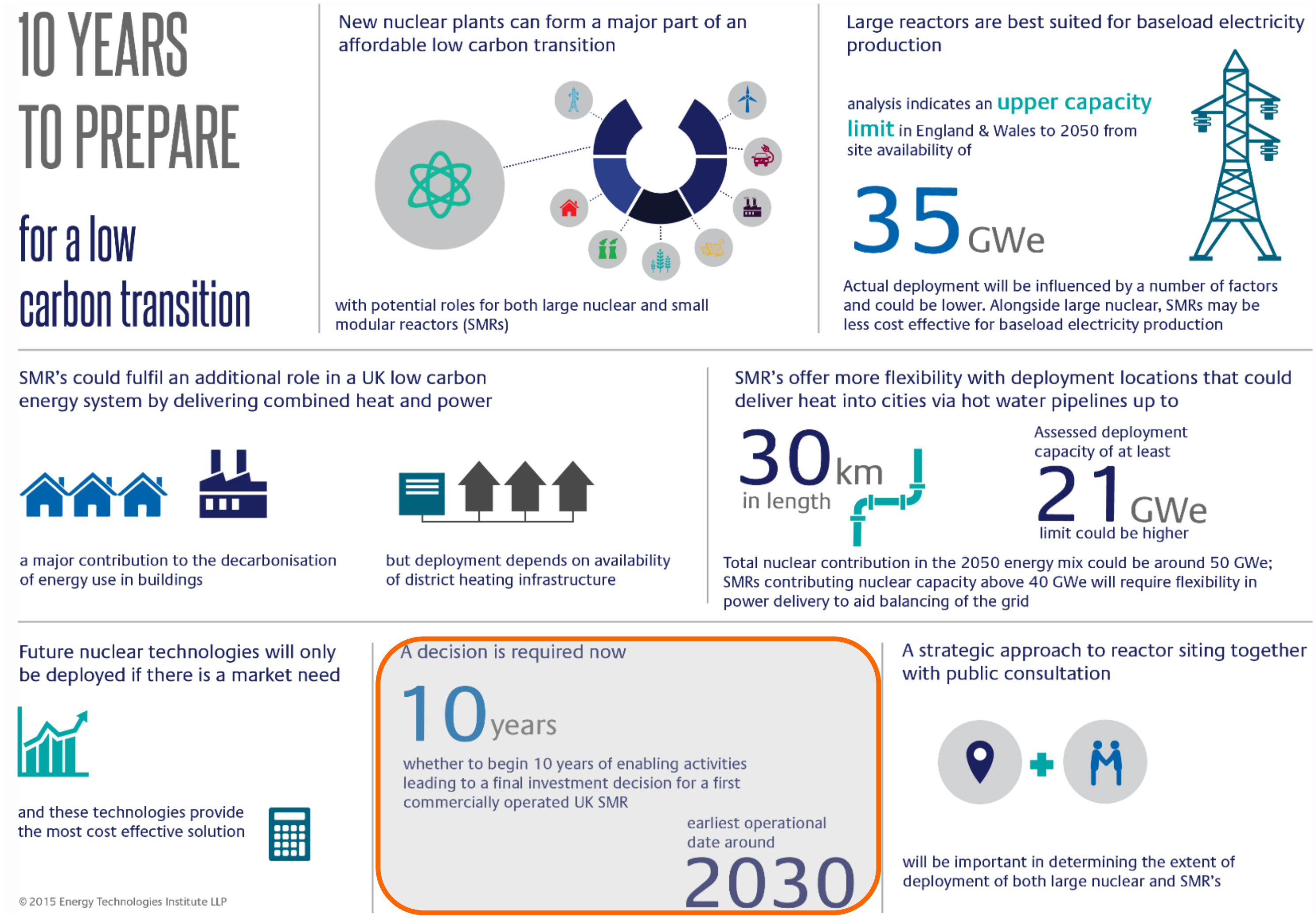
- High uncertainty
- Many assumptions
- Multi-decadal timescale
- Treat results with caution
- Indicative only

