U-Battery - A Local Modular Energy Source

9th September 2015

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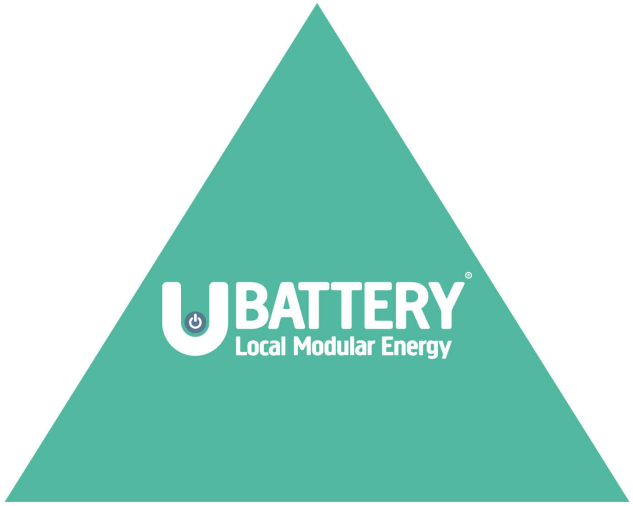
U-Battery

The Energy Trilemma

Secure Energy

Energy providers must have the ability to meet current and future demand. This requires the ongoing development of a reliable energy infrastructure and effective management of primary supply of domestic and external sources.



Economic Energy

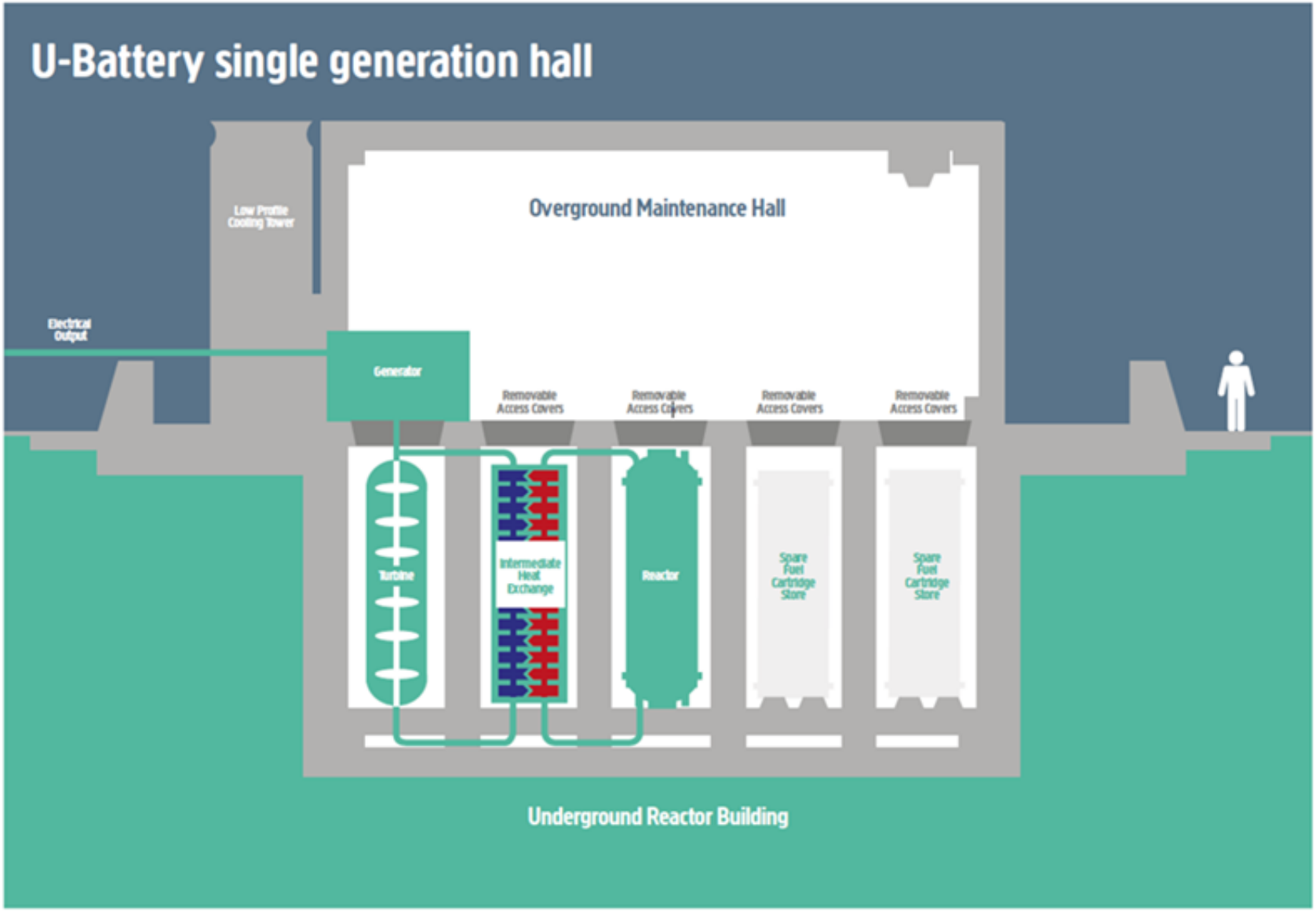
The ability to provide accessibility and affordability of energy across the nation.

