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Preparing For The Deployment Of A UK SMR By 2030

Presentation At The Small Modular Reactor UK Summit - 19th October 2016

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Presentation Structure

Introduction to the ETI

- The Energy Technologies Institute - what do we do?
- An affordable energy system transition
- Nuclear in a UK low carbon 2050 energy system

The ETI's recent projects and analysis –

- SMR Deployment Enablers Project – delivered by Decision Analysis Services
- Alternative Nuclear Technologies Study Phase 3 – delivered by Mott MacDonald
- Power Plant Siting Study Phase 3 – delivered by Atkins

Integrated analysis and 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



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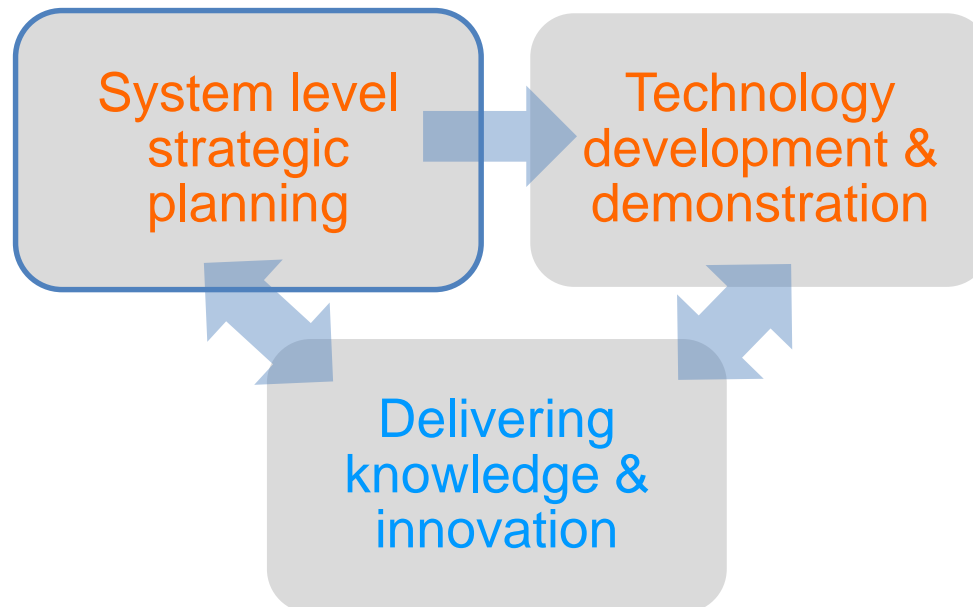
Innovate UK
Technology Strategy Board

ETI programme associate

HITACHI
Inspire the Next



What does the ETI do?





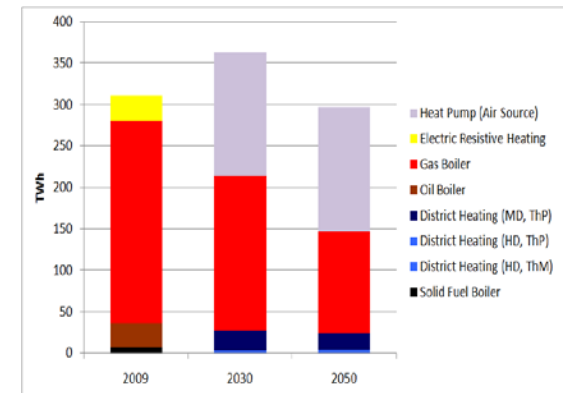
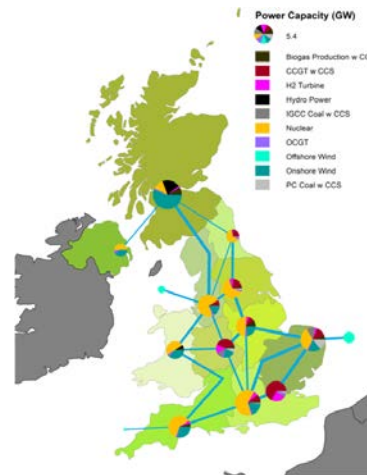
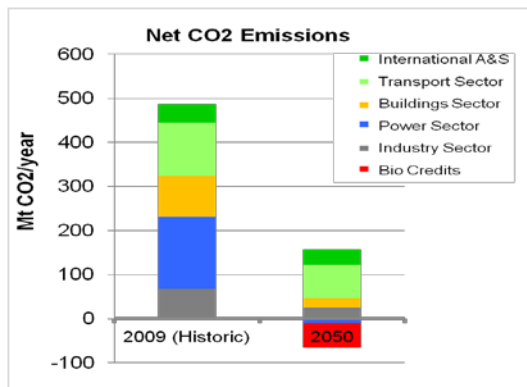
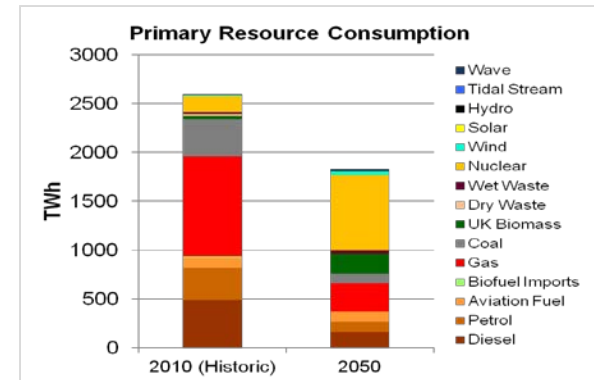
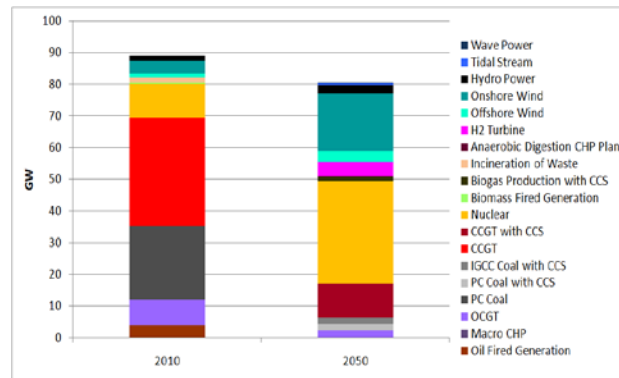
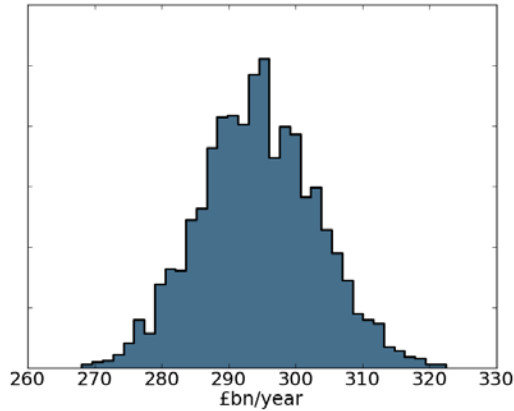
ESME – The ETI's system design tool



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



Total System Cost



ESME example outputs



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

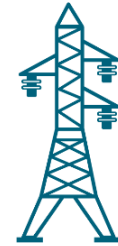


with potential roles for both large nuclear and small modular reactors (SMRs)

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



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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



Further ETI Projects Relevant To UK SMRs

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**

What are the design, 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?

