Challenge: Advancing heat exchangers, energy management and conversion systems for advanced nuclear technologies

Delivered by

Summary

The drive to achieve Net Zero Greenhouse Gas (GHG) emissions by 2050 requires us to re-consider how we apply all our low carbon energy sources to enable deep decarbonisation of all energy end use applications including home heating, shipping, land transport, aviation, agriculture and industry.

The conventional use of nuclear reactors in the UK operating fleet has been limited to electrical output. Advanced nuclear technologies (ANTs), covering both Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs), have the potential for electrical output and to support decarbonisation in a wider variety of ways. To be successful in the broader application of ANTs there is a requirement for novel methods of extracting and managing the heat they produce for subsequent use in energy conversion systems. AMRs also typically operate at higher temperatures than the current operating fleet, for which novel heat exchanger and management technologies may be required.

On behalf of the Department for Business, Energy and Industrial Strategy (BEIS) and the National Nuclear Laboratory (NNL), Game Changers are inviting proposals for innovative ideas which could advance technology for extracting and managing the heat from ANTs. This includes better understanding of the requirements placed on such systems by energy conversion systems and reactors.

Applications are therefore welcome that cover systems such as:

- Heat exchangers (e.g ceramic boilers for high temperature applications, their materials and layout).
- Manifolds capable of diverting the heat from the same reactor to various different energy conversion or use systems. (e.g. materials, control systems, safety aspects).
- Energy conversion systems in terms of the requirements that they place on any element of the heat transfer or management systems (e.g the requirements from electrolysers or the intended industrial process end use).
- The requirements advanced reactors could place on heat transfer and management systems due to operation at elevated temperatures and pressures and the use of novel cooling fluids and/or fuel

Background

This call is part of a short pilot of the Advanced Nuclear Skills and Innovation Campus (ANSIC), delivered by NNL on behalf of BEIS, as part of the UK Government's commitment to the continued development of advanced nuclear technology to help the UK reach net zero emissions by 2050.

The pilot campus programme, with a physical base near Preston on the Springfields nuclear licensed site, will serve as a research and innovation hub. ANSIC aims to support industry and academia to work on projects designed to help accelerate the deployment of advanced nuclear technology.

The pilot programme will help to build an informed, reliable evidence base to:

- Establish future demand and scope for future initiatives.
- Identify opportunities for industry collaboration and the practical challenges of delivering campus activities on a nuclear licensed site.

The UK Government has committed to significant investment in the development of SMRs and AMRs as part of the transition to a low carbon economy. In July 2021, the Government also announced plans to explore the potential of High Temperature Gas Reactors (HTGRs) to enable an AMR demonstration by the early 2030s, to support net zero by 2050. As part of the delivery of the pilot phase of ANSIC, a series of challenge-led calls offers applicants the opportunity to receive a feasibility funding grant of up to £25k to develop ideas or technologies applicable to any potential advanced nuclear technologies.

Feasibility funding is aimed at supporting the exploration and development of novel ideas and concepts. Typical activities within a feasibility project can include desk-based studies, development and production of small prototypes, and demonstrations.

Funded feasibility projects should be carried out at the applicant's own premises, and these calls do not include access to the ANSIC campus. **All agreed project tasks and final reports must be completed by 25th March 2022.**

Introduction

Nuclear power generates a significant amount of low carbon energy in the form of heat. Current and past generations of nuclear reactor typically harness this energy via a Rankine power generation cycle where heat from the reactor converts water to steam, which in turn powers a turbine, converting the heat to electricity (Figure 1). The majority of current reactors (Gen I-III) typically rely upon steam generators or boilers in order to transfer energy from the primary coolant circuit to downstream power generation processes. Currently, around 65% of energy is lost in the overall process as waste heat.[1]

The route to Net Zero, however, demands that we consider how nuclear energy can have applications beyond the production of electricity, which should make it more desirable to a low carbon energy system and enable deep decarbonisation of a wide array of end use applications. This could include using an ANT reactor to provide one or more of the following: direct heat to industrial processes, hydrogen production, sustainable fuels manufacture, direct heat to district heating systems, baseload and flexible electricity provision. This opportunity has been outlined in a number of publications.[2-6]

For AMRs that have a higher heat output, there may be an even wider range of end use applications and specific challenges in the high temperature operation.