Cost Reduction Model - Factory & Learner

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

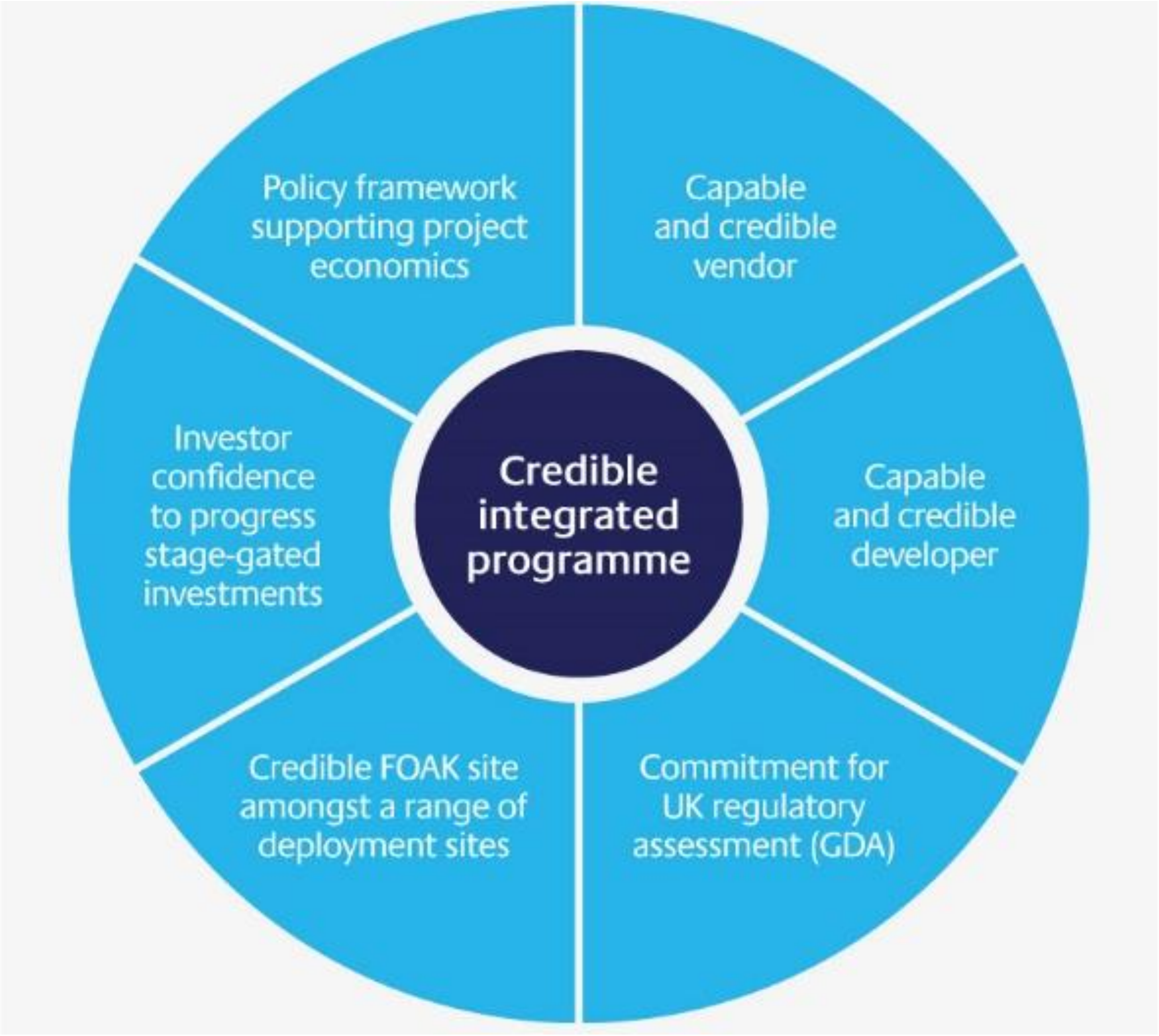


The role for nuclear including SMRs in a low carbon energy system (2015)



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

Key Elements Of A UK SMR Development Programme (2016)



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)