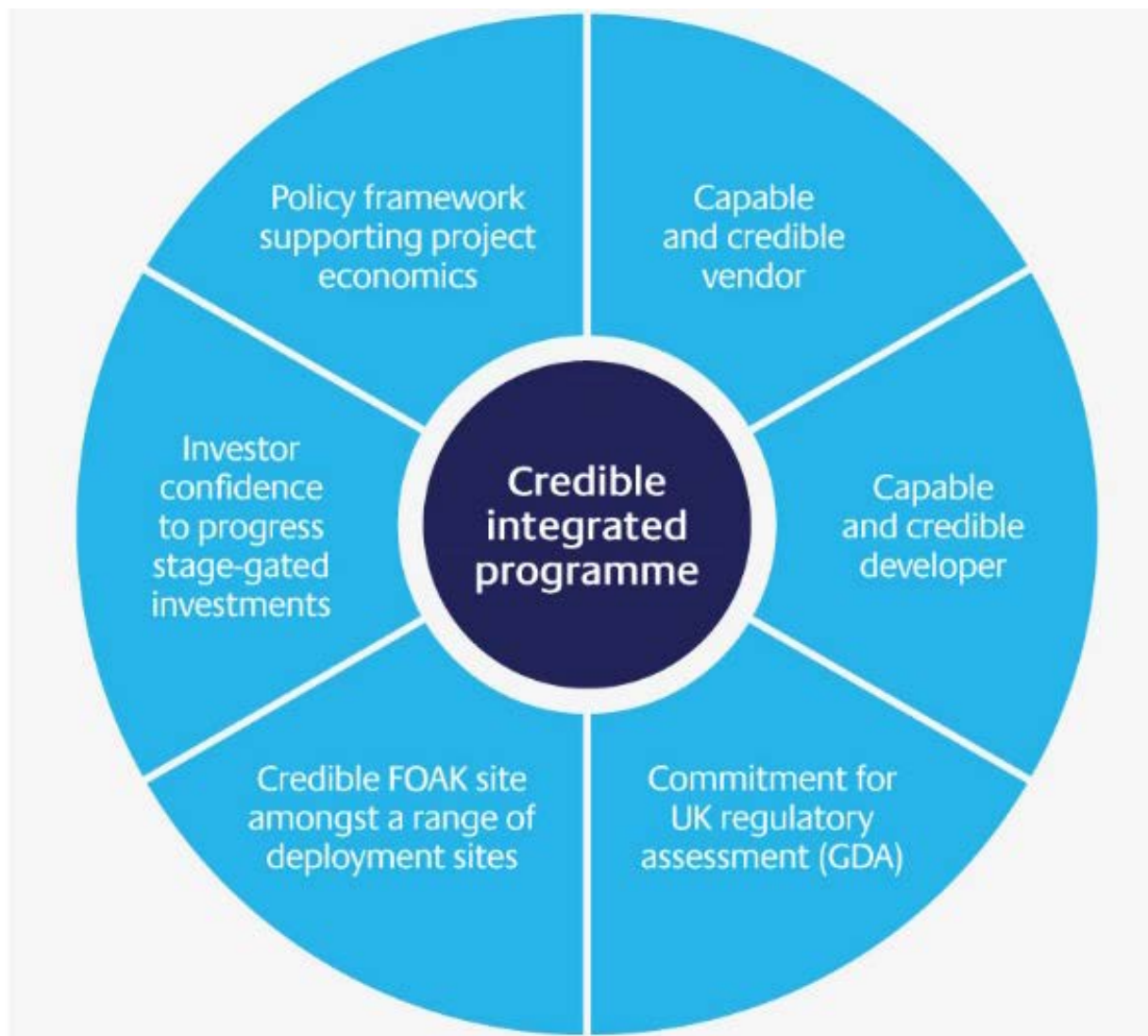
- **System Requirements For Alternative Nuclear Technologies Phase 3**

What is the range of locations suitable for early SMR deployment and is there an obvious front runner for a First Of A Kind (FOAK) SMR site?