To effectively extract heat from ANT reactors and enable it to be transferred to one of more of these applications, new technologies or novel applications of current technology, could be needed. The intent of the challenge therefore is for organisations to come forward with innovative solutions related to any or all aspects of the heat transfer and management system. For example, high temperature reactors may require a novel type of heat exchanger, or a novel manifold arrangement with appropriate control and instrumentation systems to effectively supply heat to one or more energy conversion or use systems.

If successful, the challenge will advance the understanding and technology readiness of components and systems necessary to apply heat from ANTs for the production of various energy products. Recognising that this is a new and emerging area, the scope also includes improving the understanding of the boundary conditions and requirements on these systems (see the arrows on Figure 1 below which show the region of plant that is relevant to the challenge). Submissions from ANT developers and energy conversion system vendors are therefore also welcomed. Note that the heat transfer systems may comprise one or more heat exchangers and coolant loops.

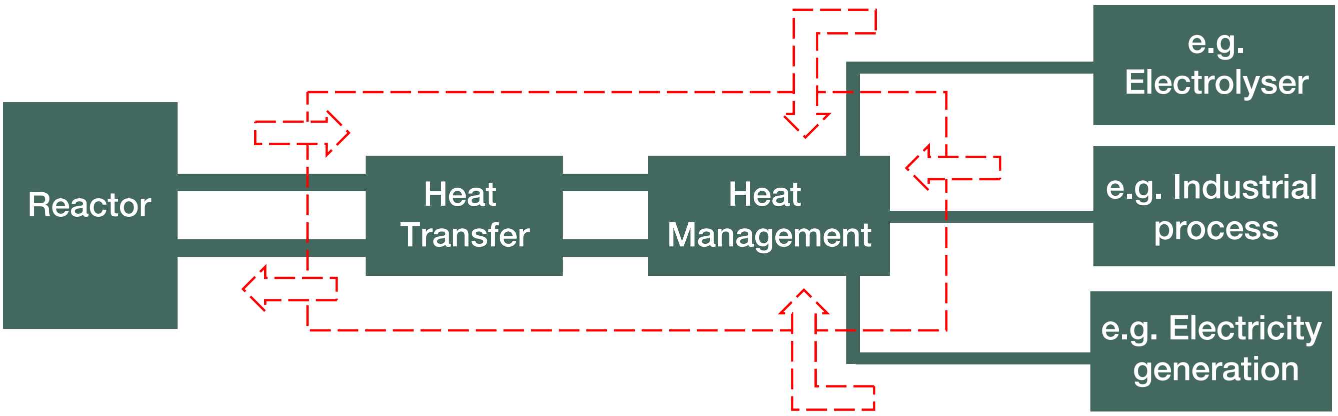


Figure 1 – Simplistic representation of the scope of the challenge as indicated by the red/dashed line boundary. Arrows represent requirements placed on the heat transfer and management systems both by the reactor or the energy conversion and use systems

[1] Nuclear cogeneration: civil nuclear energy in a low-carbon future policy briefing Issued: October 2020 ES7116 ISBN: 978-1-78252-494-6 © The Royal Society

