Notice of Intent No. DE-FOA-0001577

Notice of Intent to Issue
Funding Opportunity Announcement No. DE-FOA-0001578

The Office of Energy Efficiency and Renewable Energy (EERE) intends to issue, on behalf of the Advanced Manufacturing Office (AMO), a Funding Opportunity Announcement (FOA) entitled "Modular Chemical Process Intensification Institute for Clean Energy Manufacturing."

This FOA supports the establishment of a Clean Energy Manufacturing Innovation Institute on modular chemical process intensification. Modular chemical process intensification represents an emerging opportunity for processing industries in the U.S. manufacturing sector to improve energy efficiency, reduce feedstock waste, increase scalability and improve productivity by merging and integrating separate unit processes (mixing, reactions, separation) into single modular hardware elements of reduced size, higher efficiency and scalability. The resulting Clean Energy Manufacturing Innovation Institute is expected to be a Department of Energy supported Institute participating in the interagency National Network for Manufacturing Innovation (NNMI) program.[1,2]

Process intensification was identified as a key opportunity for innovation as an advanced manufacturing for clean energy technology in the Department of Energy's Quadrennial Technology Review (QTR).[3] EERE openly engaged a wide array of external stakeholders from industry (large as well as small/medium), national laboratories, institutions of higher education, and other government agencies in a Multi-Topic Workshop in October 2014 that included a section on Process Intensification as well as a focused Workshop in September 2015 on Chemical and Thermal Process Intensification.[4,5] EERE also participated in an inter-agency workshop hosted by the National Science Foundation (NSF) to identify foundational research challenges and opportunities related to Process Intensification.[6] EERE partnered with National Institute of Science and Technology (NIST) through the Advanced Manufacturing National

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[1] National Network for Manufacturing Innovation (NNMI) program, https://www.manufacturing.gov/nnmi/

[2] President's Council of Advisors on Science and Technology, "Accelerating U.S. Advanced Manufacturing" October 2014.

[3] U.S. Department of Energy, Quadrennial Technology Review (QTR), Chapter 6, 2015. http://energy.gov/quadrennial-technology-review-2015

[4] Multi-Topic Workshop 2014 Report, http://energy.gov/eere/amo/downloads/manufacturing-innovation-multi-topic-workshop

[5] Process Intensification Workshop 2015 Report, http://energy.gov/eere/amo/downloads/process-intensification-workshop-september-29-30-2015

[6] NSF Process Intensification Workshop (2014). http://www.aiche.org/sites/default/files/docs/conferences/pi_workshop_report_11-10_a-2-final.pdf

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Program Office (AMNPO) on the Advanced Manufacturing Technology (AmTech) program to supports the development of several industry driven roadmaps relevant to modular chemical process intensification, including sector-specific and cross-cutting technology roadmaps.[7]

With a Modular Chemical Process Intensification Institute for Clean Energy Manufacturing, EERE seeks to support applied research, development, demonstration, and transition to industry of the resulting advanced equipment and methods and new technical capabilities related to the modularization, multifunctional combination and system integration of highly efficient reaction, separation, mixing, and heating/cooling in manufacturing processes.[8,9,10,11] Modular chemical process intensification has significant potential for impact in multiple industrial sectors, including energy intensive industries (Chemicals, Refining, Pulp/Paper, Primary Metals, Food, etc.);[12,13] modularized and decentralized manufacturing (On-site Natural Gas Upgrading, Distributed Biorefining, etc.);[14,15,16,17,18] and cross-cutting industries within DOE mission