- **Power Plant Siting Study Phase 3**

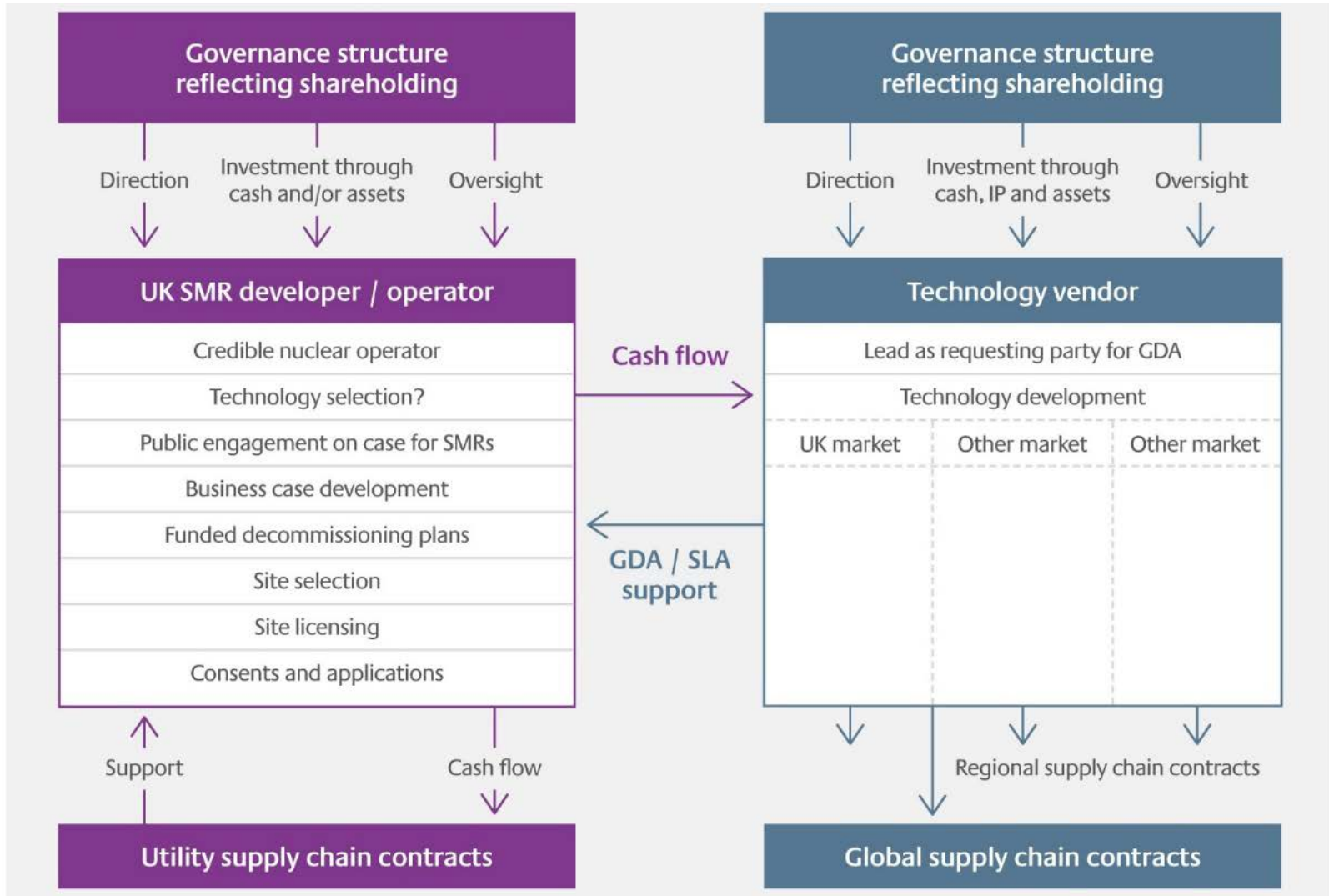


Key Elements Of A UK SMR Development Programme





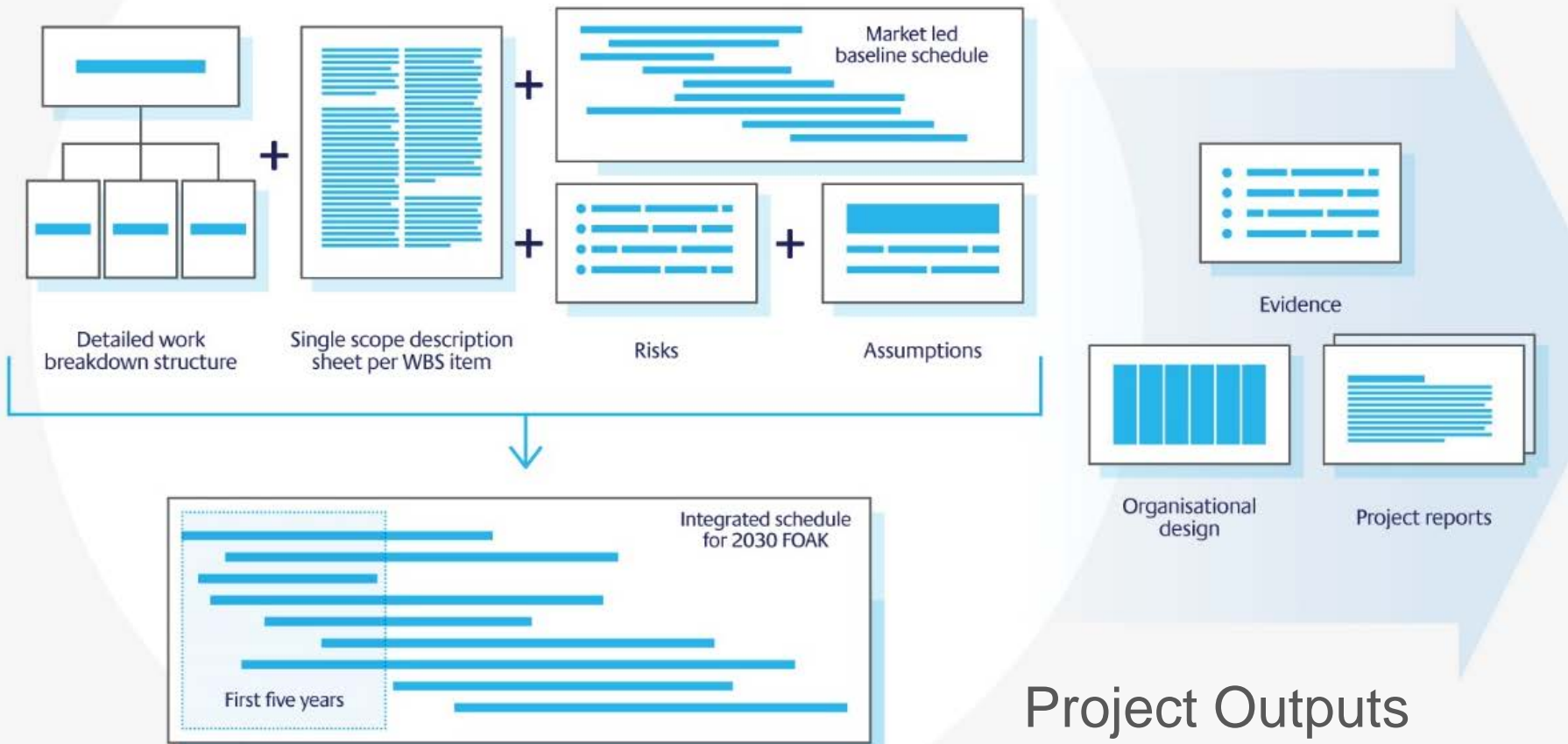
Developer And Vendor – Typical Relationship From UK GW Reactor New Build Projects





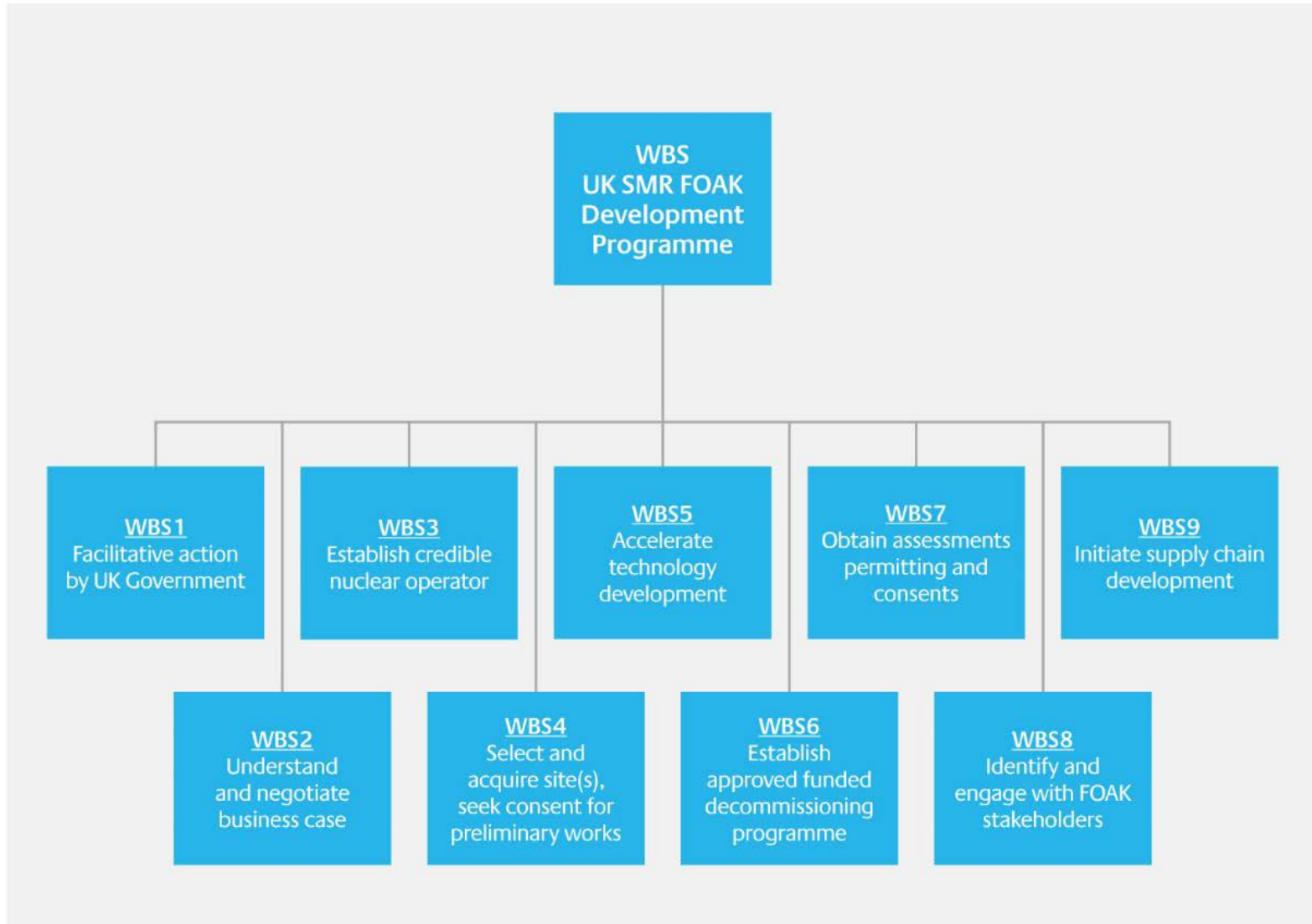
Approach To The ETI's SMR Deployment Enablers Project