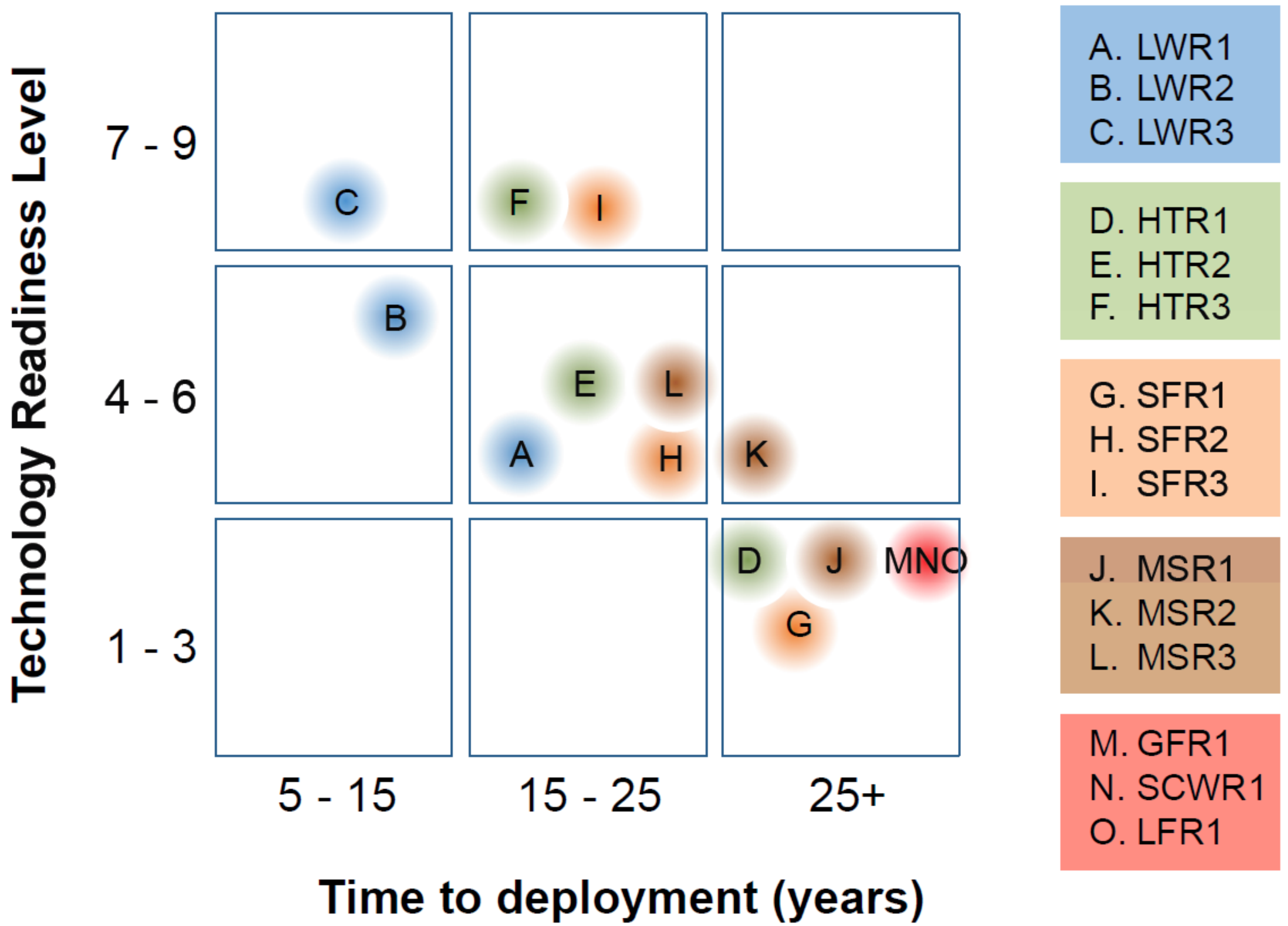
Modular in deployment:

- 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

NNL View In October 2016 of SMR Technology Readiness Levels

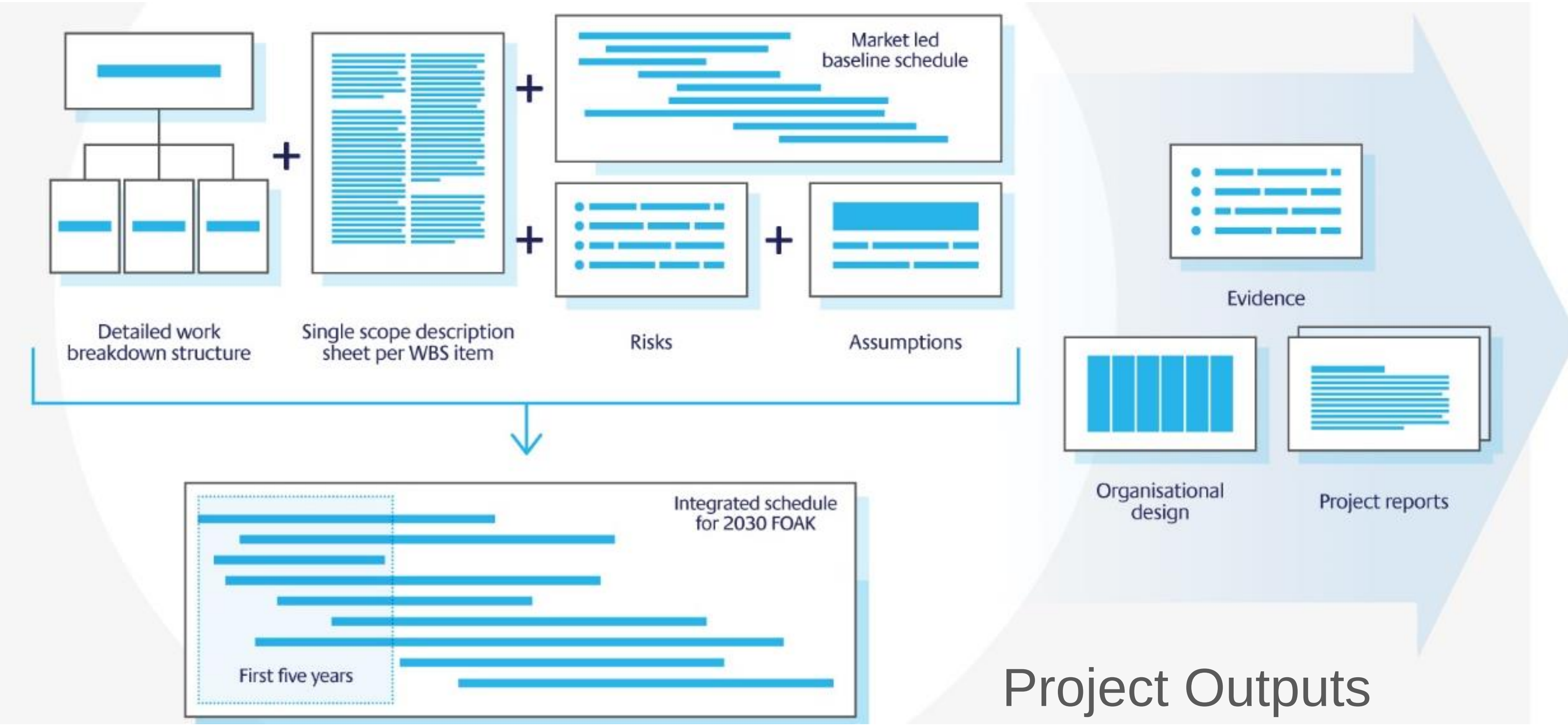


Source: NNL presentation at the London Nuclear Power Symposium 24th October 2016

