Receivers and Reactors for Concentrating Solar-Thermal Power Plants and Solar Industrial Process Heat

DATE: January 22, 2024
SUBJECT: Request for Information (RFI)

Description

This request for information (RFI) is intended to inform the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) on specific research, development, and demonstration opportunities to enable near-term deployment of receivers for concentrating solar-thermal power (CSP) plants, and reactors for CSP industries.

Background

To build a clean and equitable energy economy and address the climate crisis, SETO invests in innovative research, development, and demonstration (RD&D) projects that work to drive down costs of solar technologies and develop next-generation products ready for commercialization. This RFI seeks information to help advance the goals of achieving carbon-pollution-free electricity by 2035, and to "deliver an equitable, clean energy future, and put the United States on a path to achieve net-zero emissions, economy-wide, by no later than 2050."[1] DOE is committed to pushing the frontiers of science and engineering, catalyzing clean energy jobs through research, development, demonstration, and deployment (RDD&D), and ensuring environmental justice and inclusion of underserved communities.

CSP is unique as a renewable energy source that can be coupled to long-duration thermal energy storage (TES) to drive a high efficiency power cycle. As longer durations of energy storage are needed to enable a clean electricity grid, there becomes a stronger case for the value of CSP. To successfully fill this role, the cost of CSP must continue to decline through a generational technology shift. By 2030 SETO targets a CSP levelized cost of electricity (LCOE) of $0.05 per kilowatt-hour (kWh) enabled in part by a power cycle which is more efficient and cheaper than present day steam Rankine cycles.

The state of art in power generation uses molten salt towers, with temperatures up to 540°C. Research is ongoing using DOE funding on Generation 3 CSP (Gen3) technology with specific targets on power cycle temperature at ≥715°C and cycle efficiency ≥50%, with a LCOE of <$0.05/kWh. Particle technology demonstration at outlet temperatures ≥700°C is planned to be

[1] Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," January 27, 2021.

demonstrated using Gen3 technology at Sandia National Laboratories[2]. In parallel, and with DOE funding, Heliogen is developing a next-generation CSP plant integrating a particle receiver with thermal energy storage at temperatures up to 750°C and a supercritical carbon dioxide (sCO_2) power block at Mojave, California.[3]

Beyond power applications, the use of concentrating solar-thermal (CST) for low and high temperature process heat applications is another area of interest in this RFI. There are two separate areas of interests in this RFI.

- The first is low temperature steam generation and heating applications for all process industries. DOE's Industrial Decarbonization Roadmap[4] suggests that low and medium temperature process steam and heating applications below 300ºC represents more than 50% of industrial energy use and CO_2 emissions. Current state-of-the-art solar heating technologies such as parabolic trough, dish concentrators and Fresnel are well developed and can be used for <300ºC process heat for industry.
- The second range of process heat application is ≥300ºC for steel, cement, chemical and refining industries outlined in the roadmap can be further subdivided into three regimes, namely, 300-550ºC, 550-1,100ºC, and > 1,100ºC. Current technologies such as molten salt tower and trough, can supply heat to process industries below ≤550ºC. Research in Gen3 technologies using particles and gas have shown them to be capable of supplying heat up to 800ºC; beyond which, the current technology has not been demonstrated.

Significant technological challenges remain for high temperature process heat applications, especially with respect to the development of receivers that can attain the required thermal efficiency at temperatures. For the next generation receivers at high temperatures, there are questions regarding the receiver efficiency for open receivers such as falling particle receivers and centrifugal receivers; ability to scaleup such open aperture receivers to commercial scale; ability to manufacture balance of receiver systems such as tower, lifts, particle transport systems, flow control valves that can scale up within cost targets.