Sustainable Energy

This encompasses the development of the energy supply from low carbon and renewable sources whilst reducing the nation's reliability on oil and gas.

U-Battery: Part of the solution

- A local source of heat (800 degrees C) and electricity.
- Single unit is 10MWt, 4MWe.
- Powered by inherently safe TRISO fuel (ceramic coated uranium dioxide granules embedded in a graphite matrix).
- Helium coolant in primary circuit.
- Nitrogen in secondary circuit driving gas turbine/generator set – direct Brayton Cycle.
- Occupies volume of 2 squash courts – footprint equivalent to penalty area on football pitch.


U-Battery single generation hall
Low Profile Cooling Tower
Overground Maintenance Hall
Electrical Output
Generator
Removable Access Covers
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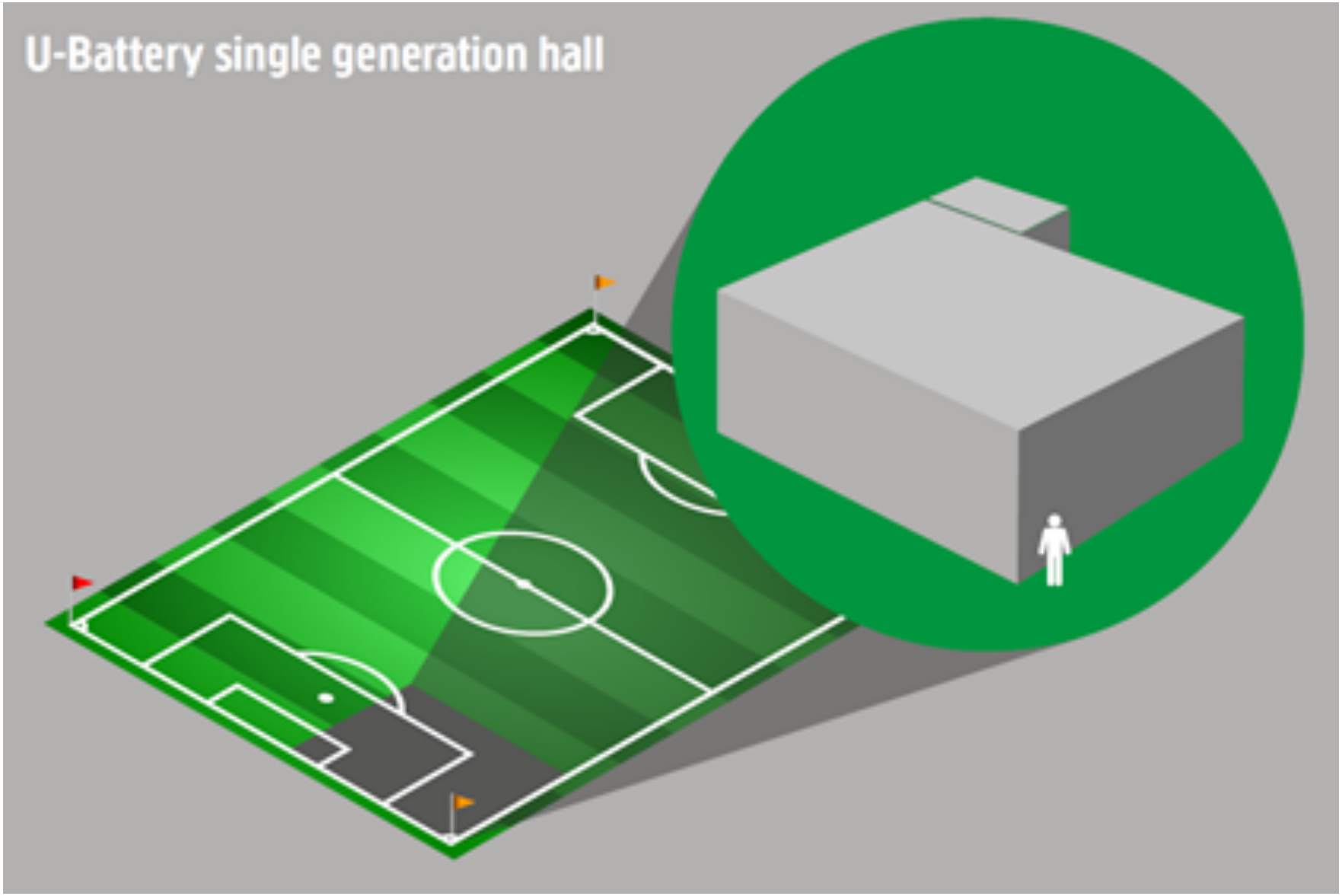
Turbine
Intermediate Heat Exchange
Reactor
Spare Fuel Cartridge Store
Spare Fuel Cartridge Store
Underground Reactor Building