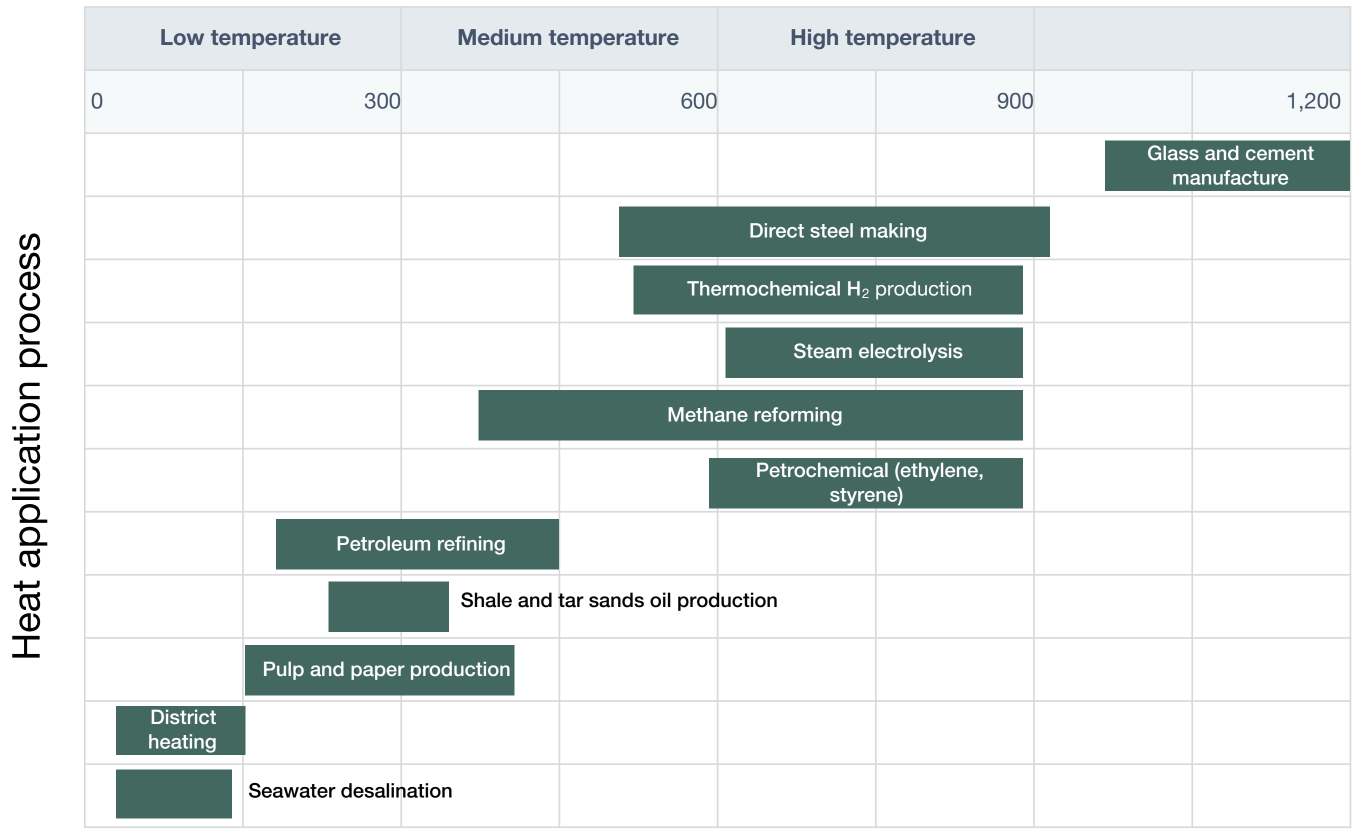
[2] The Ten-Point Plan for a Green Industrial Revolution. BEIS. 2020

[3] Energy white paper: Powering our net zero future. BEIS. 2020

[4] The Net Zero Strategy and COP26: An Opportunity for UK Leadership in Net Zero Policymaking. Catapult Energy Systems. 2021

[5] Achieving Net Zero: The role of Nuclear Energy in Decarbonisation. NIRAB. 2020

