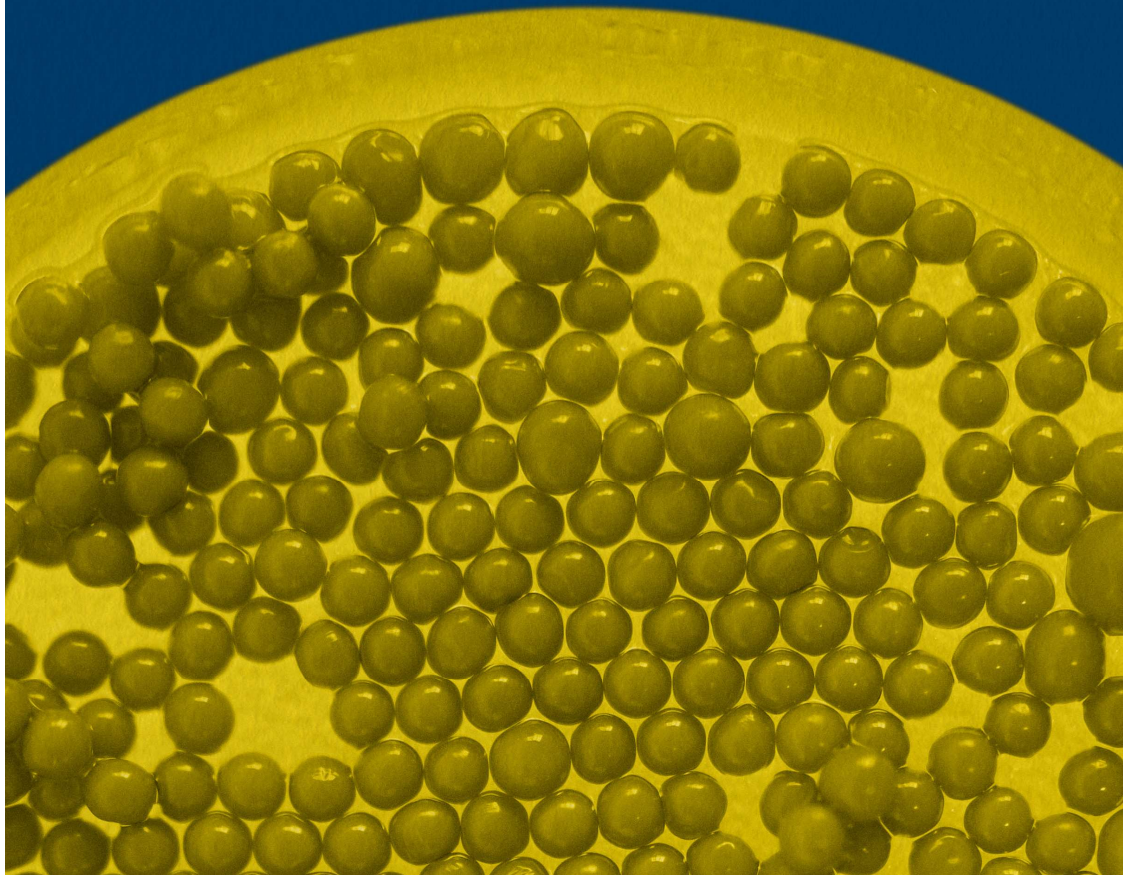
04 | Strategic Research

Leading **ground-breaking research** and partnerships to enable a UK advanced fuels and fuel cycle capability.



A flagship of NNL's Strategic Research work, the Advanced Fuel Cycle Programme (AFCP) is successfully rebuilding the UK's sovereign capabilities in the manufacture and recycling of fuels for the next wave of nuclear technologies.

Through its uniquely collaborative model, the programme unites the expertise, facilities and knowledge of over 100 organisations worldwide to help accelerate the UK's net zero ambitions, maximise domestic opportunities for jobs and growth and support the global clean energy transition.