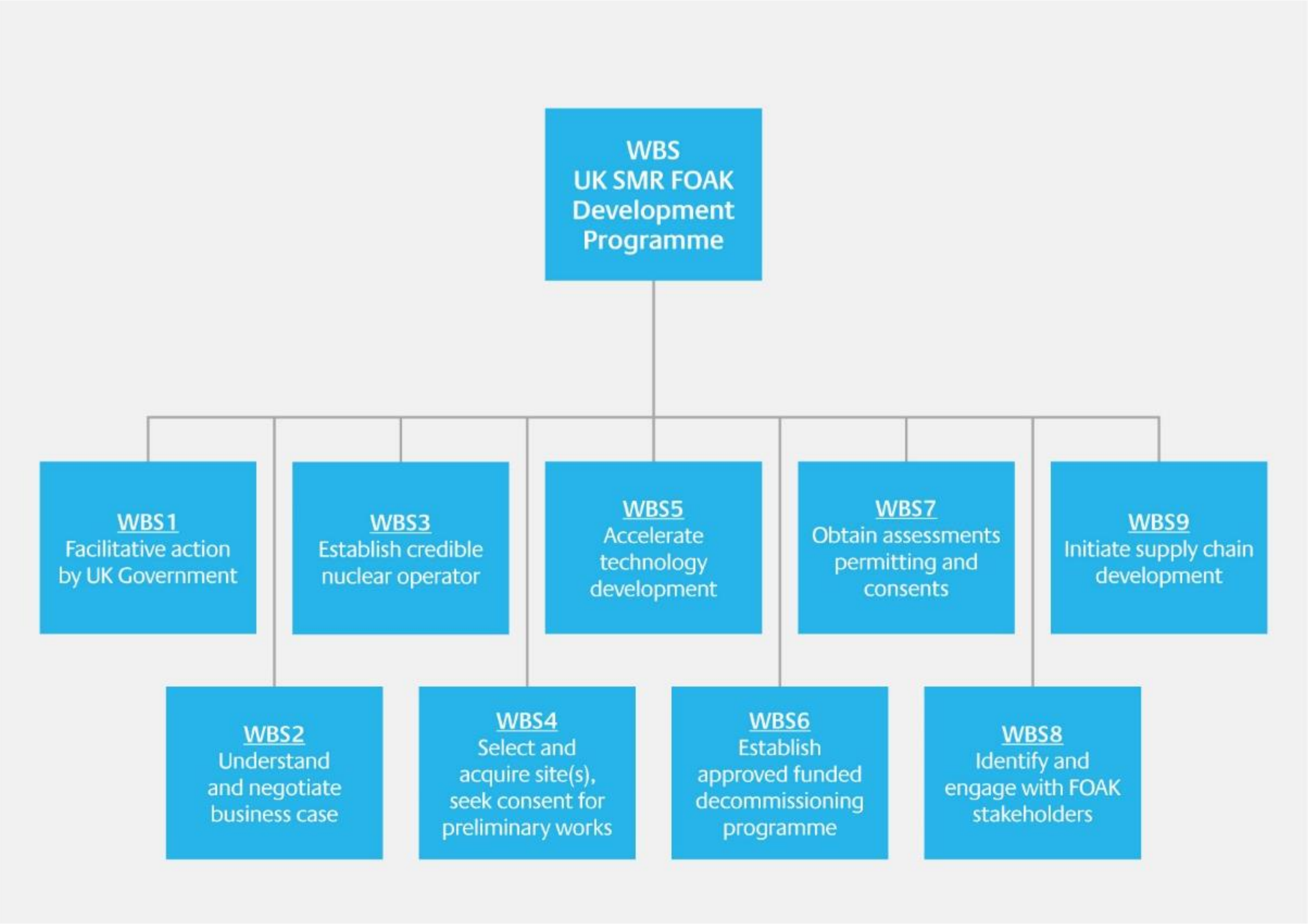
Generation IV Advanced Reactor Types

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

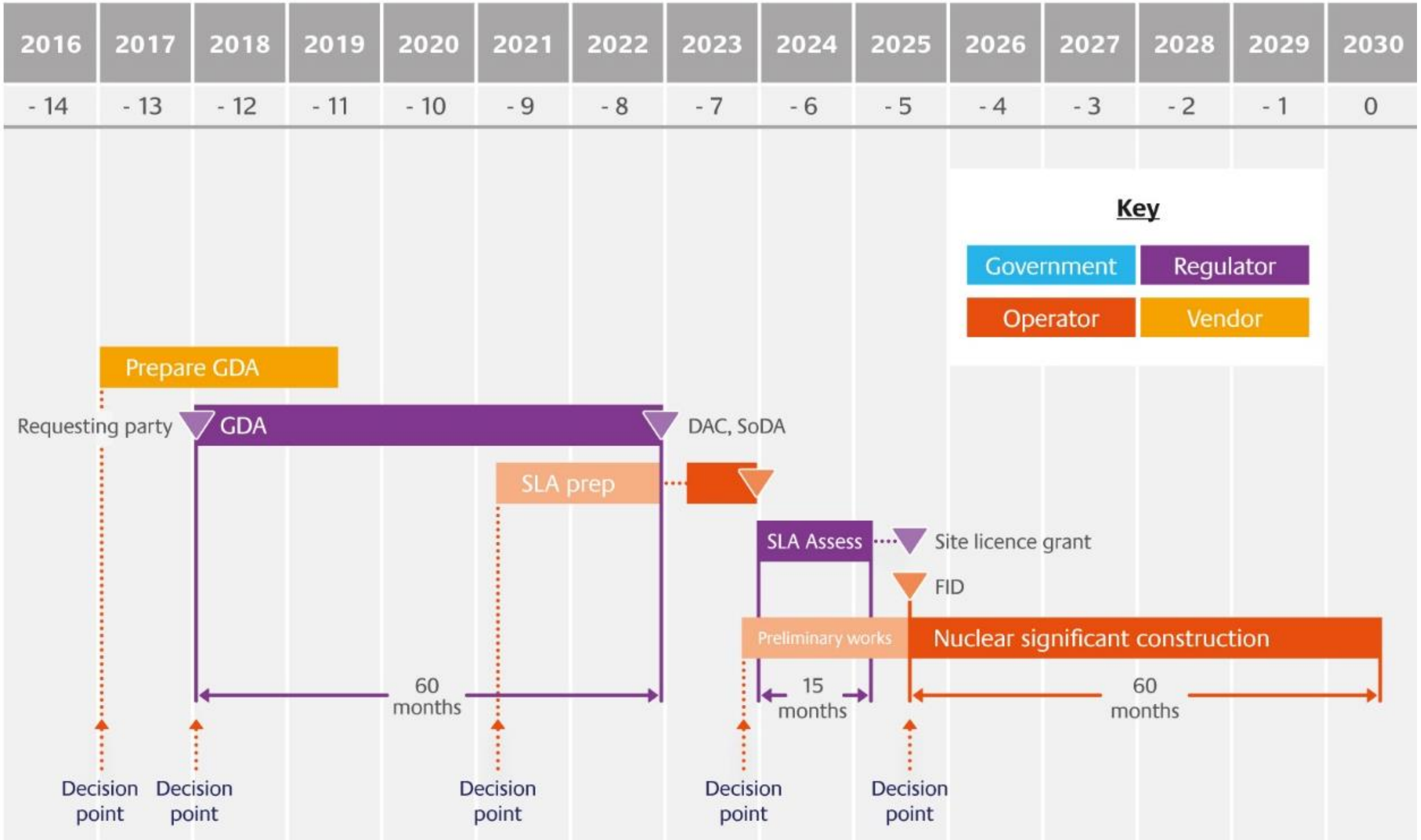