[6] UK Hydrogen Strategy. BEIS. 2021



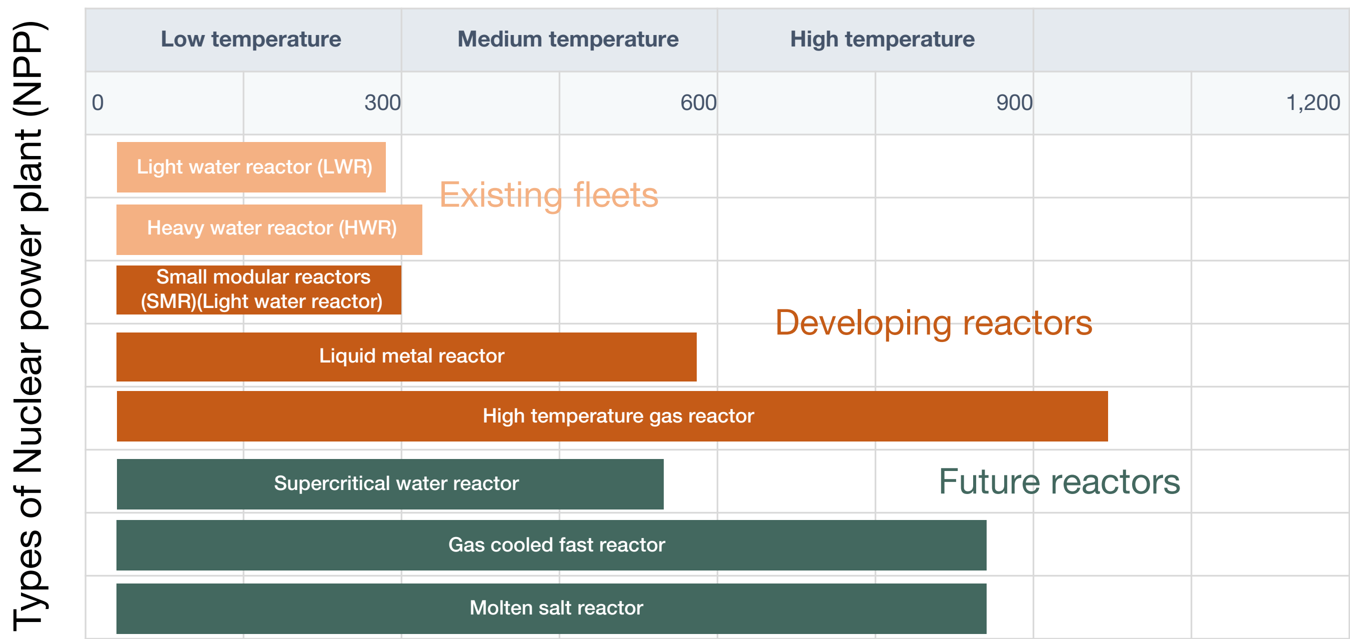


Figure 2 - Temperature ranges of heat application processes and types of nuclear power plant[7]

[7] International Atomic Energy Agency. 2017 Opportunities for Cogeneration with Nuclear Energy. See https://www.iaea.org/publications/10877/opportunities-for-cogeneration-with-nuclear-energy UK Hydrogen Strategy. BEIS. 2021

Current practice

The majority of heat exchanger systems used in current nuclear reactors are intended to be used with water, particularly on the secondary side, i.e. steam generators or boilers as part of the main power generation cycle or in passive safety systems currently employed on some reactors. These are generally large shell and tube or u-tube type steam generators. These systems are used at temperatures circa 250 – 325°C and could be applicable to SMRs, however they may not be suitable for AMRs, which would have different primary coolant and outlet temperatures potentially in the range 600-1000°C (please see Figure 2).

In some instances, and particularly for non-conventional coolant types, intermediate heat exchangers are also required, which add further layers of system separation between the reactor and the energy conversion system. These could be an additional requirement for molten salt, sodium fast reactor, lead fast reactors and HTGRs with an indirect Brayton cycle.

Examples are the use of helical coil heat exchangers for HTGRs, as trialled in Japan, and printed circuit design heat exchangers (PCHX), as are being proposed for some designs due to their smaller size. These are manufactured using diffusion bonding whereby a single unit with no joints, welds, or points of failure is formed. In addition to heat exchanger design and engineering, materials development is also of interest, and recent work has been carried out on nickel-based superalloys where operation at higher temperatures (circa 950°C) is needed.

Due to the immaturity of designs, a number of challenges remain, for example, understanding material degradation in molten salt systems, reducing and removing leakage paths for helium and tritium in high temperature gas systems, and overcoming the large size constraints of some conventional designs.

Challenges also remain with regard to maximising the versatility of a nuclear reactor and the number of energy conversion and heat use applications that can be supported from the same reactor, and as a consequence its potential ability to economically deliver electricity to the national grid in a flexible way that compensates for the intermittency of renewable energy supply. Novel approaches need to be developed to achieve these outcomes, which could involve 'Smart Manifold' designs that can directly carry amounts of heat to a range of downstream energy conversion and use systems while maintaining constant reactor power.

As part of the challenge we might expect that projects would consider the following elements of heat exchanger and heat management system design and operation:

- Operating in a radiological environment
- Restricted access, necessitating:
  - Low maintenance
  - Long life
  - Known lifecycle
- Cost
- Structural integrity
- Efficiency under anticipated operational conditions
- Minimisation of size or footprint
- Materials, taking into account the potential for corrosion, and thermal effects
- Thermal Hydraulic Transients
- Chemicals i.e. tritium/hydrogen transfer/water or coolant ingress

We would also expect that solutions can demonstrate the potential to deliver on the following high-level functional requirements:

- Alignment with safety criteria and regulatory standards
- Ability to allow nuclear reactors to provide flexible energy outputs
- Potential to achieve economic competitiveness in terms of the solutions themselves and how they can enable ANTs to achieve commercial competitiveness with other energy sources
- Ability to provide an appropriate element of SMART technology and automated response to demand signals. This applies specifically to the Heat Management System, which may autonomously divert heat to alternative applications depending on demand

Challenge aims

The aim of this challenge is to establish or develop concepts, technologies, solutions and requirements on heat transfer and management systems for ANTs.