U-Battery single generation hall

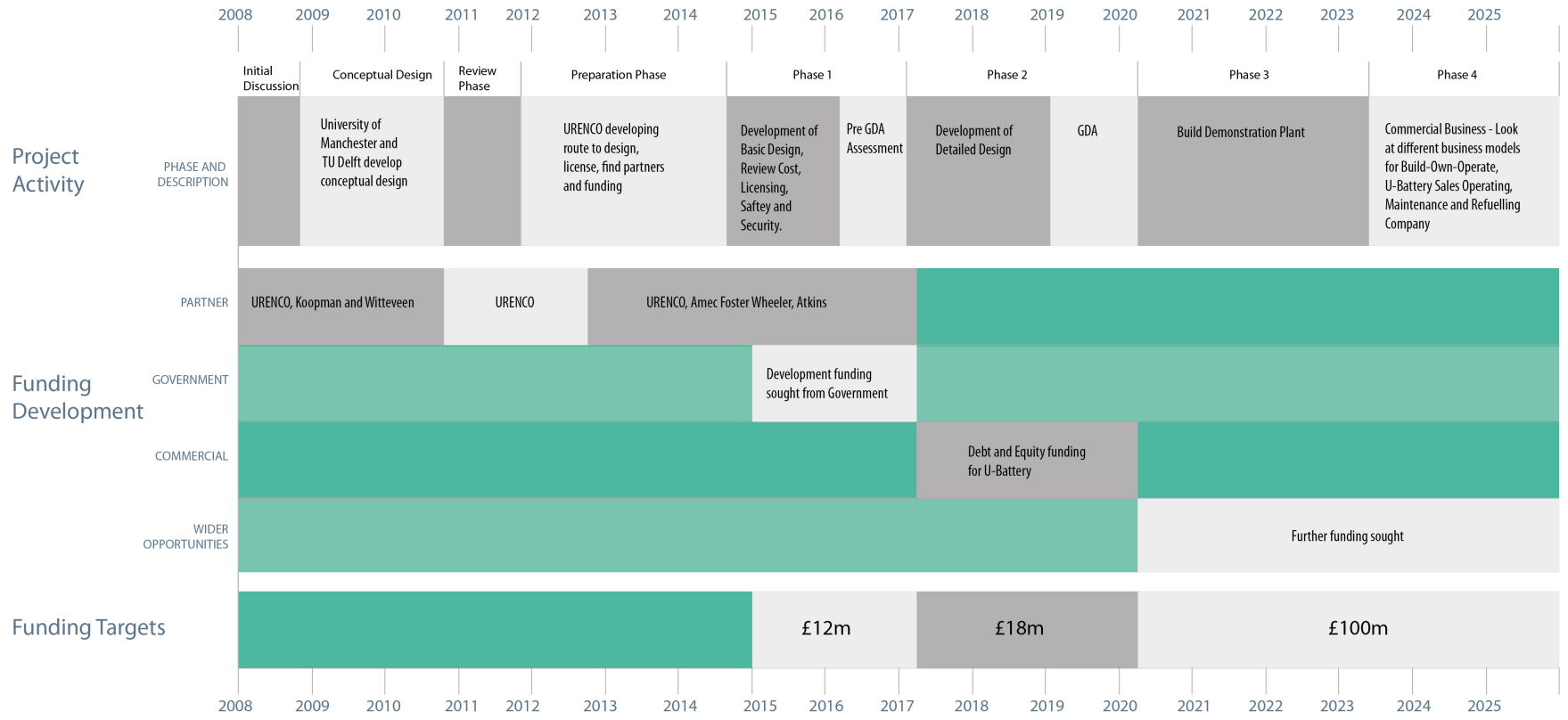
Origins of U-Battery

- Concept developed by University of Manchester (UK) and Technical University of Delft (NL) following challenge set by URENCO CEO, Dr Helmut Engelbrecht.
- Constraints for Concept:
  - Known, proven technology.
  - Inherently safe fuel.
  - Fuel cartridge to fit inside existing internationally licensed spent fuel transport flask.
  - Factory made/assembled/tested.
  - Delivered to point of use on conventional road transport.

Timeline

- Concept work completed 2011.
- 2012 consortium formed to take concept to commercial reality.
- Aim is to have first of a kind in operation at URENCO UK Capenhurst Site by 2023 to prove:
  - Technology can be approved and licensed in UK.
  - Technology works.
  - Technology delivers power (heat and electricity) at competitive cost.

Project Development



Phasing of Project

Phase 1

- Mid 2015 to Mid 2017.
- £12M.
- Basic design.
- Refinement of cost estimate.
- Preliminary regulatory submissions.

Phases 2 and 3

- 2018 to 2023.
- £18M design and licensing.
- £100M hardware.
- Detailed design.
- Procurement and manufacture.
- Licensing application and approval.
- Construction, installation, testing, commissioning.
- Operation.