Systematic Application Of Project Tools



Work Breakdown Structure In SDE Analysis



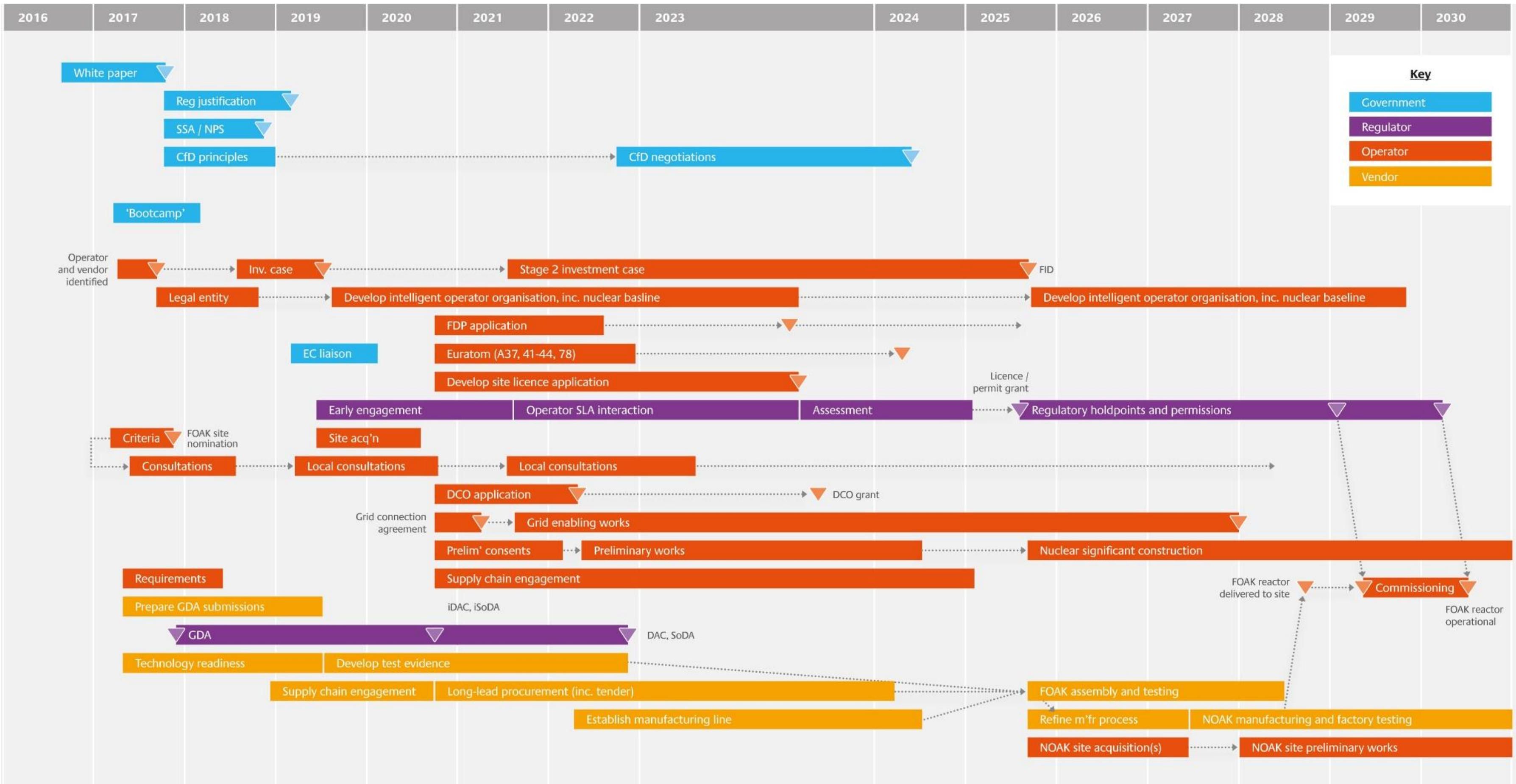
The Critical Path Of A 2030 Schedule



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)