Examples of areas of interest include but are not limited to:

- **Heat Exchanger Design**
  - How could geometry of the heat exchanger components enhance performance? (i.e. maximising heat transfer efficiency and area)
  - Are there novel materials or manufacturing technologies that can be applied?
  - How can new innovations help to reduce the size/footprint?
  - How can new innovations help to reduce cost?
  - How reactor specific is a given heat exchanger design? Or could multiple reactor designs or types use a common heat exchanger design?
  - What requirements are placed on heat exchangers by the reactors or the downstream energy conversion or heat usage systems?
- **Heat management systems**
  - What technologies could support heat supply usage intelligently switching from electrical power generation to an alternate downstream process based on current and forecast grid demand?
  - Modelling of the heat exchanger and heat management system to understand dependencies and requirements.
  - What are the likely performance characteristics of a smart manifold, for example, how long would the switch process take?
  - What configuration of heat exchanger would work best for multiple take-offs, and where is the optimal placement within the reactor system?
  - What requirements are placed on the heat management system by the reactors or the downstream energy conversion or heat usage systems?
- **System safety**
  - What are the implications of switching? Are there thermal hydraulic transients that need to be considered? Is there an impact on the various components around the reactor?
  - What methods could help minimise transients moving across from the reactor to the heat exchangers and on through the take-offs?
  - How quickly could the switch process happen safely and how often could changes to the system be made?
  - How is structural integrity maintained? Does the design have an appropriate life/ safety margin given anticipated operational conditions?
  - Behaviour and transients in targeted anticipated operational occurrences and design-basis accidents (do appropriate codes exist to assess this?)
  - How is the asset integrity and status monitored throughout its lifetime?

Assessment of applications

Submissions will be assessed by a panel and written feedback will be provided by Game Changers for all applications, whether or not successful. The panel will comprise members of the ANSIC Steering Group, which includes representatives from NNL, BEIS and the Nuclear Innovation and Research Office (NIRO).

Application forms and posters will be assessed consistently and transparently using the following criteria:

1. Clarity of project objectives and alignment to the challenge aims
2. The level of technical innovation involved in the proposed work
3. The skills, capability and capacity of the applicant team to deliver the proposed project
4. Value for money
5. Identification of risks and mitigating actions

Benefits

If successful, projects delivered through the challenge will advance the understanding and technology readiness of components and systems necessary to apply heat from ANTs for the production of various energy outputs and products.

The overall benefit of the project will be a clearer understanding and increased technology readiness level of systems required to convert the heat from an ANT to alternative useable forms in a way that is cost effective, efficient and meets the requirements of a decarbonising energy system. As a further benefit this will provide confidence (or otherwise) in the ability of ANTs to deliver heat and energy products as envisaged, and identify the further steps that may be needed to realise that overall ambition. Overall these outcomes will support delivery of the Government's 10-point plan[1] and energy white paper[2], alongside other sector specific policy, which together outline plans for decarbonising the energy system and indicate a more expansive role for nuclear energy in terms of the applications that the technology can support.

Constraints

Due to the nature of the funding allocated from BEIS, applicants must outline how their technology or idea can be applied to ANTs. Applications that are focussed on large scale GW reactors (such as the design being built at Hinkley Point C) are not eligible for funding.

Applications should focus on the heat transfer and management systems, or the requirements placed on these from the reactor or energy conversion systems, as indicated in Figure 1.

What Next?

Game Changers are hosting an online briefing webinar for this challenge. Details of the webinar will be available on the Game Changers website www.gamechangers.technology. If you have new ideas or innovations which can be applied to address this challenge we invite you to join us.

Please visit our FAQs for ANSIC on the website for answers to some commonly asked questions, or contact us on apply@gamechangers.technology if you have further queries about this call.

Applications must be submitted using the Game Changers online application portal. This includes a short application form and a requirement for a poster outlining the proposed solution.

The deadline for applications for this challenge is 12 noon on Friday 12th November 2021.

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Key dates

Date	Activity
30th September 2021	**Call Opens.**
18th October 2021	**Briefing Webinar. Registration via Eventbrite.**
12th November 2021	**Call Closes at 12 noon.**
W/C 22nd November 2021	**Panel Review of Proposals.**
W/C 29th November 2021	**Notification of Panel Decisions and Feedback.**
W/C 6th December 2021	**Project Kick-off Meetings.**
December 2021 – March 2022	**Project Work in Progress.**
25th March 2022	**All Project Work and Final Reporting Completed.**

Advanced Nuclear Skills Innovation Campus

GAMECHANGERS
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Department for Business, Energy & Industrial Strategy

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