Systematic Application Of Project Tools



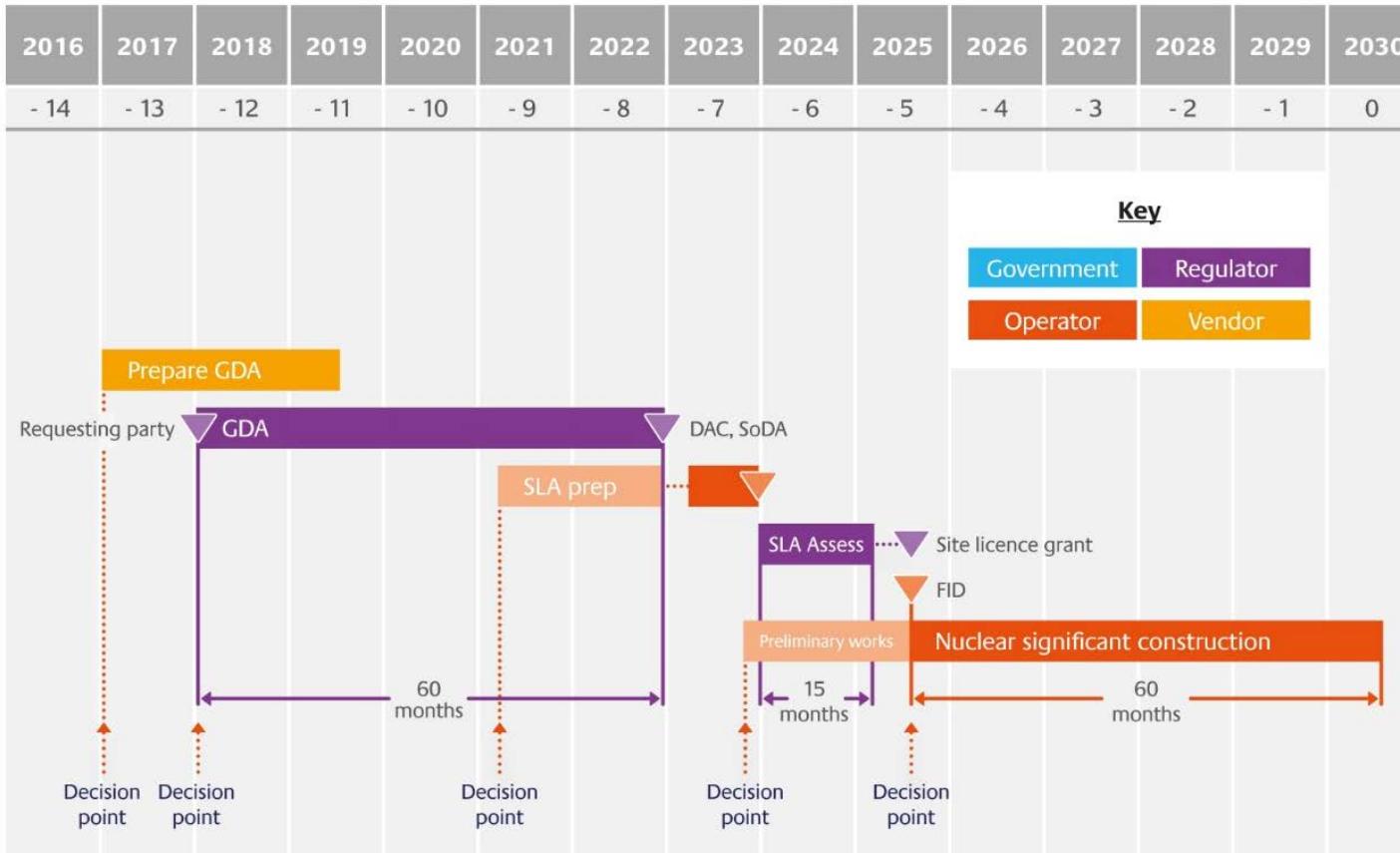


Work Breakdown Structure In SDE Analysis





The Critical Path Of A 2030 Schedule

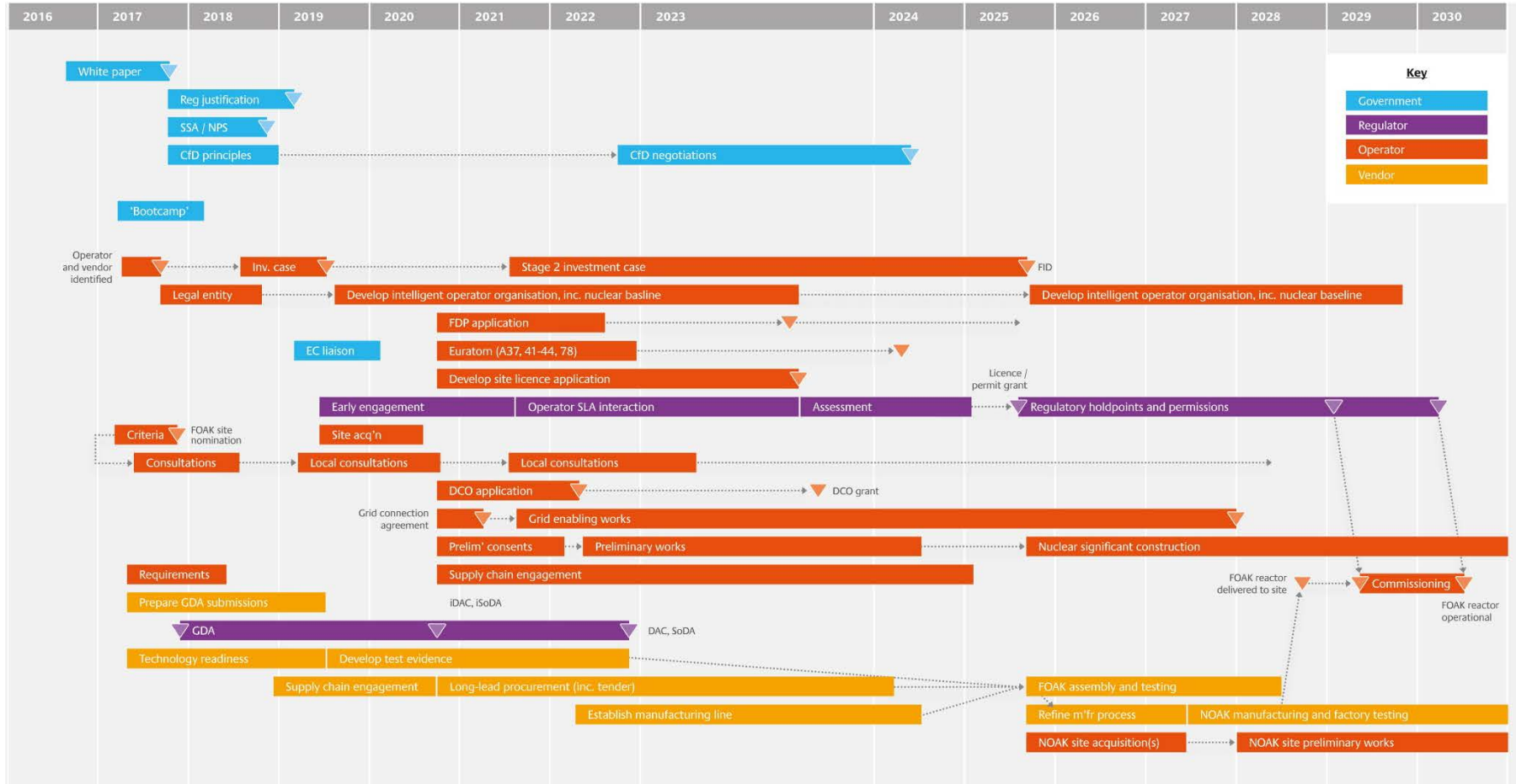


Key dates & assumptions (durations):