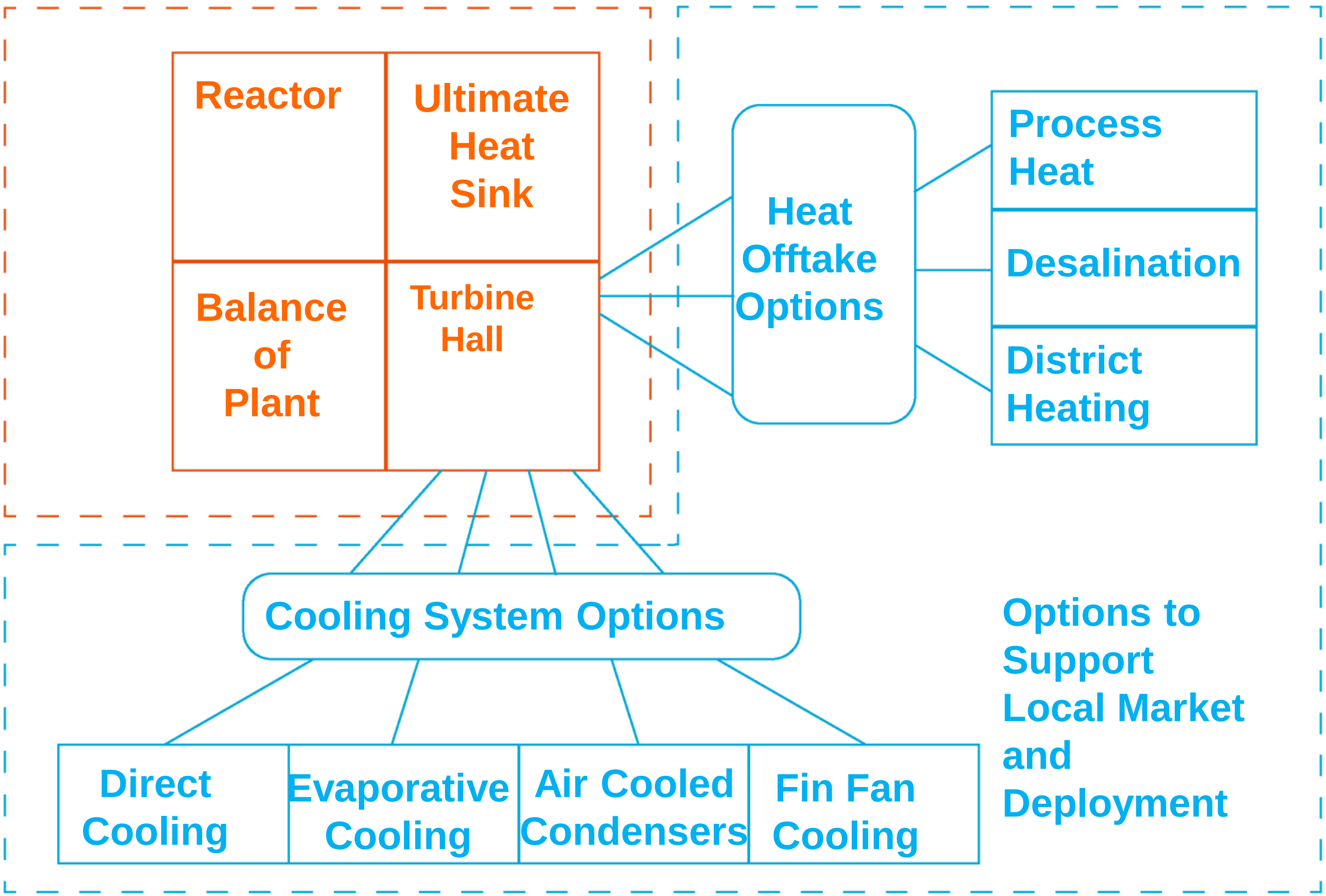
Integrated Schedule Leading To FOAK Operations By 2030



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

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

Standardise To Exploit Economies of Multiples



Scope of Design To Be Assessed Through Generic Design Assessment

ETI Projects Delivered (2016)

Power Plant Siting Study – Phase 3

- Explore range of potential early sites for SMR deployment in the UK
- Identify potential lead sites for SMR deployment in the UK
- Delivered by Atkins

System Requirements For Alternative Nuclear Technologies – Phase 3

- Review of existing CHP and DH applications
- Feasibility design of LWR CHP by steam extraction with the goal of delivering independently flexible heat and power
- Cost estimation associated with upgrade to CHP and cost estimation associated with different cooling systems
- Delivered by Mott MacDonald and available from the ETI knowledge zone

SMR Deployment Enablers Project

- Programme approach to develop range and sequence of activities in delivering a UK SMR
- Delivered by Decision Analysis Services (DAS) Ltd