Pertaining to industrial process heating (IPH) systems < 300ºC, the technology is well-developed, but the cost reduction necessary to meet the current state of the art using natural gas-based steam boilers is in question. In addition, TES systems necessary to supply heat/steam

[2] https://www.energy.gov/eere/articles/doe-breaks-ground-concentrating-solar-power-pilot-culminating-100-million-research, https://www.energy.gov/eere/solar/generation-3-concentrating-solar-power-systems-gen3-csp
[3] https://www.heliogen.com/press-releases/heliogen-announces-major-milestones-in-concentrated-solar-technology-project-with-woodside-energy-and-u-s-department-of-energy/
[4] https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

at < 300 ^{o}C, on a near continuous basis, are not readily available for procurement from suppliers.

Regarding receivers/reactors for use in CSP-based IPH technologies, there is uncertainty regarding the use of solar-thermal heat in on-sun receiver/reactor technologies. While this RFI is focused on both on-sun receiver reactors and reactors, heated by off-sun thermal energy storage systems, the design and development of solar reactors is still in its infancy. Beyond the existing reactor designs, based on current power industry applications, the need for high temperature process heat opens the design space to receivers normally not considered for the power industry, such as beam down systems.

Finally, DOE seeks insight into the specific challenges preventing more widespread deployment of high temperature receivers for CSP applications. For CST systems useful for process heating applications, the application space varies from 150-200^{o}C (steam) applications which form the majority of IPH applications, to as much as 1,500^{o}C. High temperature receivers that can supply heat > 900^{o}C are not available, as material issues and receiver efficiency losses limit the applicability of traditional receiver designs.

Purpose

This RFI solicits feedback from industry, academia, research laboratories, government agencies, and other stakeholders on three separate categories, grouped by receiver exit temperatures:

- Category A: High temperature receivers for CSP applications (≥650^{o}C)
- Category B: Low temperature (<300^{o}C) CST receivers for IPH applications
- Category C: High temperature (≥300^{o}C) CST receivers and reactors for IPH applications

Disclaimer and Important Notes

This RFI is not a Funding Opportunity Announcement (FOA); therefore, EERE is not accepting applications at this time. EERE may issue a FOA in the future based on or related to the content and responses to this RFI; however, EERE may also elect not to issue a FOA. There is no guarantee that a FOA will be issued as a result of this RFI. Responding to this RFI does not provide any advantage or disadvantage to potential applicants if EERE chooses to issue a FOA regarding the subject matter. Final details, including the anticipated award size, quantity, and timing of EERE funded awards, will be subject to Congressional appropriations and direction.

Any information obtained as a result of this RFI is intended to be used by the Government on a non-attribution basis for planning and strategy development; this RFI does not constitute a formal solicitation for proposals or abstracts. Your response to this notice will be treated as information only. EERE will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. EERE will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that EERE is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind EERE to any further actions related to this topic.

Confidential Business Information

Pursuant to 10 CFR 1004.11, any person submitting information that he or she believes to be confidential and exempt by law from public disclosure should submit via email, postal mail, or hand delivery two well-marked copies: one copy of the document marked "confidential" including all the information believed to be confidential, and one copy of the document marked "non-confidential" with the information believed to be confidential deleted. Submit these documents via email or on a CD, if feasible. DOE will make its own determination about the confidential status of the information and treat it according to its determination.

Evaluation and Administration by Federal and Non-Federal Personnel

Federal employees are subject to the non-disclosure requirements of a criminal statute, the Trade Secrets Act, 18 USC 1905. The Government may seek the advice of qualified non-Federal personnel. The Government may also use non-Federal personnel to conduct routine, nondiscretionary administrative activities. The respondents, by submitting their response, consent to EERE providing their response to non-Federal parties. Non-Federal parties given access to responses must be subject to an appropriate obligation of confidentiality prior to being given the access. Submissions may be reviewed by support contractors and private consultants.

Request for Information Categories and Questions

Category A: High temperature receivers for CSP applications (≥650^{o}C)

1. Particle receivers have been developed for high temperature applications, and work is in progress to test high temperature, open aperture, falling particle and centrifugal receivers. Currently, DOE is funding two demonstration-scale facilities and associated research into open aperture falling particle receiver[5] at 2 thermal megawatt (MW_{th}) scale; and 14 MW_{th} scale centrifugal receivers [6].