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



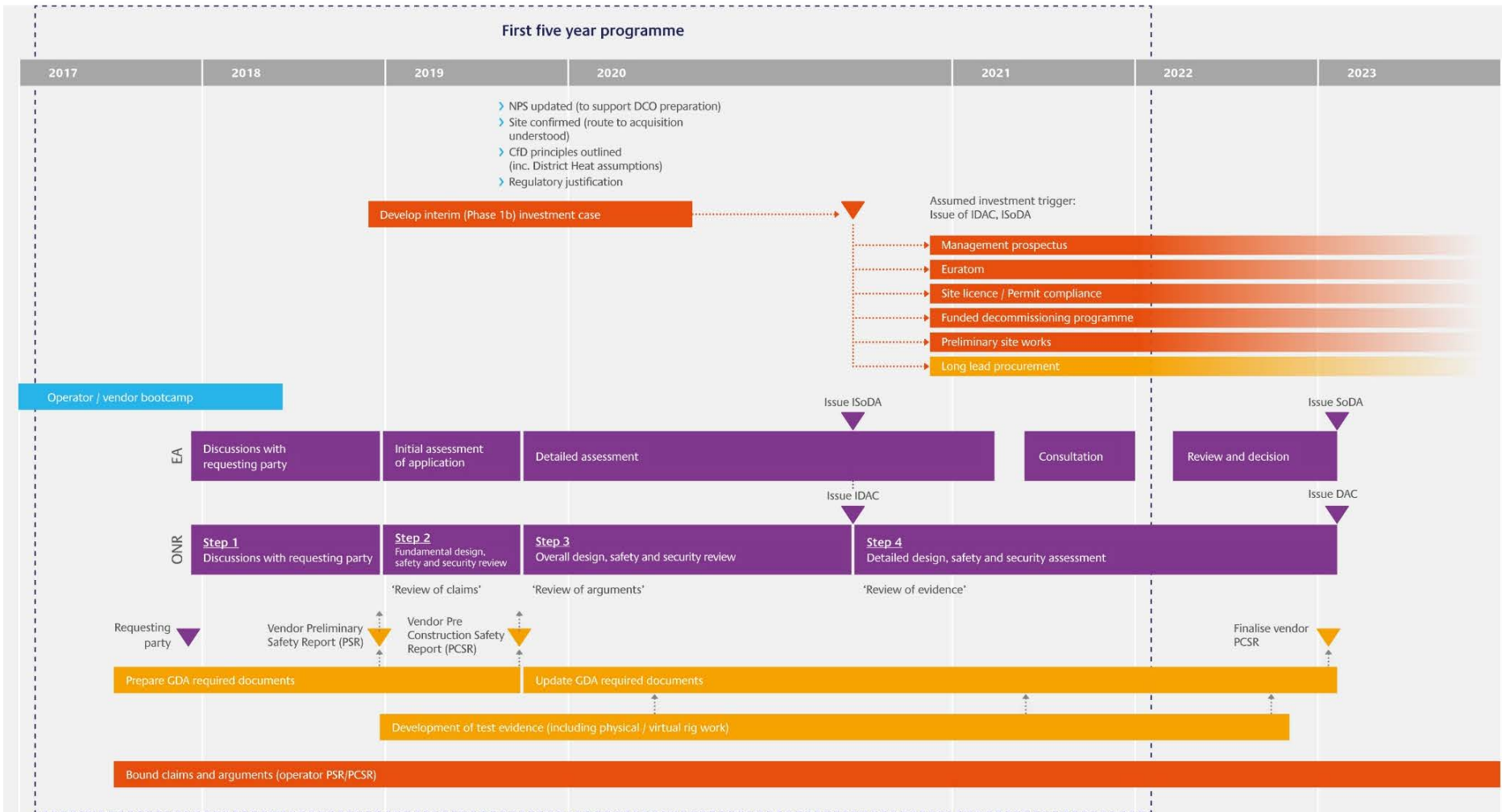
Integrated Schedule Leading To FOAK Operations By 2030



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





Enabling Activities In The First 5 Years





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



SMRs For CHP – Analysis Of Impact Of Module Size and Thermal Efficiency



Results scaled for same electricity output (300 MWe) when operated in power only mode

System design and cost estimation used to compare heat extraction from:
 A - smaller, reactor module and secondary steam system with lower thermal efficiency, against
 B - larger reactor module and secondary steam system with higher thermal efficiency

Conclusions

- An SMR with relatively lower thermal efficiency produces more heat
- An SMR selected for cost effectiveness for power will still be cost effective for CHP



CHP – Comparison With Earlier Work and Impact On Internal Rate of Return

| | | ANT1&2 (power only) | ANT1&2 (CHP) | ANT 3 Plant A (CHP) | ANT 3 Plant B (CHP) |
|---|--|---------------------------|-----------------|---------------------------|---------------------------|
| Model | Gross electrical efficiency in power-only mode | 37% | 37% | 31.4% | 34.4% |
| | CHP CAPEX increment - £/kW _e (net) | - | £200 | £544 | £529 |
| | CHP OPEX increment - £/kW _e p/a (net) | - | £5 | £4 | £4 |
| Scenario 1: Base electricity-only plant CAPEX = ~£4,700 (indicative cost scenario from Phases 1 & 2) | | | | | |
| | Model output – internal rate of return | 7.7% | 11% | 11.2% | 10.6% |
| Scenario 2: Base electricity-only plant CAPEX = ~£3,600 (target cost from Phases 1 and 2) | | | | | |
| | Model output – internal rate of return | 10.1% | 13.7% | 13.7% | 13.0% |

Scenarios from previous modelling work reported earlier:

1. Indicative NOAK CAPEX of around £4,700/Mw_e
2. Competitive baseload CAPEX target of £3,600/Mw_e

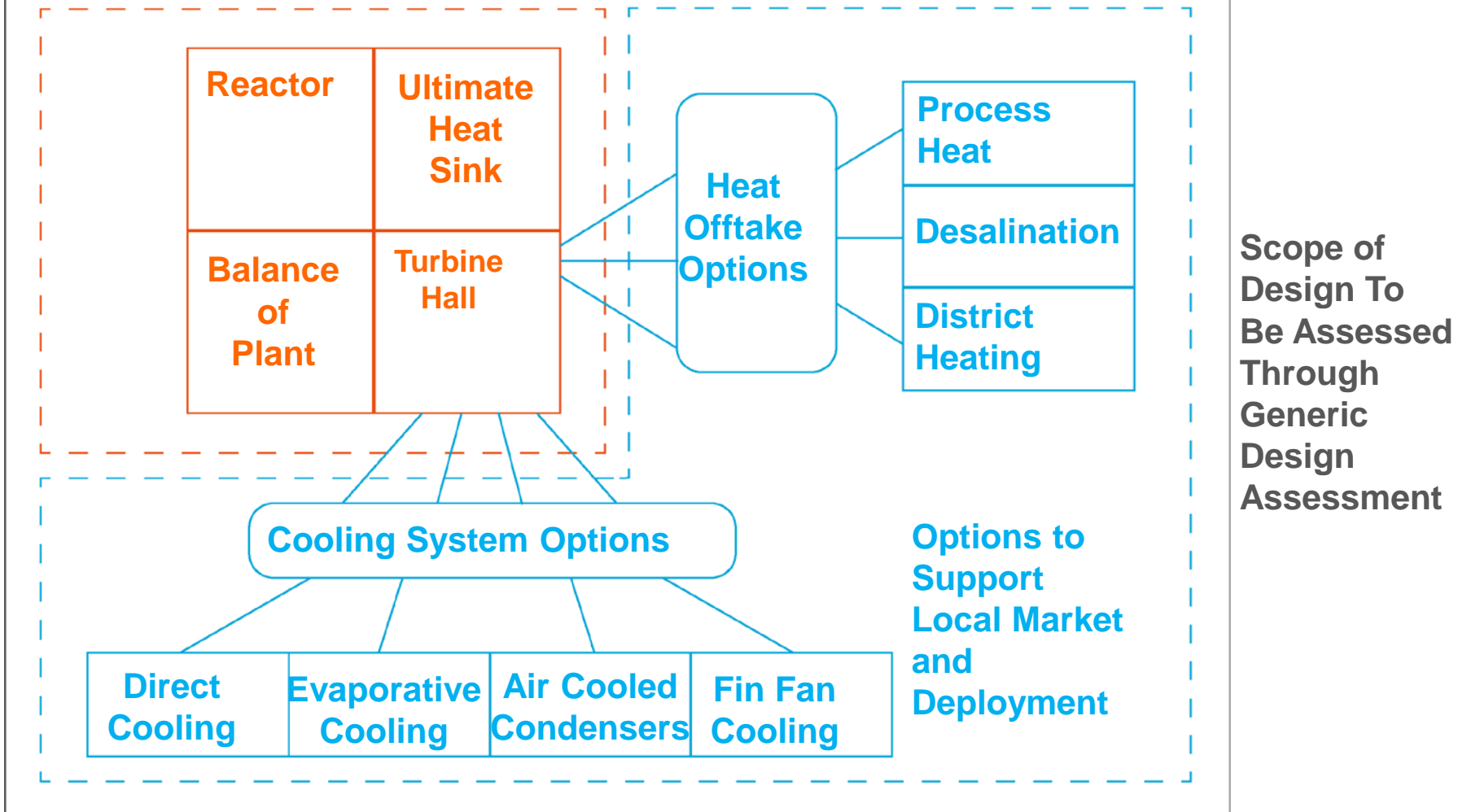
Conclusions:

- SMR economics more favourable as CHP plants compared with electricity only
- Details within analysis have changed from earlier work, but conclusions have not
- Economic differences between plants A and B are small when modified for CHP



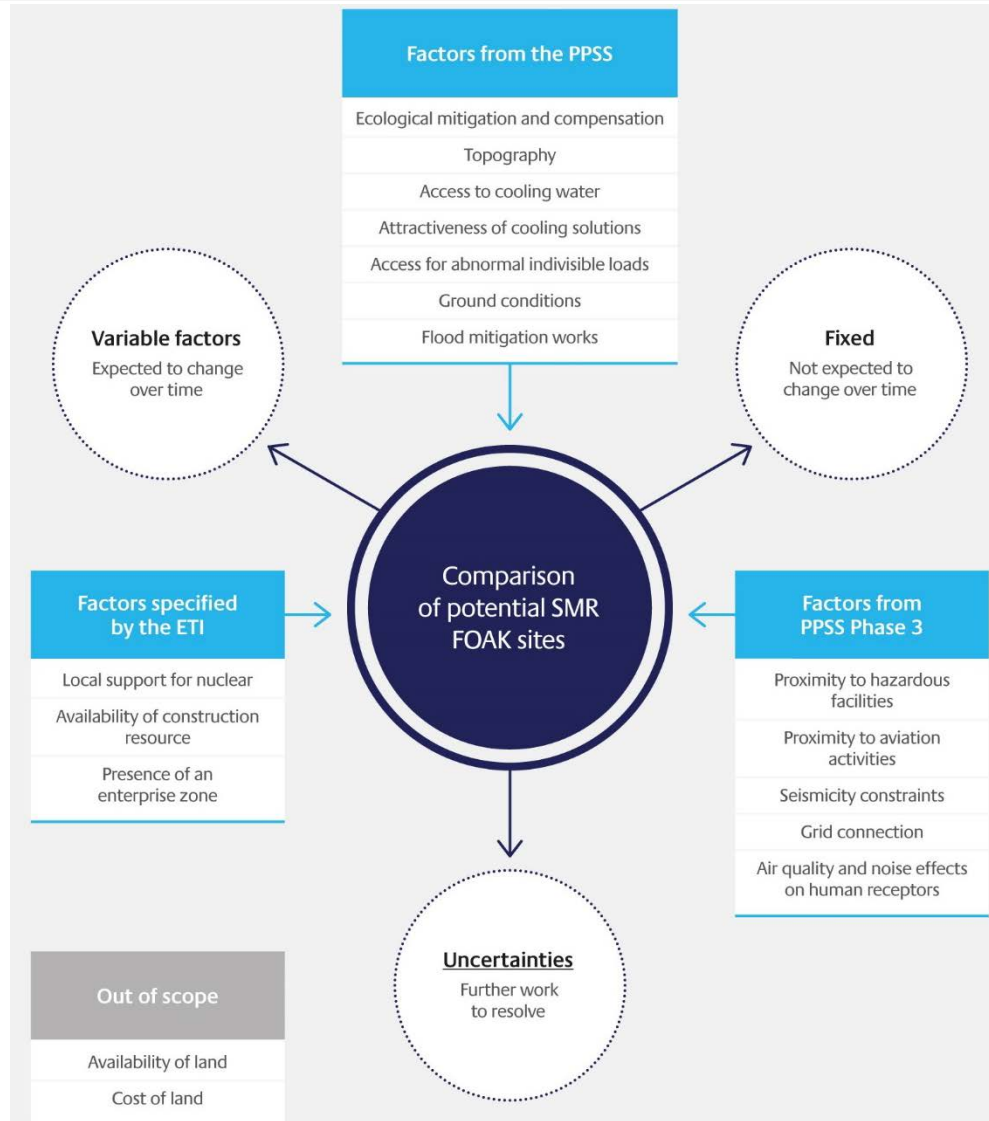
Exploiting The Economies Of Multiples – UK GDA and Coping With Variants

Standardise To Exploit Economies of Multiples





Comparison Of Potential Early SMR Sites Using Ranking Factors





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



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>



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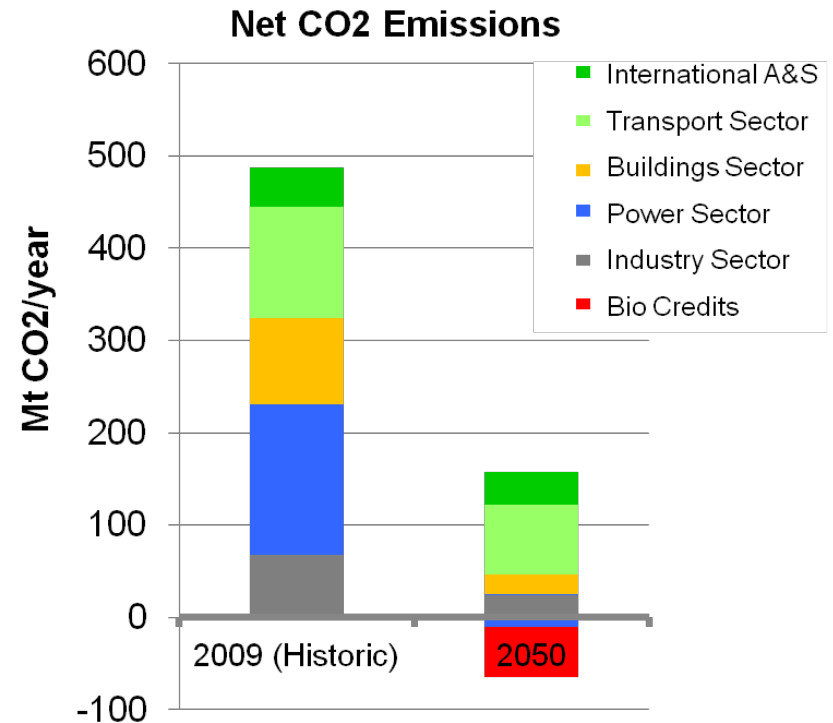
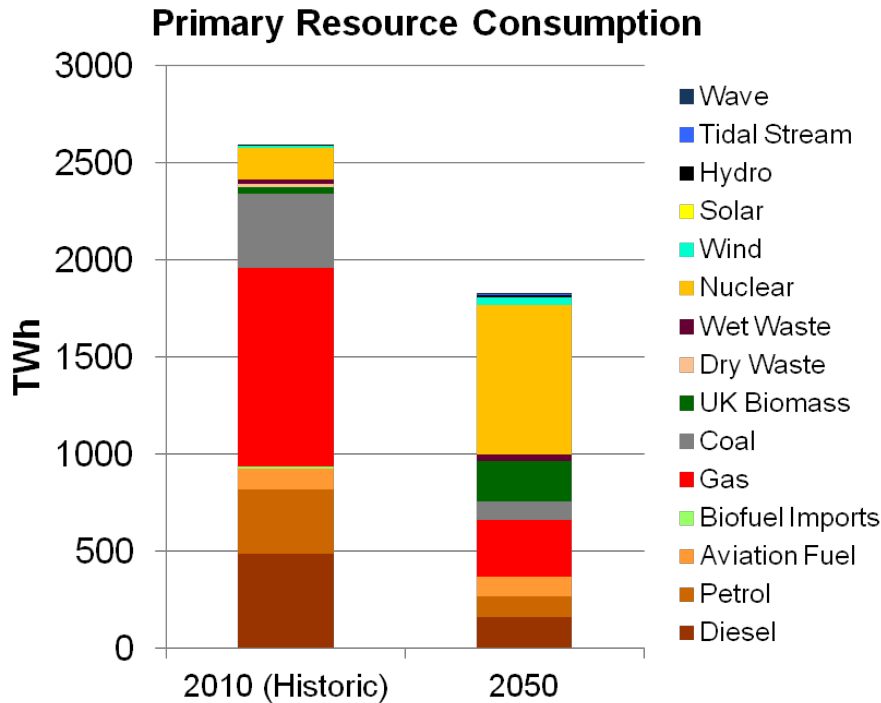
Back Up Slides