Development Consortium

Leading Members

urenco

amec foster wheeler

ATKINS

LAING O'ROURKE

CAMMELL LAIRD
SHIPREPAIRERS & SHIPBUILDERS LTD

Supporting Members

SUPPORTING the NUCLEAR AMRC

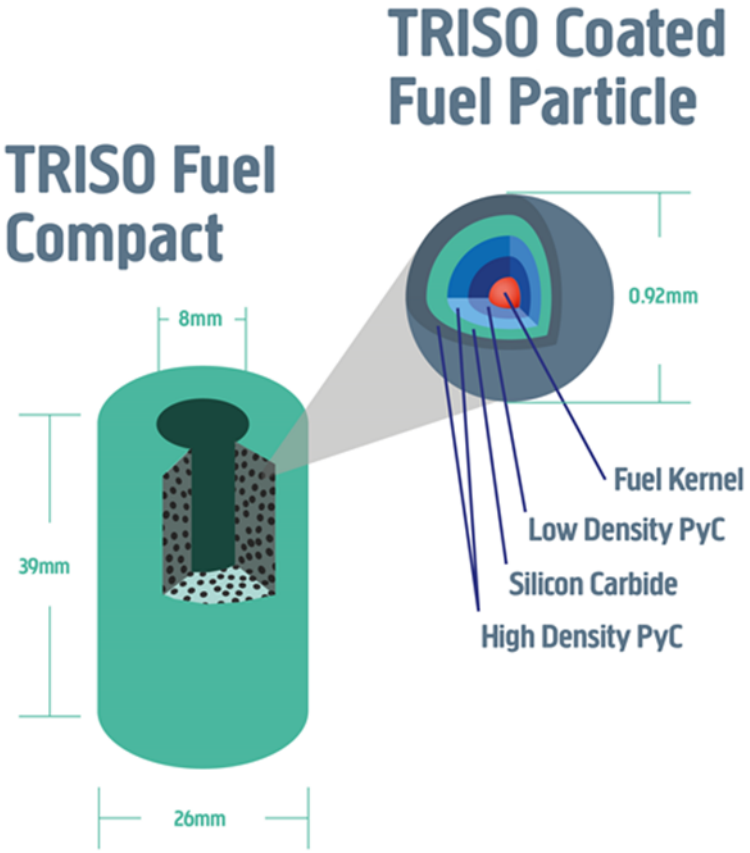
MANCHESTER 1824
The University of Manchest

NATIONAL NUCLEAR LABORATORY

Current Key Work

Work stream	Lead Partner
1. Security/Non-proliferation assurance.	Amec Foster Wheeler
2. Fuel supply.	URENCO
3. Fresh and spent fuel cartridge transport licensing.	Atkins
4. Reactor design and fuel codes.	Amec Foster Wheeler
5. Cost estimate confirmation.	Amec Foster Wheeler
6. Spent fuel cartridge handling at installation.	Cammell Laird
7. Spent fuel management strategy.	NNL
8. Turbine/Generator set.	Atkins
9. Gas/Gas heat exchanger.	Amec Foster Wheeler
10. Building layout/modularisation/ constructability/integration/programme acceleration.	Laing O'Rourke

TRISO Fuel



- High Melting Point
- U-Battery runs at 800 degrees C
- Not enough energy in reactor to approach melting point of fuel in any normal, abnormal or emergency situation
- U-Battery is Passively Safe – with no coolant, with control rods fully out and with no human intervention, temperature of fuel rises slightly.

TRISO Fuel

- Used in Dragon prototype reactor at Winfrith, Dorset, UK in 1980's.
- Used in test reactors in US, Japan and in commercial HTR in Germany.
- Currently being manufactured in US.
- Fuel for First of a Kind at UK will be sourced from US (B and W).
- Inherent safety of fuel reduces/eliminates need for expensive diverse engineered safety systems and reduces size of emergency planning zone.

Two independent market studies commissioned by URENCO

- Collinson Grant 2014 (UK and Global)
- Aurora 2015 (UK)

Market Study

A qualitative comparison between the U-Battery and other generating technologies, and of customers' priorities in each market, indicates that:

- the U-Battery's strengths are most suited to the embedded generation and on-site generation markets.
- for electricity-only generation, gas is the most attractive alternative to generate heat and electricity, Gas-CHP is currently the most competitive alternative.
- whereas fossil fuel prices are forecasted to rise, the U-Battery offers price stability.

