Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-526

Proposal Title: Solar-Driven Near-Zero-Liquid-Discharge for PFAS-Contaminated Minnesota Water Resources

Project Manager Information

Name: Xiaojia Wang

Organization: U of MN - College of Science and Engineering

Office Telephone: (612) 625-1583

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Project Basic Information

Project Summary: We will develop a solar-driven, near-zero-liquid-discharge system to safely concentrate PFAS-rich brines from Minnesota waters, reducing residual volume, preventing airborne release, and lowering disposal burdens for decentralized groundwater treatment.

ENRTF Funds Requested: $218,000

Proposed Project Completion: June 30, 2029

LCCMR Funding Category: Small Projects (G)
Secondary Category: Water (B)

Project Location

What is the best scale for describing where your work will take place?
Statewide

What is the best scale to describe the area impacted by your work?
Statewide

When will the work impact occur?
During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Per- and polyfluoroalkyl substances (PFAS) are a class of persistent synthetic chemicals widely detected in drinking water and groundwater across Minnesota and the United States. Because PFAS are extremely stable in the environment and can accumulate in the human body, long-term exposure has been associated with adverse health effects such as immune suppression, developmental impacts, and increased cancer risk. Addressing PFAS contamination has therefore become an urgent priority for protecting Minnesota's water resources and public health. Many water-treatment systems remove PFAS from water using technologies such as granular activated carbon or ion-exchange resins. However, these processes do not destroy PFAS. Instead, they concentrate PFAS into secondary waste streams, including spent media or liquid brines that must ultimately be transported and treated through high-energy destruction methods. Managing these concentrated residuals is often costly and logistically challenging, particularly for small communities, rural water systems, and private wells. Solar-driven interfacial steam generation (SISG) offers a low-energy, renewable approach to reduce the volume of PFAS-contaminated residuals before final disposal. By using solar energy to evaporate water at the air–water interface, this method can concentrate PFAS into a much smaller liquid or solid stream.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

This project proposes a solar-driven near-zero-liquid-discharge (NZLD) strategy to reduce the volume of PFAS-contaminated residuals generated by existing treatment systems. Rather than destroying PFAS directly, the system will use SISG to evaporate water, recover a clean condensate stream, and concentrate PFAS into a much smaller liquid or solid residual for final management. This approach is designed to complement existing PFAS capture technologies such as ion exchange and reverse osmosis, not replace them. The project will first build a PFAS-free, enclosed lab-scale SISG prototype that adapts heat-localization and thermal-concentration concepts from prior solar evaporation research while adding features required for PFAS safety: a sealed headspace, condensate collection, aerosol trap, and complete PFAS tracking across phases. The prototype will then be used to test synthetic PFAS brines representative of residual streams that may arise from groundwater treatment. Performance will be evaluated by concentration factors, water recovery, PFAS distribution among feed, condensate, brine, deposited solids, and air-side sampling media, and energy consumption under one-sun and cold-climate conditions relevant to Minnesota. Finally, the project will optimize system geometry and operating conditions for cold-climate performance and higher concentration factors relevant to Minnesota applications.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

This project will help protect Minnesota's water resources by developing a low-energy method to reduce the volume of PFAS-contaminated residuals generated during water treatment. Instead of transferring PFAS into large secondary waste streams, the proposed system will concentrate them into a much smaller residual for safer downstream handling while recovering water as condensate. The project will also establish safeguards against PFAS release to air through aerosol carryover, an important environmental concern for evaporation-based systems. The resulting design rules and prototype data will support practical, decentralized concentrate-management options for rural communities, utilities, and private well treatment systems across Minnesota.

Activities and Milestones

Activity 1: Design and validate a PFAS-free enclosed solar-interfacial-steam-generation (SISG) system with condensate collection, aerosol control, and complete mass balance

Activity Budget: $95,752

Activity Description:
Activity 1 will establish the experimental foundation by building a lab-scale solar-interfacial-steam-generation (SISG) system for solar-driven near-zero-liquid-discharge (NZLD) PFAS concentration. The device will be designed as an enclosed interfacial evaporator rather than an open beaker-style platform so that condensate can be collected and the air phase can be monitored. This is critical because PFAS are expected to remain primarily in the concentrated liquid or solid residual, so aerosol-mediated transfer to the vapor stream must be explicitly evaluated. The prototype will use a circular evaporation area of ~10-cm diameter and will incorporate a spectrally absorbing top layer, floating thermal insulation, and a capillary-fed wick. All wet components, tubing, seals, and sample-contact surfaces will be selected to avoid fluoropolymer contamination and enable low-background PFAS analysis. A transparent cover, condenser, and aerosol trap will be integrated to collect recovered water and quantify airside PFAS transport. Thermal performance will be characterized by evaporation flux, solar-to-vapor efficiency, heat loss pathways, and temperature distribution. Blank tests with PFAS-free water will verify background cleanliness, while non-PFAS salt solutions will be used to debug water transport and salt accumulation behavior before PFAS experiments begin. The result will be a validated, reproducible testbed for subsequent concentration and cold-climate studies.