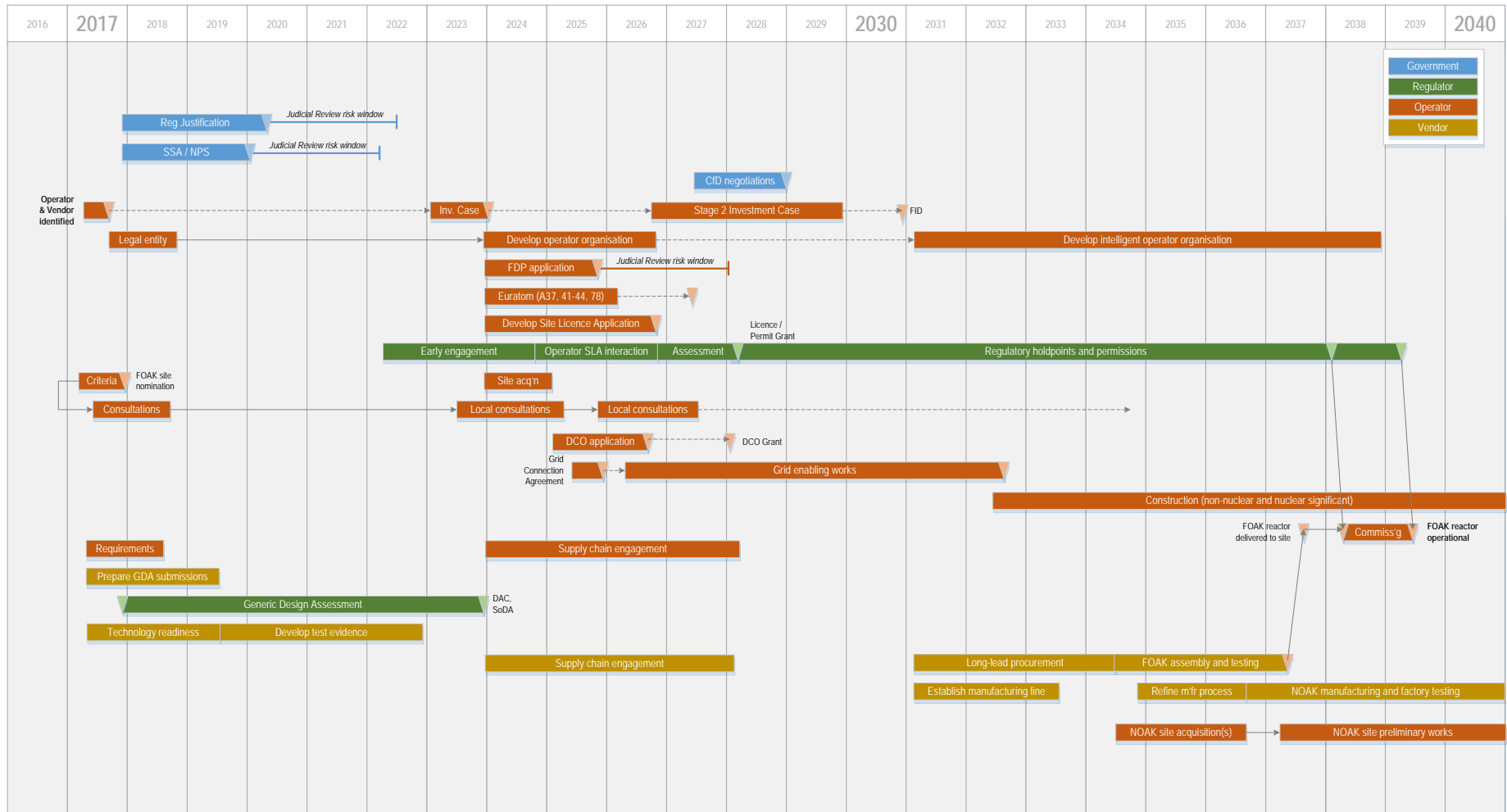
Priorities for the UK energy system

Efficiency (inc. Smart), Nuclear, CCS, Bioenergy, Offshore Wind and Gases are immediate development priorities





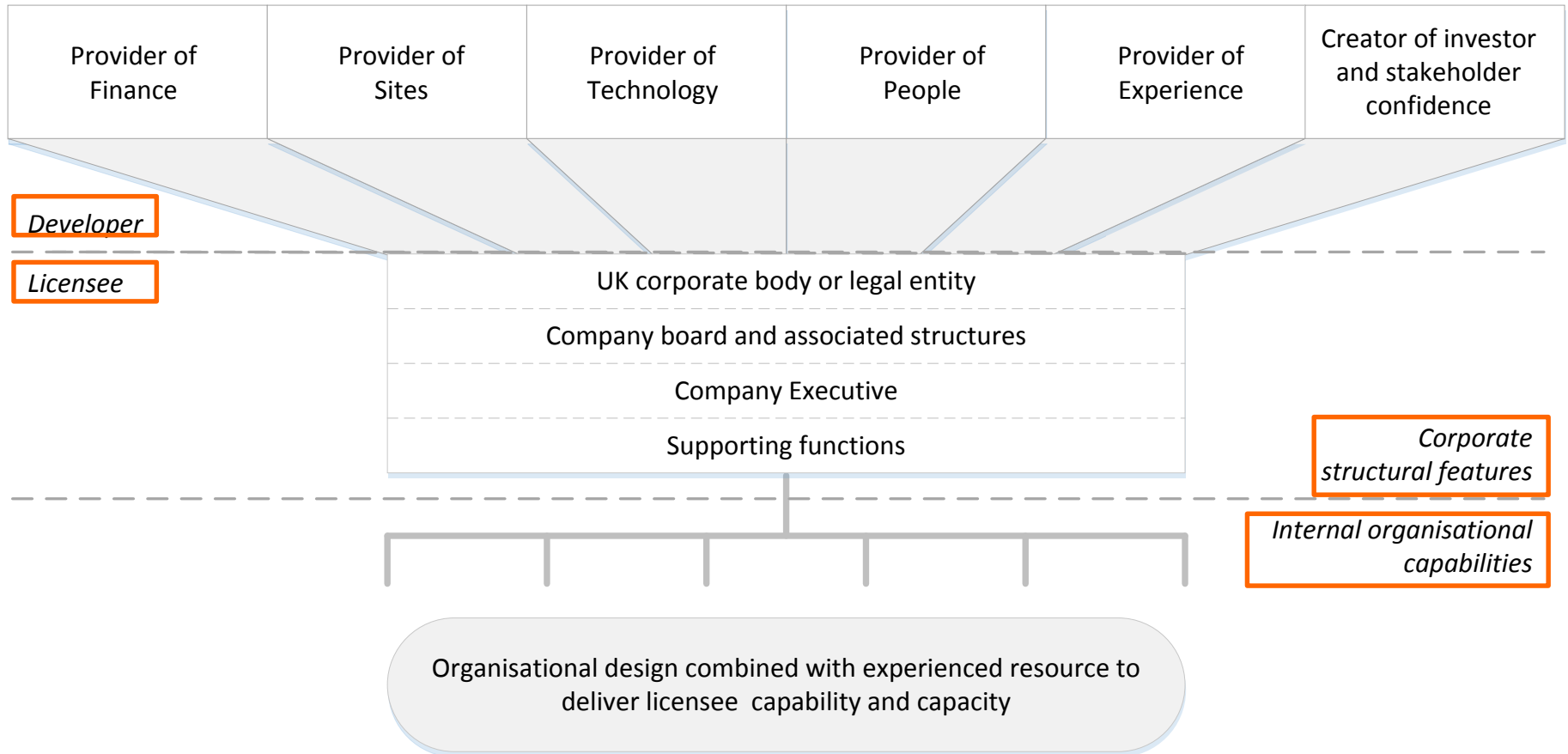
Market led Schedule – First Operations 2040?