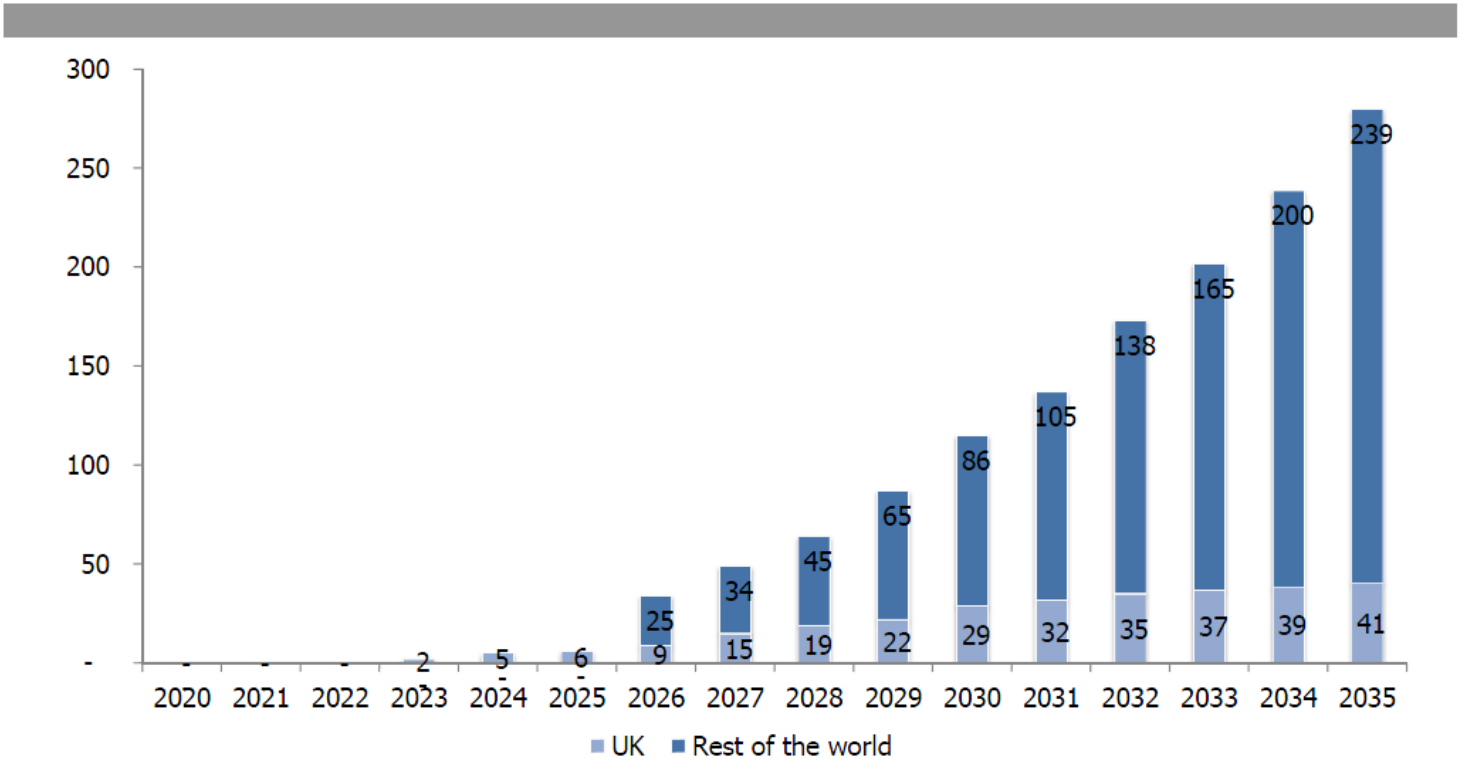
Levelised cost estimates of gas technologies and of U-Battery (£MWh)

	Gas at 73.8 p/therm	Gas at 105.4 p/therm
CCGT (Combined cycle gas-turbine plants)	76	94
CCGT-CHP (Combined cycle gas-turbine plants - Combined Heat & Power)	113	141

	Initial cost estimates (2011)	Scenario 1*	Scenario 2**
U-Battery	121	108	96

Projected market

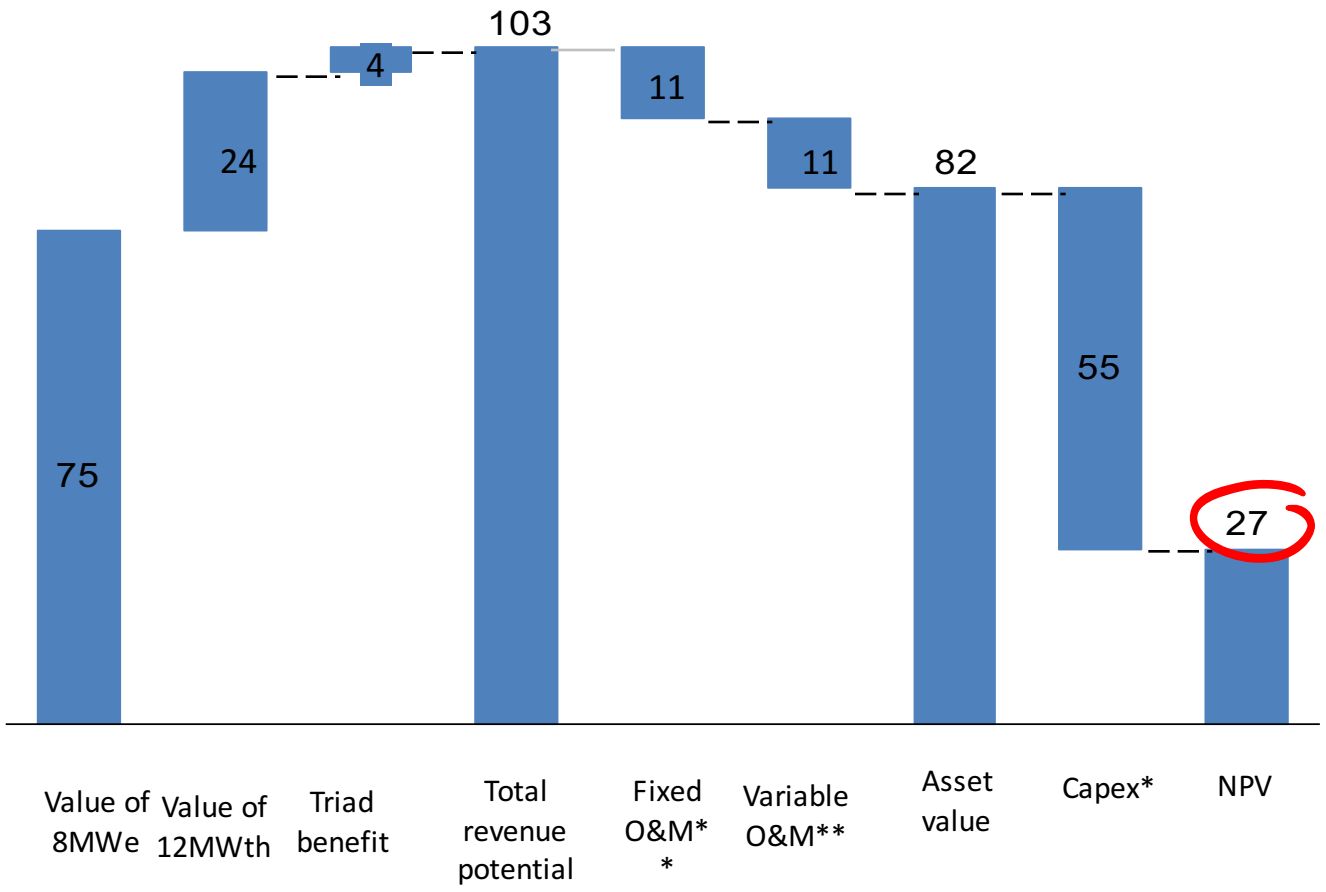
Projected U-Battery installations between 2020 and 2035 based on relative attractiveness of country markets