[5] https://energy.sandia.gov/programs/renewable-energy/csp/current-research-projects/gen-3-particle-pilot-plant-g3p3/

[6] https://www.heliogen.com/press-releases/heliogen-announces-major-milestones-in-concentrated-solar-technology-project-with-woodside-energy-and-u-s-department-of-energy/

1.1. Falling particle system scaleup and research/testing plan: For open aperture free falling particle receivers, what should the focus of research and scaleup funding from DOE and industry be? In the order of priority, what activities should DOE conduct to enable scaleup of the particle receiver to ~50 MW_{th} scale that can attain receiver efficiency sufficient to enable DOE goals of LCOE?
1.2. Component risk amelioration: In order of priority, what sub-components of a free-falling particle receiver are most in need of de-risking to improve performance (receiver efficiency) and reliability?
1.3. Balance of plant systems: What research in the balance of plant systems (high temperature lifts, particle mixing and horizontal/vertical conveying systems) would be needed, in the order of priority, to de-risk the particle CSP systems? What available systems and designs can be reused from existing commercial industries.
1.4. Particle metering systems: What research in particle control systems, such as high temperature valves, flow control valves, and metering systems should DOE prioritize to enable high temperature CSP systems?
1.5. Centrifugal receiver scaleup: Focusing on centrifugal receivers, what should the focus of research and scaleup funding from DOE and industry be? In the order of priority, what activities should DOE conduct to enable scaleup of the receiver to ~50 MW_{th} scale that can attain receiver efficiency sufficient to enable DOE goals of LCOE?
1.6. Component risk amelioration: In order of priority, what sub-components of a centrifugal receiver are most in need of de-risking to improve performance (receiver efficiency) and reliability?
1.7. Photovoltaic (PV) hybridization: High-capacity factor solar plants using a combination of photovoltaics (PV) and CSP to charge TES and directly produce electricity may have a techno economic advantage over a CSP only plant. What research in PV-based particle heating systems, particle mixing, and system development are needed to develop such systems with particle-based TES?
1.8. Particle losses and particulate matter (PM)-10/2.5 control: For open aperture receivers, particle losses through the open aperture, and particle attrition through the particle loop are concerns that contribute to the high cost of particle systems. What research should be funded to measure and control particle losses and PM emissions?
1.9. Particle receivers beyond falling or centrifugal aperture designs: Designs that confine particles, and closed aperture receivers have not been widely explored. What research is needed for closed aperture particle receivers, to enable meeting lifetime requirements and receiver efficiency needs?

2. Ancillary research for towers: Receive tower construction forms the critical path in the plant construction schedule. Cost reduction and simplification of tower design, eliminating the need for supporting bins and heat exchangers, can lead to very simplified steel, hybrid, and

concrete tower designs. How can tower design be simplified, and schedule time reduced to achieve a $30 per thermal kilowatt($kW_{th}$) cost target? What experience from wind tower and telecom tower construction can be used to enable standardized design and rapid construction of towers?

3. Teaming: With respect to teaming for both commercial impact and the Justice40 Initiative[7], and near-term opportunities to deploy Gen 3 particle CSP plants, what opportunities exist to significantly impact DOE's diversity, equity, and inclusion goals? How could DOE better facilitate impact?

4. Gas receivers are of interest for both power generation and high temperature industrial applications for temperatures of ≥650°C.
   4.1. Channeled gas receivers: Micro-channeled or 3D printed receivers have been funded by DOE for both, reactor, and receiver applications. Scaleup and lifetime/reliability are crucial limitations. What research activities are needed to de-risk, scaleup and test such receivers, and address lifetime concerns?
   4.2. Volumetric air receivers: Volumetric air, passing through a porous volumetric absorber, which is directly irradiated by the concentrated solar radiation, has been the most studied configuration of gas receivers. In both, open and closed configurations, due to low heat transfer coefficient of air, and parasitic losses, the scaling up of air receivers has not proven successful. What further research can enable air receiver operation for power applications that can meet receiver efficiency requirements and lead to LCOE of $0.05 / kW_e? For chemical reactor applications, what research is needed to establish air receivers as a source of heat for Levelized Cost of Heat (LCOH) targets of $0.02-0.03/ kW_{th}?
   4.3. Tubular gas receivers: Traditionally, gas has been confined inside tubes for reactor applications. However, the low heat transfer inside the tubes and lifetime issues due to high wall temperatures. It has been difficult to develop gas receivers for applications. What research and development are feasible to enable tubular gas receivers?