Over the past year, AFCP has:

Delivered technical UK 'firsts' in the development and demonstration of advanced solutions, including for Coated Particle Fuels for High Temperature Gas Reactors (HTGRs);

Leveraged NNL's specialist nuclear facilities to conduct active experiments that would not be possible elsewhere in the UK and grown skills and expertise across the programme to support the future talent pipeline;

Strengthened existing relationships across industry and academia, maximising the input, skills and opportunities of all partners and continuing to ensure that investment is spread across the UK value chain;

Enabled the UK to influence global research and development by providing significant contributions to bi-lateral and multi-lateral international programmes, including with the International Atomic Energy Agency (IAEA), the OECD Nuclear Energy Agency and the US/UK Civil Nuclear Energy Research and Development (R&D) Action Plan.

Led by NNL as part of the Department for Business, Energy and Industrial Strategy's *(BEIS)* Energy Innovation Programme – now the Net Zero Innovation Programme – AFCP represents the biggest investment in future nuclear fission fuel cycle research in a generation. Further, it reflects the essential role nuclear must play in a secure, affordable, low-carbon future.

Over the past three years, AFCP has leveraged over £130million in investment across national and international programmes to drive nuclear fuel cycle innovation, ensuring we have the capabilities to underpin advanced nuclear technologies for net zero. This has involved over 100 partnerships worldwide and more than 90 in the UK alone – bringing together universities, industrial heavyweights and small and medium-sized enterprises *(SMEs)* – to pioneer new solutions and begin to establish a UK supply chain for advanced fuels development and manufacture.

Recognising the value, impact and quality of this work, in 2021 the programme received a £10million extension from government, which we have combined with over £500,000 of NNL's own Science and Technology investment in advanced fuels and fuel cycle. Through this, we have been able to dovetail priority research areas with the UK government's 2021 Net Zero Strategy. This includes greater focus on Coated Particle Fuels for HTGRs, which were announced as BEIS's Advanced Modular Reactor *(AMR)* technology of choice for demonstration by the early 2030s.

Quality

UK Foundations for a net-zero future

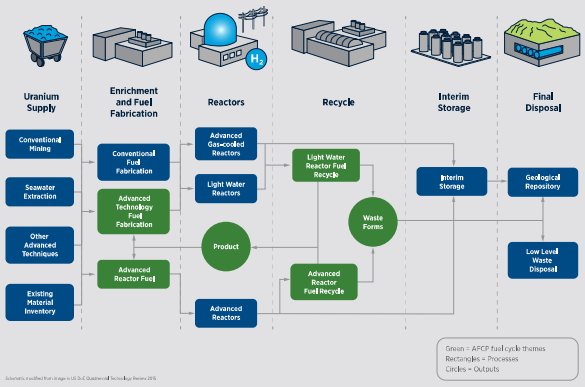
Over the past year, AFCP has re-prioritised its strategic research towards the advanced fuels that will power new HTGRs, as the UK progresses development of these technologies ready for deployment. This has been combined with a continued focus on and investment in advanced fuels for light water reactors and sustainability within the fuel cycle, recognising the importance of new products for existing reactors and maintaining our world-class capabilities in recycle science. Through ongoing trials in our unique active laboratories, we are providing credible technical options for reprocessing spent fuels that are cost-competitive with other fuel cycle options – maximising our valuable resources and continually improving processes for the future.

By growing this base of knowledge, AFCP is helping to maintain and develop a future UK fuel manufacturing capability focused on fuelling nuclear for net zero – building on the decades of success in fuelling the AGR fleet. Doing so successfully will not only unlock future export opportunities but will also retain necessary skills and talent, high-value jobs and supply chain growth for decades to come in the UK.

"I was delighted to visit the National Nuclear Laboratory at their world-leading laboratory for scientific research and innovation in the North West of England. The work they are doing to develop advanced fuels for the next generation of nuclear reactors will be essential to the UK's ambitions to build our national capabilities to secure our position as a global leader in these clean energy technologies. It is fantastic that we have a national laboratory in the NNL that is driving the key research and development we need to meet our net zero goals, whilst promoting UK skills."

