U.S. Department of Energy
Advanced Research Projects Agency – Energy (ARPA-E)

Request for Information (RFI)
DE-FOA-0003011
on Nuclear Hybrid and Non-Electricity Energy Systems

Introduction

The purpose of this RFI is to solicit input for a potential future ARPA-E research program focused on the integration of nuclear reactor facilities into industrial processes to enable their provision of carbon-free heat and/or power. ARPA-E is seeking information regarding transformative and implementable technologies to facilitate this integration.

Background

Traditionally, nuclear energy produces electricity via the conversion of fission reactions to heat, to mechanical energy, and finally to electricity. As a fundamentally clean, zero-carbon source of heat, nuclear energy offers a path to decarbonization in hard-to-abate industries where heat, especially high-quality heat, is a major energy input.

Historically, there have been applications of nuclear heat outside of electricity generation, such as desalination and district heating, but with the imminent deployment of advanced reactors (ARs), the opportunity to widen the application scope is expanding. ARs are distributed bi-axially in terms of thermal and electric output and temperature. Capacity ranges from a single megawatt (MW) for microreactors, to a few tens or low hundreds of MWs for small modular reactors (SMRs), and even up to gigawatt scale. Operating temperatures range from 300 up to 900°C.

The recent focus on decarbonization and sustainability has created new opportunities for novel combinations of existing, or emerging, technologies in new sector applications. Industrial processes, which generate 24% of our nation's greenhouse gas emissions[1], remain difficult to decarbonize due to their large heat requirements. The potential to integrate advanced nuclear reactors with industrial processes offers a potential pathway to reduce or eliminate carbon emissions from this sector.

Various industries, such as oil and gas, petrochemicals, and steel and aluminum production, that have significant heat and power needs, can potentially couple their processes to nuclear reactors to drive sector decarbonization. Coupling can be achieved in multiple forms, with some example configurations listed below:

- direct provision of heat from the nuclear reactor via heat exchanger

[1] EPA, "Sources of Greenhouse Gas Emissions." 2022

- combined heat and power from a single reactor, with heat provided via heat exchanger, separate from the power cycle
- combined heat and power from a single reactor through steam extraction from the power cycle
- modularized heat and power from separate reactors.

This coupling will require both technical and commercial innovation in areas such as process co-design and co-optimization, sensors, controls, and interface component development -- while meeting reliability, availability, and maintainability metrics cost effectively. Regulatory regime co-existence, ownership structure, insurance framework, site development, and co-location are areas where new business models might be needed.

This request for information aims to gather information from interested and relevant stakeholders on general, technical, technology-to-market, and regulatory issues related to the coupling of nuclear heat and power to industrial processes beyond pure power production.

Current Hypotheses/Top Level

1. Hypothesis 1: Nuclear Heat or Combined Heat and Power (CHP) is a viable route to decarbonizing industrial processes.
2. Hypothesis 2: Regulatory approvals can be obtained on a predictable basis.
3. Hypothesis 3: Fuel cycle (including waste processing & repository) can be reliably and economically defined and implemented.
4. Hypothesis 4: Warranty protection and insurability can be established.

Please carefully review the REQUEST FOR INFORMATION GUIDELINES below. Please note, in particular, the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

Purpose and Need for Information

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

REQUEST FOR INFORMATION GUIDELINES

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential.**

Depending on the responses to this RFI, ARPA-E may consider the rapid initiation of one or more funded collaborative projects to accelerate along the path towards commercial deployment of the energy technologies described generally above.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on Thursday, March 30, 2023.** Emails should conform to the following guidelines:

• Please insert "Responses for Nuclear Hybrid and Non-Electricity Energy Systems RFI" in the subject line of your email, and include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center (FFRDC), government-owned/government-operated (GOGO), etc.), email address, telephone number, and area of expertise in the body of your email.
• Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
• Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential processes.
• Where possible, please provide the question number and question text you are responding to.

Program Framing

1. What are the advantages and disadvantages of alternative technologies for decarbonized heat compared with nuclear + heat?
    a. Fossil fuels with carbon capture?
    b. Hydrogen?
    c. Concentrated Solar Power?
    d. Geothermal?
    e. Electricity-based options? (Induction, resistive heating)
2. How many industrial facilities and at what size need to be decarbonized? What is the target timeline for such decarbonization efforts? Where are these facilities located?
3. How many new facilities are expected in the next 20 years that would represent new growth to your industry?
4. What are major hurdles/risks to coupling non-electricity processes to nuclear heat? (Reliability, regulations, insurability, financing, siting, etc.)
5. What are the largest outstanding questions (technical, regulatory, technology-to-market) regarding the use of nuclear-origin heat in industry?