[7] NIST Advanced Manufacturing Technology (AmTech) program. (through 2015) http://nist.gov/amo/amtech
[8] D.Reay, C.Ramshaw, A.Harvey "Process Intensification: Engineering for Efficiency, Sustainability and Flexibility" IChemE, (2013).
[9] A.Stankiewicz, J.A.Moulijn "Process Intensification: Transforming Chemical Engineering" Chemical Engineering Progress 96:1, 22-33 (2000).
[10] J-C.Charpentier "In the Frame of Globalization and Sustainability, Process Intensification, A Path to the Future of Chemical and Process Engineering (molecules into money)" Chemical Engineering Journal 134:1 84-92 (2007).
[11] F.M.Dautzenberg, M.Mukherjee "Process Intensification Using Multifunctional Reactors" Chemical Engineering Science 56:2 251-267 (2001).
[12] Energy Analysis by Sector, (including 2015) Bandwidth Studies of Energy Intensive Industries http://energy.gov/eere/amo/energy-analysis-sector
[13] F.Friedler "Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction" Applied Thermal Engineering 30:16 2270-2280 (2010)
[14] ARPA-E REMOTE Program. http://arpa-e.energy.gov/?q=arpa-e-programs/remote
[15] D.A.Wood, C.Nwaoha, B.F.Towler "Gas-to-Liquids (GTL): A Review of an Industry Offering Several Routes for Monetizing Natural Gas" Journal of Natural Gas Science and Engineering 9 196-208 (2012).
[16] W.M.Jack "Scaling Laws and Technology Development Strategies for Biorefineries and Bioenergy Plants" Bioresource Technology 100:24, 6324-6330 (2009)
[17] J.P.M.Sanders, J.H.Clark, G.J.Harmsenc, H.J.Heeres, J.J.Heijnend, S.R.A.Kerstene, W.P.M.van Swaaij, J.A.Moulijn "Process Intensification in the Future Production of Base Chemicals from Biomass", Chemical Engineering and Processing: Process Intensification 51 117-136 (2012).
[18] "Equipment Design and Cost Estimation for Small Modular Biomass Systems, Synthesis Gas Cleanup, and Oxygen Separation Equipment, Task 1: Cost Estimates of Small Modular Systems", Nexant Inc., NREL/SR-510-39943 (2006)

(Carbon-Capture, Tank Waste Processing, Helium-4 Separation, Wastewater Treatment, etc.).[19,20,21,22,23,24,25,26]

Modular chemical process intensification is framed around four technical principles: maximized effectiveness of intramolecular and intermolecular interactions; uniformity of molecular scale experience through process modules; optimized driving force for reactions at all scales and surface areas at relevant scales within modules; and maximized synergistic chemical and thermal effects throughout modules to reduce energy, reduce carbon intensity and improve feedstock utilization on an economically competitive basis.[27] Modular chemical process intensification also represents an opportunity to transform industrial process economics from a scale-up paradigm (where cost declines at a 2/3 scaling law) to a scale-out approach, where the learning from the production of multiple parallel modules leads to cost-effective economics.[28,29,30] As a result, it is expected that new technologies for the manufacturing of chemical process modules and components themselves might also be explored in an Institute.

It is recognized that high fidelity modeling and simulation are essential to advancement of modular chemical process intensification and it is expected that a proposed Institute might leverage (on an open and fair basis), existing activities in the use of High Performance Computing (HPC) in manufacturing applications.[31] Similarly, it is recognized that advanced

[19] A.Qi, B.Peppley, K.Karan, "Integrated Fuel Processors for Fuel Cell Application: A Review" Fuel Processing Technology 88:1 3-22(2007)

[20] J.Klaehn, E.Peterson, C.Orme et. al."Water-Gas-Shift Membrane Reactor for High-Pressure Hydrogen Production: A Comprehensive Project Report (FY 2010 – FY 2012)" Report Number: INL/EXT-12-27377 Under Contract DE-AC07-05ID14517 (2013)

[21] E.Favre "Membrane Processes and Post-Combustion Carbon Dioxide Capture: Challenges and Prospects", Chemical Engineering Journal 171:3 782-793 (2011)

[22] D.G.Vlachos, S.Caratzoulas "The Roles of Catalysis and Reaction Engineering in Overcoming the Energy and the Environment Crisis", Chemical Engineering Science 65:1 18-29 (2010)