Rt Hon Greg Hands MP
Minister for Energy, Clean Growth and Climate Change, 2021-2022

AFCP fuel cycle themes



Quality and talent

Building technical capability and capacity

Over the past year, AFCP has continued to deliver technical UK 'firsts', demonstrating the potential for advanced fuels and fuel cycle, and supporting the wrap-around structures which will be needed for future delivery.

This has included:

Demonstration in the UK of the technology to manufacture uranium oxide (UO_2) kernels for Coated Particle Fuels for HTGRs and installation of the scale-up manufacturing facilities required for the next stage of its development – delivered alongside the Universities of Bangor, Bristol, Lancaster and Manchester;

Production of full-length fuel cladding coating technology for Advanced Technology Fuels, working with Worcestershire-based SME Teer Coatings, to be installed on the Springfields site;

Also with Teer Coatings and Westinghouse, completion of irradiation testing on a UK advanced fuel concept completed at the Massachusetts Institute for Technology test reactor;

Demonstration of flash sintering of UO_2 fuel pellets in the UK for the first time, representing a novel technology that is faster and operates at lower temperatures than existing methods, thus providing potential cost benefits in the manufacture of a range of nuclear fuels. This work has been delivered in partnership with Lucideon, an SME based in Stoke-on-Trent, and the University of Manchester;

Increasing the technical maturity of advanced fuel recycle processes by conducting world-leading specialist scaled rig trials in NNL's active laboratories and working collaboratively with partners to build the modelling and 'non-active' base to retain our world-class capabilities in fuel recycle science;

Supporting the development of international best practice by establishing collaborations under the US/UK Civil Nuclear Energy Research and Development (R&D) Action Plan with several US national laboratories, driving advancements and efficiencies in recycle processes – including in uranium recovery – to reduce overall environmental impacts.

This ground-breaking work is enabling us to move up the technology-readiness scale and growing the UK knowledge base in these areas of research, priming the talent pipeline with higher level skills.

Judgement on technology readiness level of advanced fuel and fuel cycle areas developed as part of AFCP in the UK

(based on expert opinion from within AFCP)

The UK Advanced Fuel Cycle Programme (AFCP) (2016–2022)		**TRL at start of AFCP**	**TRL at 2022**
Accident tolerant fuels (ATF) or advanced technology fuels for light water reactors (LWRs)	High density fuels	1	3
	Coated Cladding	2	6
	SiC cladding	2	3
Coated particle fuels (CPF) for high temperature reactors (HTRs)	Kernels	3	4
	Coating	3	3
Fast reactor fuels		3	3

Partnerships

Greater impact through collaboration

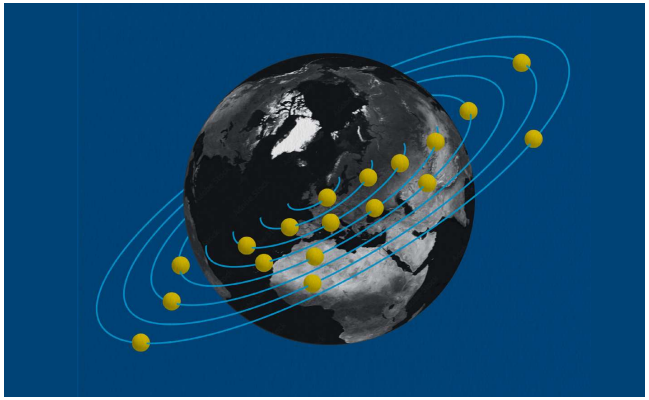
The success of AFCP to date, and the quality of its outputs, are thanks to its collaborations across leading academic, industrial and research institutions – both in the UK and globally. In leading these partnerships, we have been able to leverage our existing capabilities – the skills of our people, our decades' expertise in fuel cycle science and our specialist active facilities – to enable others to progress ideas, concepts and strategic research.

"As a work package leader within AFCP's aqueous recycle research programme, I had my first opportunity to organise and run a major project which has been hugely valuable experience – both in terms of new techniques developed in the laboratory and skills gained across the whole team. For example, we were able to train early careers researchers in plutonium active operations which are vital for maintaining alpha skills in this area of work, ensuring we are continually building expertise and capacity for the future.