Taking the U-Battery from concept to market
10th April 2014

For off-grid applications, we estimate the U-Battery could deliver an IRR of 12-15%

PV for a twin unit of U-Battery, £m
(at 10% discount rate)



- Assuming a central case capex estimate of £55m and 80% of heat output being valued, we estimate £27m NPV for each twin unit of the U-battery for industrial applications
- This equates to 15% IRR on the investment
- If capex were £70m, IRR would be 12%

* Nth of a kind, central case estimate
** Operations & Maintenance

On-grid, we estimate that a £72/MWh CfD could be sufficient to make the U-battery competitive

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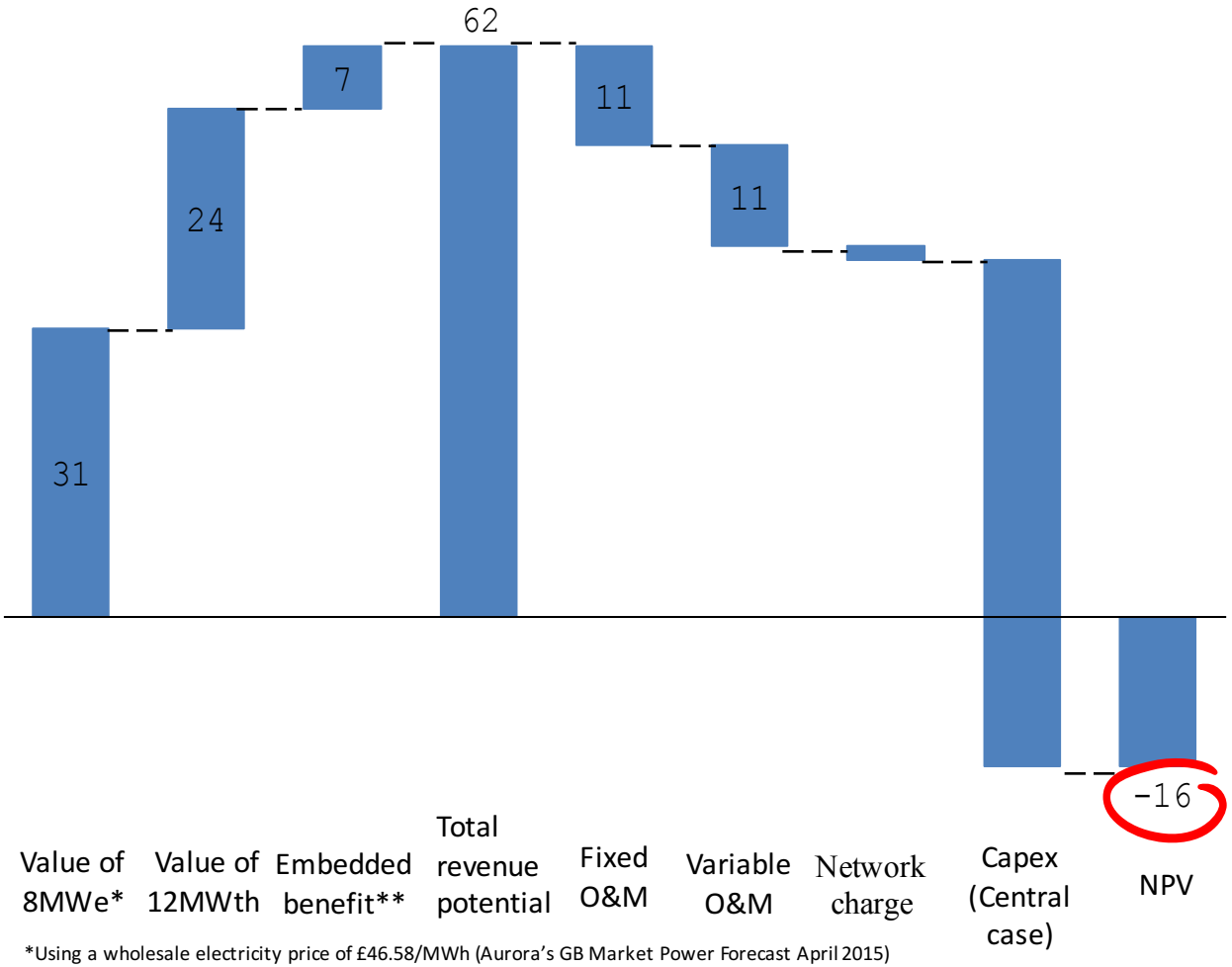
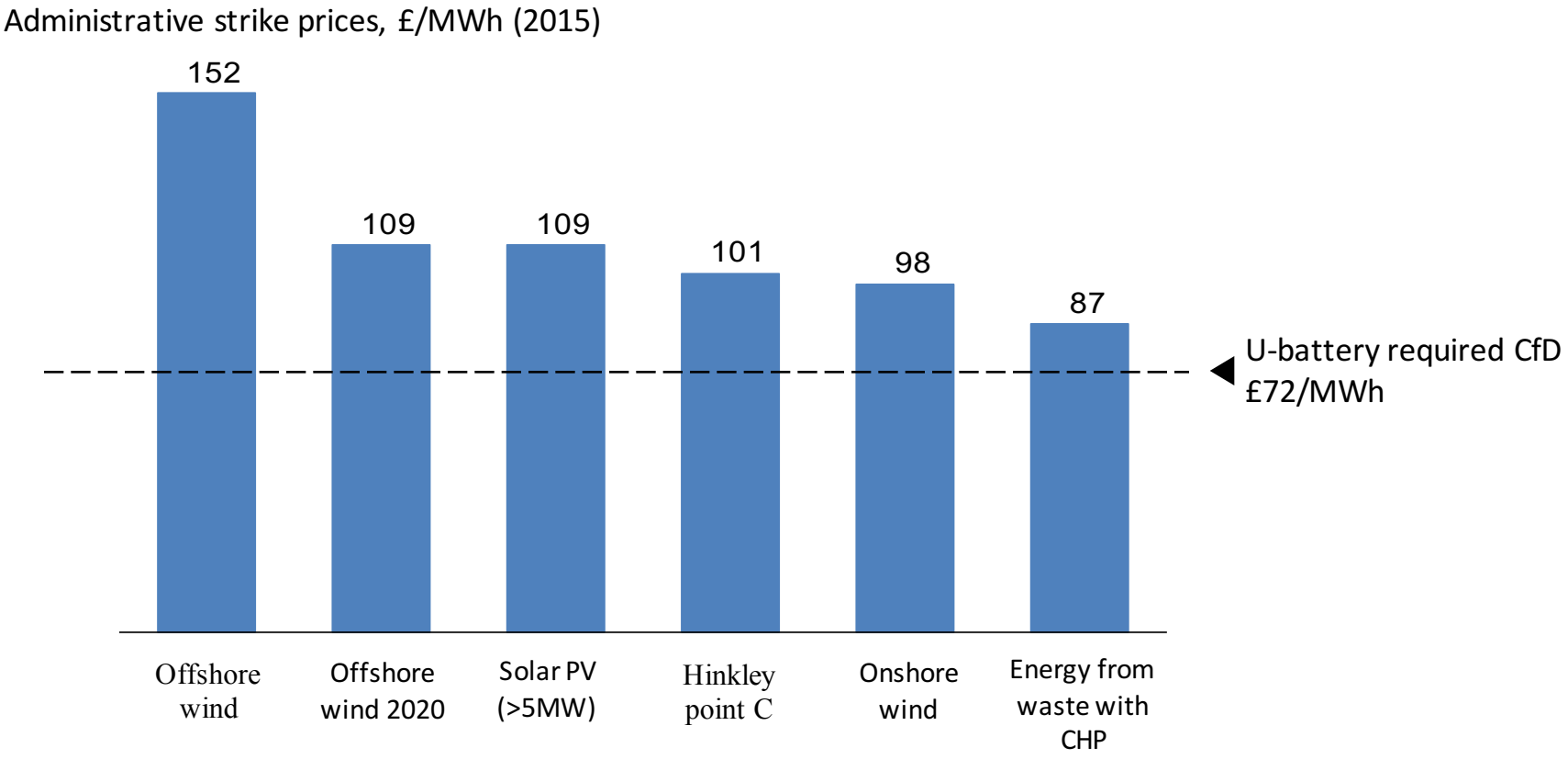


*Using a wholesale electricity price of £46.58/MWh (Aurora's GB Market Power Forecast April 2015)
**Includes TNUoS savings, BSUoS savings and transmission losses savings