[23] J.Flouret, Y.Barré, H.Muhr, E.Plasari "Design of an Intensified Co-precipitation Reactor for the Treatment of Liquid Radioactive Wastes", Chemical Engineering Science, 77 176-183 (2012)

[24] Helium Stewardship Act (2013), https://www.congress.gov/113/plaws/publ40/PLAW-113publ40.pdf

[25] B.VanDerBruggen, E.Curcio, E.Drioli "Process Intensification in the Textile Industry: the Role of Membrane Technology" Journal of Environmental Management, 73:3 267-274 (2004)

[26] US. Department of Energy, "The Water-Energy Nexus: Challenges and Opportunities" (2014) http://energy.gov/downloads/water-energy-nexus-challenges-and-opportunities

[27] T.VanGerven, A.Stankiewicz "Structure, Energy, Synergy,Time – The Fundamentals of Process Intensification" Ind. Eng. Chem. Res. 48, 5 (2009).

[28] A.Qi, B.Peppley, K.Karan, "Integrated Fuel Processors for Fuel Cell Application: A Review" Fuel Processing Technology 88:1 3-22 (2007)

[29] D.Boysen "Modular Chemical Processes: A Revolution in Process Technology to Capture America's Natural Gas Opportunity" Gas Technology Institute (2015). https://www.biorenew.iastate.edu/files/2015/05/Modular-Chemical-Processing.pdf

[30] C.Bramsiepea, S.Sievers, T.Seifert, G.D.Stefanidis, D.G.Vlachos, H.Schnitzer, B.Muster, C. Brunner, J.P.M.Sanders, M.E. Bruins, G.Schembecker "Low-Cost Small Scale Processing Technologies for Production Applications in Various Environments—Mass Produced Factories" Chemical Engineering and Processing: Process Intensification 51 32-52 (2012)

[31] High Performance Computing for Manufacturing (HPC4MFG), https://hpc4mfg.llnl.gov/

sensors, process controls and communication platforms are essential to realizing modular chemical process intensification for real-time operation and it is expected that a proposed Institute might leverage (on an open and fair basis), a pending Smart Manufacturing Institute, as well as other Institutes in the National Network for Manufacturing Innovation (NNMI) program.[32,33] Plans for partnership and engagement with these two activity areas (without duplicating efforts) would be expected as a part of any Institute management plan, including partnerships through the NNMI.[34]

While some elements of modular chemical process intensification technology exist in some form and level of maturity today, the scale of the required industry collaboration and development needed to advance the enabling technologies, test-bed platforms, and widespread cost-effective adoption of these technologies is beyond the scope of individual private sector organizations (particularly for small- and medium-sized enterprises). Global leadership in technology development and workforce training is expected to result from the development of modular chemical process intensification in a public-private partnership with the U.S. manufacturing enterprise, resulting in significant positive impact on the U.S. economy and the overall state of domestic manufacturing, while reducing energy consumption and greenhouse gas emissions (GHG) in energy-related manufacturing industries, while creating new business opportunities for small and medium sized enterprises.

It is anticipated that the FOA may include, but is not limited to, the following Areas of Interest:

- Applied research, development and demonstration of methods, tools, technical know-how and equipment for modularly intensified chemical processes, including new approaches to combining reactions with mass and thermal transport operations; alternatives to thermal distillation; lower cost, higher temperature membranes for separation processes; scaling and development of new catalyst materials for chemical reaction modules, and new methods of producing complex structures for modular components (3D printing) enabling advanced heat exchangers, mixers and microchannel reactor designs.