Conclusions - Preparing for deployment of a UK SMR by 2030 (released 2016)

energy technologies institute

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

power

heat

flexibility

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

Conclusions At Early 2017

- 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

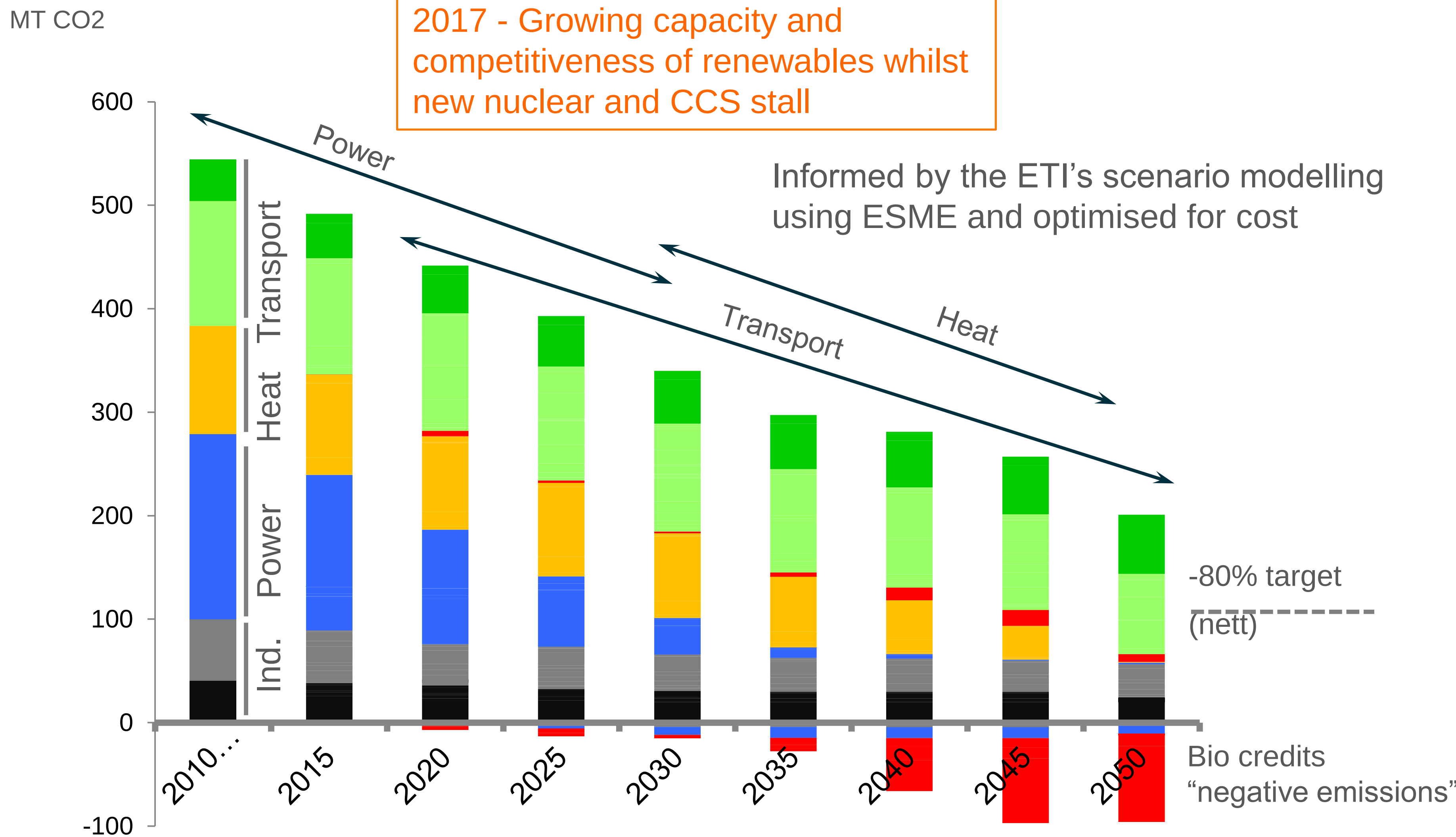
A UK emissions reduction plan

Power now, heat next, transport gradual – cost optimal

energy technologies institute

2017 - Growing capacity and competitiveness of renewables whilst new nuclear and CCS stall

Informed by the ETI's scenario modelling using ESME and optimised for cost



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 SMR 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

The ETI's Nuclear Cost Drivers Project

- Purpose to identify potential for cost reduction:
  - Current technologies in delivery (large Gen III+ LWRs)
  - Advanced reactors including SMRs
  - Potential for step change in cost of electricity from advanced reactors
- Evidence based project
- Identify principal drivers (which drive costs either up or down)
- Develop a cost model and associated database
- Subject to targeted independent review

Procured by competition and being delivered by CleanTech Catalyst and Lucid-Strategy

Conclusions At End 2017

- 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
  - Advanced reactors for tomorrows energy system – heat, power and flexibility
- New nuclear needs to establish a trajectory of cost reduction
  - Applies to large light-water reactors and advanced reactors
  - Reactor designs and power station projects driven by economics and LCOE
- 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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