Technology

6. Beyond innovations in reactor development, what are potential major technical innovations needed to utilize nuclear energy for non-electricity applications?
    a. What sector-specific innovations are needed to couple nuclear energy to process heat applications? (heat exchangers, controls, materials, etc.)
    b. Please define the sector and the sector-specific innovations and requirements.
7. What are temperature and load ranges (power and/or heat) of interest for coupling industrial processes to nuclear heat? Is there an optimal industry market sector for nuclear heat based

upon microreactor, SMR, or large reactor working conditions and process heat thermal requirements with respect to temperature and load ranges?

8. What are facility footprint requirements for industrial plants and nuclear facilities? Please specify the type of industrial plant or reactor.
    a. Are there specific standoff distances?
    b. What are the longest pipe runs for fluid flow that are acceptable?
9. For technology development and deployment at the integrated system level, what are the typical demonstration sequence, timelines, and scales (lab, pilot, demo)? What is the minimum scale for nuclear heat and power provision to test viability?
10. Maintenance cycles for nuclear heat sources might need to align with the process plant to ensure economically acceptable availability. What are minor and major service intervals for process facilities?
11. What type of process and operational flexibility do industrial processes and nuclear reactors have regarding uptime, heat duty, etc.? What process R&D could support decreasing the temperature of industrial processes to facilitate the utilization of lower temperature heat?
12. What are current construction timelines for CHP facilities? How many facilities is a given entity responsible for building over a five-year period?
    a. How often do delays occur in construction and how long are delays when they occur?
    b. What are the largest sources of delays?
    c. How have technology, supply chain, or factors evolved to minimize (or increase!) construction delays?
    d. How much is off-site manufacturing leveraged to support CHP construction?
13. How much does a CHP facility cost and how is this financed? Please provide on a normalized basis, e.g., $/kWh, thermal or electric.
14. What is the current state-of-the-art for digital engineering technologies for process modeling, construction, and facility lifecycle management that enable large power and industrial plant construction?
15. How many software packages and how much time would be required to develop a full 7D (spatial, time, cost, energy balance, facility lifecycle operations and management), cloud-based, high-fidelity model of a nuclear facility providing heat to an industrial process? This includes to construction timelines, cost information, P&IDs, component-level specifications, and would provide the ability to model process heat from one facility to another.
    a. What would be the computational resources associated with such a model?
    b. Would the computational need be so substantive that the model would be functionally useless?
16. What computational libraries, software packages would be necessary across nuclear, non-nuclear, and other stakeholders to develop the digital effort associated with high fidelity process or construction models?

Technology-to-Market

17. What are the major sectors/areas of opportunity to couple nuclear to non-electricity uses? Can we quantify the market opportunity by sector (hydrocarbon cracking & petrochemical, metals, ammonia, cement, ceramics, glass, pulp & paper, food & beverage, …). Who might be the first customers?

18. What is the current/projected price for zero carbon heat as a function of temperature, pressure, medium, mass flow, and special requirements (e.g., purity) for different/your processes?
19. What are cost targets for heat/electricity input? What is an acceptable price premium relative to fossil heat?
20. What are major hurdles to co-locating nuclear reactors with process heat applications? What siting limitations need to be considered? How would insurance be structured for an integrated nuclear-industry facility?
21. What are potential business models for coupling nuclear reactors with process heat applications? (e.g., build-own-operate; own-operate; contract operator; off-take)
22. What are potential business models for coupling nuclear reactors with process heat applications? (e.g., build-own-operate; own-operate; contract operator; off-take;) What would the ideal business model be?
23. Are there any special supply chain or procurement requirements for your industry? For example, are references required for capital equipment?
24. What type of heat flexibility (both in temperature and flux) is required?

Regulatory

25. What are the relevant regulatory bodies (sector specific and general) and regulatory considerations to coupling nuclear reactors to industrial processes?
26. What are the liability and/or insurability ramifications to the industrial plant in co-locating with a nuclear reactor?