5. SETO has a stated goal[8] of reducing high temperature receivers below $120/kilowatt electric ($W_e$). What scaled up demonstration efforts would be needed to improve materials and manufacturing readiness level to attain such goals?

6. What should be the focus of SETO research, regarding scaleup of high temperature receivers for power applications, beyond the current demonstration stage? How can such

[7] https://www.whitehouse.gov/environmentaljustice/justice40/
[8] https://www.energy.gov/eere/solar/articles/2030-solar-cost-targets

scaled up equipment be tested, and, in what facilities? What receiver size should be appropriate for scaleup, and what efficiency and cost metrics are appropriate targets for scaleup? How can industry contribute to such efforts?

7. With respect to scaled up demonstration efforts, what are the most significant challenges to the success of these efforts and how can these issues be avoided?

Category B: Low temperature (<300°C) CST receivers for IPH applications

8. Most of the IPH involve steam at lower temperatures. Parabolic, dish and Fresnel concentrators are available for steam and hot water application for industry. While corresponding TES applications are not within the scope of this RFI, what low temperature IPH applications are feasible within your industry? What research in capital cost reduction of the parabolic, dish and Frensel systems would be required to meet with your LCOH needs and allow for drop-in replacement of natural gas-based steam systems? What existing policy and market structures offer the best opportunities or have the greatest impact on near term solar IPH applications?

Category C: High temperature (≥300°C) CST receivers and reactors for IPH applications

9. What high temperature industries would be best served using CST energy? In your industry, what would be the best way to introduce solar-thermal energy for replacing fossil energy for endothermic reactions and other heat requirements?

10. For your industry, what do you believe would be the best path to incorporate solar-thermal energy into the process heat input, direct integration with solar receiver, or integration with thermal energy storage? Would you be able to describe conceptual pathways for solar-thermal integration with the process, for further research by DOE?

11. Catalyst integration with solar-integrated thermal input for reactions is not widely considered in research. Catalyst costs are significant and regeneration circuits are a significant part of chemical plant design. Incorporation of catalysts with particle based heating and direct solar heating is not well explored. In your opinion, how can a catalyst system and supports be integrated with particle-based heating systems, and how can such catalysts be regenerated?

12. The current state of art electricity generating system concepts are derived from particle and molten salt-based receiver systems for heat supply via thermal energy storage. However, reaction systems require heat at broader temperature ranges than electrical power

systems. It is widely accepted that receiver efficiency significantly deteriorates with receiver temperature. Currently, there is a strong need for higher temperature reactions, that allow for high temperature designs. Specific examples include beam down systems and fluidized bed reactor systems that can integrate receivers and TES. What specific areas of research are needed to enable ≥900^{o}C receiver applications that need high concentration and advanced materials development?

Request for Information Response Guidelines

Responses to this RFI must be submitted electronically to SETO.RFI.CSP@ee.doe.gov no later than 5 p.m. ET on February 20, 2024. Responses must be provided as attachments to an email. It is recommended that attachments with file sizes exceeding 25MB be compressed (i.e., zipped) to ensure message delivery. Responses must be provided as a Microsoft Word (.docx) attachment to the email. Only electronic responses will be accepted.

Please identify your answers by responding to a specific question or topic if applicable. Respondents may answer as many or as few questions as they wish.

EERE will not respond to individual submissions or publish publicly a compendium of responses. A response to this RFI will not be viewed as a binding commitment to develop or pursue the project or ideas discussed.

Respondents are requested to provide the following information at the start of their response to this RFI:

- Company / institution name.
- Company / institution contact.
- Contact's address, phone number, and e-mail address.

This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.