Breadth and scale of the challenge – look beyond technology/GDA to the necessary speed and sequence of activities order to achieve success



Licensing Preparations From Around 2021

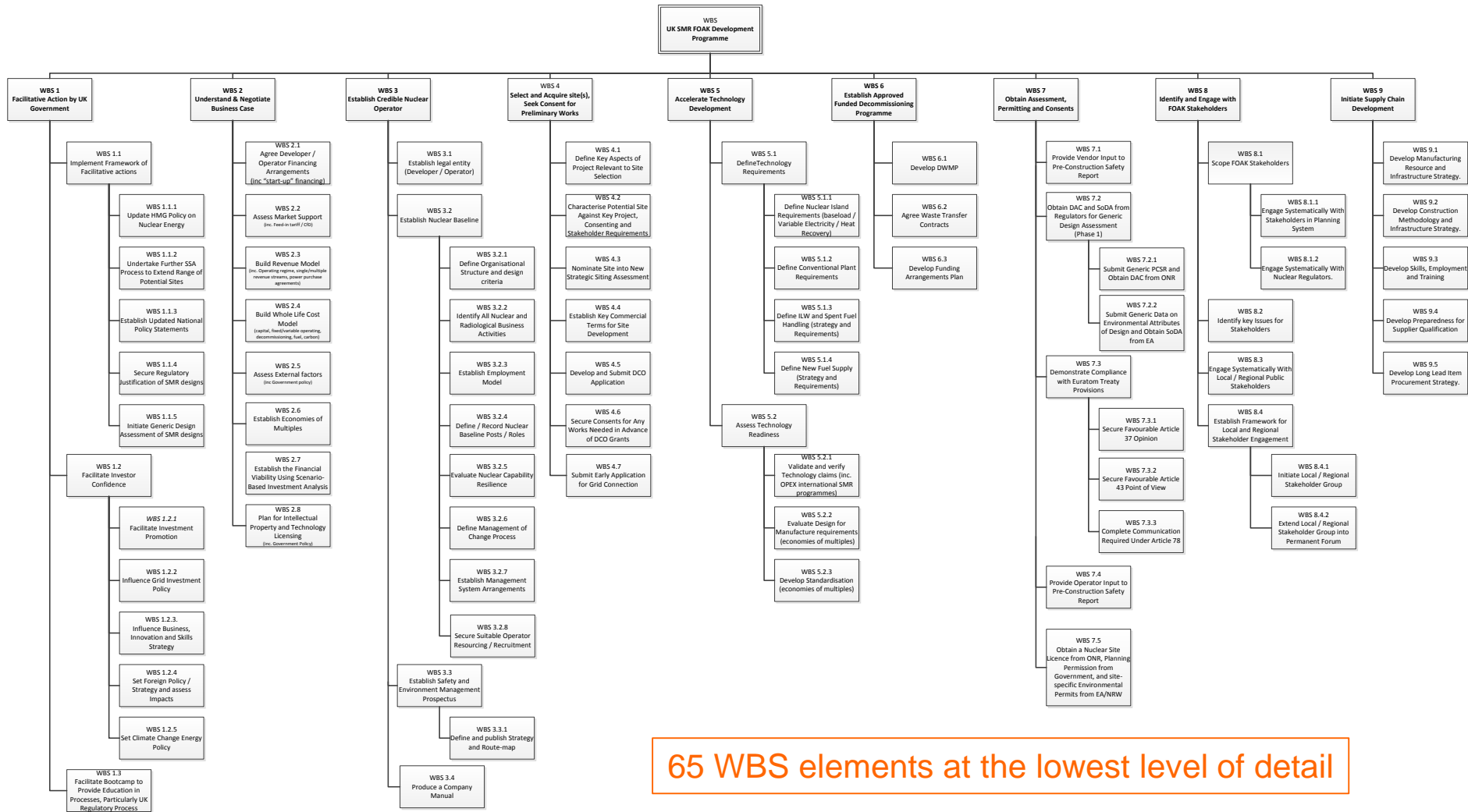


Options regarding relationship between developer and the SMR operating organisation (licensee)

- wholly owned - share in a Joint Venture operating organisation - operation under contract
- Could take 4 to 5 years if a new start up Licensee; faster for an existing mature organisation



Work Breakdown Structure In Detail



65 WBS elements at the lowest level of detail



Economic Impact Of Air Cooling Condensers – Electricity Only and CHP

| Assumes 12C dry ambient temperature | | Electricity-only (Plant A) | | | CHP (Plant A) | | |
|---|--|----------------------------|-------------------------------------|--------------------------|---------------------|-------------------------------------|--------------------------|
| | | Cooling Tower (ECT) | Cooling Tower + ACC (unconstrained) | ACC only (unconstrained) | Cooling Tower (ECT) | Cooling Tower + ACC (unconstrained) | ACC only (unconstrained) |
| Model | Max. net power output – MW _e | 47.7 | 48.2 | 48.2 | 34.1 | 33.9 | 33.9 |
| | CAPEX increment - £/kW _e (net) | £0 | £347 | £169 | £544 | £886 | £708 |
| | OPEX increment - £/kW _e p/a (net) | £0 | £10 | £7 | £4 | £15 | £12 |
| Scenario 1: Base electricity-only plant CAPEX = ~£4,700 (indicative cost scenario from Phases 1 & 2) | | | | | | | |
| | Model output – internal rate of return | 7.7% | 7.1% | 7.4% | 11.2% | 10.4% | 10.7% |
| Scenario 2: Base electricity-only plant CAPEX = ~£3,600 (target cost from Phases 1 and 2) | | | | | | | |
| | Model output – internal rate of return | 10.1% | 9.1% | 9.6% | 13.7% | 12.6% | 13.1% |

ANT project assumption that sufficient water always available for reactor cooling should normal systems be degraded or unavailable

Conclusions:

- Evaporative cooling towers more economically favourable than air condenser cooling
- For inland applications delivering CHP, still financially attractive if ACC addition needed later
- Incremental CAPEX for CHP readiness £10/kWe - costs small but potential future revenues large