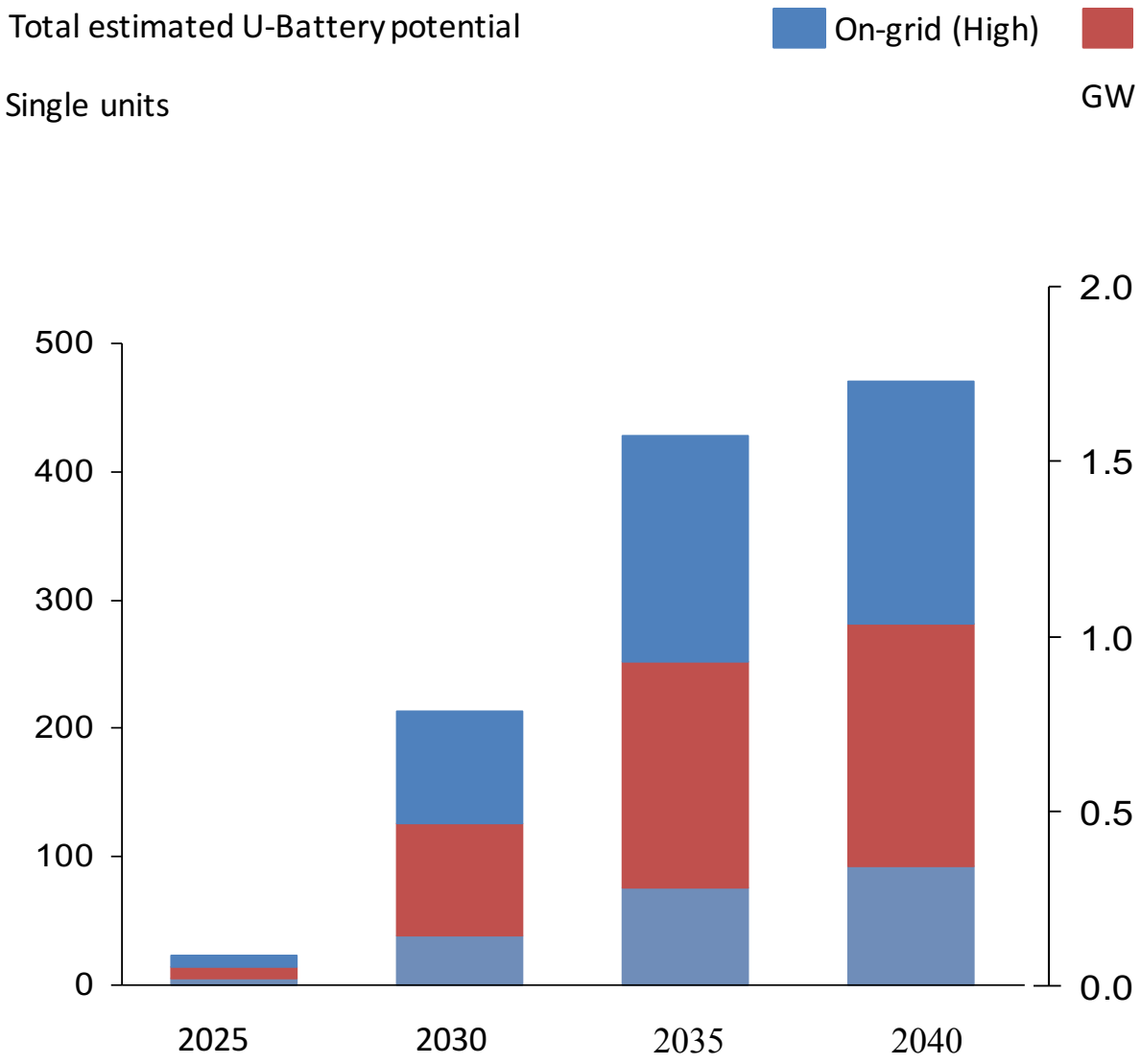
- For on grid applications, we estimate a twin U-battery unit is £16m short of returning the 10% IRR that would be required to attract investment
- A CfD with strike price of £72/MWh would bridge this gap

A £72 CfD compares favourably to other low-carbon technologies, and is lower than offshore wind in 2020



[1]DECC's Electricity Market Reform: Contract for Difference – Allocation Methodology for Renewable Generation (Aug 2013)

In total, we see potential for up to 400 U-batteries by 2035, and this would deliver a number of benefits



The installation of 400 U-Batteries (1.7GW) by 2035 would:

- Reduce the need for 2GW of offshore wind and 1.4GW of CCGT
- Deliver a total system savings of £550m per year (£20/household)
- Reduce total power sector CO2 emissions by 11% (2.7Mt per year)

Summary

- Will be in operation by 2023.
- Follow on units will be truly factory built and achieve cost reductions in manufacture from the economics of multiples.
- Cost for Nth of a Kind (number 8 onwards) £40M - £70M for 20 MWt, 8MWe twin unit.
- Factory build minimises time on site before revenue earning operation.
- Does not need to be located by a water source for cooling, (can be air cooled).
- Compliments large nuclear and SMR projects, (they address completely different markets).
- Independent Market Studies show U-Battery is competitive with package gas plants and demand will be pulled by market.
- u-bat.com
- @U_Battery