"Additionally, because partnerships are at the heart of AFCP, I had the opportunity to network with a wider range of individuals and organisations from the global nuclear community. This was an excellent way to engage with international work and perspectives, share ideas and showcase AFCP's ambitions and achievements. It is fantastic to know that the programme is driving crucial research in the fuel cycle, whilst also feeding into other future projects and capabilities." *Hannah May Colledge, NNL Senior Research Technologist, Separation Science & Special Nuclear Materials*

"Through our bilateral collaboration with the UK, we hope to enhance state-of-the-art technologies that promote the unique expertise and facilities each country brings. Currently, we are collaborating on radioisotopes for use in space technologies, advanced reactor technology, advanced fuels, fuel cycle technologies, modelling and simulation, and enabling technologies. It is great to see the role of national laboratories in driving forward the collaboration in all areas. The work on fuel cycle technologies has seen real progress underpinned by the work of the US national laboratories and NNL in the UK through the U.K. Advanced Fuel Cycle Programme (AFCP)."

Andrew Griffith
Deputy Assistant Secretary for Nuclear Fuel Cycle and Supply Chain, Office of Nuclear Energy, US Department of Energy



Impact

Mapping out future systems

Alongside specific research programmes, we have also developed modelling of the whole energy landscape – looking at the projected demand for clean energy, the resourcing required to meet this and the gaps that therefore need to be filled in the UK.

Over the past year, this has contributed to several transformative reports, including:

Whole energy system modelling with Energy Systems Catapult, which enabled nuclear deployment scenarios to be produced for the first time to show the role of nuclear in a UK net zero energy system. This allowed us to develop detailed fuel cycle modelling to understand resource demand for future systems, including HTGRs;

Detailed technology development roadmaps – building on the energy system modelling – as guidance for policymakers and the wider sector;

Joint publications with the University of Manchester on the environmental and economic implications of advanced fuel cycles, providing crucial underpinning evidence for industry and policymakers to support future strategic fuel cycle decisions;

An assessment of a number of future fuel cycle scenarios using life cycle analysis *(LCA)*, working with academic partners including University College London. LCA is a method used to evaluate the environmental impact of a product through its life cycle, encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling and final disposal. Once again, this is enabling a strategic assessment of future fuel cycle decisions.

All of this modelling work is underpinned by our sophisticated modelling capabilities, created by NNL with the support of our partners – ranging from Orion, our internationally-recognised fuel cycle modelling tool, to Sim Plant, which models what future advanced fuel cycle industrial complexes could look like based on the latest underpinning technical data from AFCP experimental programmes.

Targeting 2050 and beyond

Due to the size and scale of the programme, it is impossible to highlight all the achievements and successes that have been secured so far. Further information on the work that has been undertaken and delivered through AFCP is available on the programme website.

As we look ahead, we are pleased that the importance of ongoing research and development on the future UK fuel cycle is recognised by the UK government's Net Zero Research and Innovation Framework, as essential to achieving net zero by 2050. Building on this, however, we recognise our role as a national laboratory stretches further than this key milestone. So, whilst we continue to drive the research needed to fill current gaps in UK technical expertise, using our extensive technical and modelling capability, we are looking at the impact and opportunity of advanced fuels and fuel cycle for future generations. This means considering what, for example, 2100 could look like and enabling strategic decision-making in support of the future role of nuclear in mitigating climate change.

"My research team has had a long and very productive relationship with the scientists, technologists and engineers at NNL – a relationship that has had a major influence on our research strategy for more than two decades. However, it was ACFP that allowed us to take that relationship, the work produced and its impact, to another level. It is in the area of product finishing where the work has been most rewarding and probably made the most significant contribution to the generation of new intellectual property for the UK. Through the programme, innovative technologies have been developed and nuclear-relevant skills inculcated in more than a dozen researchers. Driving step changes in technology and capability, AFCP has been a real UK success story."

Professor Colin Boxall
The Lloyd's Register Foundation Chair in Nuclear Engineering, Lancaster University