- Development and test-bed demonstration of intensified chemical modules in integrated processes, for example: innovative modules for the generation of syngas from natural gas or biomass derived methane might be integrated with an intensified catalytic

[32] DOE Funding Opportunity Announcement: DE-FOA-0001263 Manufacturing Innovation Institute for SMART Manufacturing: Advanced Sensors, Controls, Platforms, and Modeling for Manufacturing, https://eere-exchange.energy.gov/#FoaIda7d7bd9b-c3b2-45c5-8111-55384aaf6393
[33] National Network for Manufacturing Innovation (NNMI) Institutes, https://www.manufacturing.gov/nnmi-institutes/ (2016)
[34] National Network for Manufacturing Innovation (NNMI) Preliminary Design, NSTC/PCAST (2013) https://www.manufacturing.gov/files/2015/12/NNMI_prelim_design.pdf

reaction / separation module to test the potential for efficient and scalable gas-to-liquids, at sufficient scale to demonstrate economic viability. Development and test-bed of the physical hardware provides an opportunity to also demonstrate complementary information technology related innovations in sensors, controls, and data algorithms (Digital and/or Smart Manufacturing) developed with NNMI Institute partners as scalable and secure cyber-physical systems.

- Module manufacturing development and demonstration, including applied research and development of automated and low-cost manufacturing approaches for individual reactor modules, enabling cost reduction through economies of mass manufacturing and parallelization of modules in integrated systems.
- Applied research, development and knowledge dissemination of cross-cutting technologies that include alternative approaches to energy input (electro-magnetic technology, direct energy technologies, rotational buoyancy gradient separation, etc.) for process heating and driving forces; hybrid or multifunctional reactions and separations; enabling technologies to address fouling and degradation of membranes as well as the regeneration of catalysts; development of harsh service environment materials for process intensified hardware; advanced simulation, processing and data management tools to maximize design and implementation productivity of modular systems.
- Development of open-architecture, open-standard, and open-source (when possible) software and design tools for design and application of modular chemical process intensification technology that are applicable across multiple and diverse industries.
- Integration of technology and workforce development from all the areas of interest would be expected to make a significant contribution to process intensification adoption.

EERE envisions awarding a single financial assistance award in the form of a cooperative agreement. It is anticipated that the award will include approximately $70 million of federal funding and require a minimum non-federal cost share of 50% of the total project costs. The estimated period of performance for the award will be 5 years with the goal of the Institute to be self-sustaining by the end of the award period.

This Notice is issued so that interested parties are aware of the EERE's intention to issue this FOA in the near term. All of the information contained in this Notice is subject to change. EERE will not respond to questions concerning this Notice. Once the FOA has been released, EERE will provide an avenue for potential Applicants to submit questions and provide an optional teaming list.

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EERE plans to issue the FOA on or about May 2016 (with the intention of competitively selecting an awardee in calendar year 2016) via the EERE Exchange website https://eere-exchange.energy.gov/. If Applicants wish to receive official notifications and information from EERE regarding this FOA, they should register in EERE Exchange. When the FOA is released, applications will be accepted only through EERE Exchange.

In anticipation of the FOA being released, Applicants are advised to complete the following steps, which are **required** for application submission:

- Register and create an account in EERE Exchange at https://eere-exchange.energy.gov/. This account will allow the user to register for any open EERE FOAs that are currently in EERE Exchange. It is recommended that each organization or business unit, whether acting as a team or a single entity, use only one account as the contact point for each submission.

  Questions related to the registration process and use of the EERE Exchange website should be submitted to: EERE-ExchangeSupport@hq.doe.gov
- Obtain a Dun and Bradstreet Data Universal Numbering System (DUNS) number (including the plus 4 extension, if applicable) at http://fedgov.dnb.com/webform
- Register with the System for Award Management (SAM) at https://www.sam.gov. Designating an Electronic Business Point of Contact (EBiz POC) and obtaining a special password called an MPIN are important steps in SAM registration. Please update your SAM registration annually.
- Register in FedConnect at https://www.fedconnect.net/. To create an organization account, your organization's SAM MPIN is required. For more information about the SAM MPIN or other registration requirements, review the FedConnect Ready, Set, Go! Guide at https://www.fedconnect.net/FedConnect/Marketing/Documents/FedConnect_Ready_Set_Go.pdf
- Register in Grants.gov to receive automatic updates when Amendments to a FOA are posted. However, please note that applications will not be accepted through Grants.gov. http://www.grants.gov/. All applications must be submitted through EERE Exchange.