Activity Milestones:

Description	Approximate Completion Date
Controlled enclosed SISG reactor designed, constructed, and leak-tested	October 31, 2027
PFAS-free materials screening and blank mass-balance validation completed	December 31, 2027
Baseline thermal and water-production performance established under one-sun illumination	June 30, 2028
Activity 1 summary report	June 30, 2028

Activity 2: Demonstrate safe PFAS concentration, condensate quality, and air-emission control using synthetic brines representative of Minnesota treatment residuals

Activity Budget: $64,774

Activity Description:
Activity 2 will evaluate whether the enclosed SISG platform can safely concentrate PFAS-containing brines while maintaining high PFAS mass accountability. Synthetic feedwaters will represent residual streams relevant to Minnesota groundwater treatment, including PFAS mixtures with co-occurring salts and alkalinity. The main performance targets are concentration factors, water recovery, and PFAS partitioning among retained brine, deposited solids, condensate, and air-side sampling media. Because many common PFAS in water are nonvolatile ionic species, they are expected to remain largely in retained phases; however, possible transfer through aerosols will be tested using demisters, aerosol filters, and headspace sampling. Representative long-chain and short-chain PFAS will be studied to determine how molecular structure influences retention during solar concentration. Condensate will be analyzed to verify whether recovered water remains below detection or near-background PFAS levels under controlled operation. The work will also examine how concentration factors change with feed composition, evaporation rate, and residence time, with an initial target of >10× concentration and at least 95% total PFAS mass accounted for in liquid and solid retained phases. These experiments will provide a rigorous dataset linking SISG operating conditions to PFAS-safe concentration performance and an experimentally validated basis for solar-driven PFAS concentration management.

Activity Milestones:

Description	Approximate Completion Date
PFAS concentration and condensate recovery protocols established	December 31, 2028
>10× PFAS concentration with at least 95% mass accountability demonstrated	December 31, 2028
No significant PFAS air-phase carryover under controlled operation verified	December 31, 2028
Activity 2 summary report	December 31, 2028

Activity 3: Optimize cold-climate operation for scalable decentralized PFAS residual management in Minnesota water-treatment applications

Activity Budget: $54,379

Activity Description:
Activity 3 will translate the validated SISG concept into a Minnesota-relevant operating framework by improving cold-climate robustness and pushing concentration factors to more practical levels for downstream disposal. Interfacial evaporation systems are sensitive to heat loss, salt accumulation, and water-delivery limits, which become more severe under low temperatures. This activity will therefore optimize absorber geometry, insulation, wick design, condensation management, and enclosure configuration to maintain stable evaporation under colder conditions representative of Minnesota shoulder-season operation. The system will also be challenged at progressively higher concentration factors, targeting roughly 30× to 100× volume reduction where feasible, while monitoring flux decline, salt precipitation, PFAS redistribution, and cleaning requirements. Attention will be given to whether PFAS remain preferentially in concentrated liquid versus solid deposits, because that distinction affects downstream handling and disposal logistics. Techno-economic metrics will be estimated, including recovered water volume, residual-volume reduction, and energy use relative to electrically heated evaporation. The final delivery will be a prototype-scale operating envelope and engineering guidelines for decentralized PFAS concentration management using solar energy. Rather than claiming PFAS destruction, this activity will establish a realistic and scalable pretreatment or residual-reduction pathway that can reduce hauling and disposal burdens for Minnesota communities using PFAS capture technologies.

Activity Milestones:

Description	Approximate Completion Date
30x or greater concentration factor demonstrated under optimized conditions	March 31, 2029
Cold-climate enclosure and thermal-management upgrades implemented	June 30, 2029
Prototype operating envelope and scale-up guidelines completed	June 30, 2029
Activity 3 summary report	June 30, 2029

Activity 4: Reporting, Results Dissemination, and Outlook for Technology Translation to Real-World Implementation

Activity Budget: $3,095

Activity Description:
Activity 4 will focus on data analysis, reporting, and broad dissemination of project findings. Project results will be disseminated to water utilities, environmental engineers, and state agencies, who can benefit from improved PFAS residual management in Minnesota. Research findings, system design guidelines, and experimental protocols for the solar-driven concentration platform will be shared through peer-reviewed journal publications, conference presentations, and technical reports accessible to professionals working on PFAS remediation. Data on PFAS mass balance, evaporation performance, and cold-climate operation will be documented to support future pilot-scale implementation in Minnesota water treatment systems. If the project leads to novel device configurations or operational strategies, intellectual property protection may be pursued through patent applications to enable

responsible technology transfer and potential commercialization while ensuring environmental benefits. Public-facing summaries and outreach materials will also be prepared to communicate project outcomes to Minnesotans in accessible language. All publications, presentations, and outreach materials will acknowledge support from the Environment and Natural Resources Trust Fund.

Activity Milestones:

Description	Approximate Completion Date
Documentation and progress reports for Activity 1	June 30, 2028
Documentation and progress reports for Activity 2	December 31, 2028
Documentation and progress reports for Activity 3	June 30, 2029
Patent filing (before paper submission), paper draft writing, and manuscript submission	June 30, 2029
Final project report	June 30, 2029

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
Our Activity 4 will focus on data analysis, reporting, and broad dissemination of project findings. Project results will be disseminated to water utilities, environmental engineers, and state agencies, who can benefit from improved PFAS residual management in Minnesota. Research findings, system design guidelines, and experimental protocols for the solar-driven concentration platform will be shared through peer-reviewed journal publications, conference presentations, and technical reports accessible to professionals working on PFAS remediation. Data on PFAS mass balance, evaporation performance, and cold-climate operation will be documented to support future pilot-scale implementation in Minnesota water treatment systems. If the project leads to novel device configurations or operational strategies, intellectual property protection may be pursued through patent applications to enable responsible technology transfer and potential commercialization while ensuring environmental benefits. Public-facing summaries and outreach materials will also be prepared to communicate project outcomes to Minnesotans in accessible language. All publications, presentations, and outreach materials will acknowledge support from the Environment and Natural Resources Trust Fund.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
This 24-month project (July 1, 2027-June 30, 2029) will deliver a practical solar-driven near-zero-liquid-discharge (NZLD) strategy for volume reduction of PFAS-contaminated residuals from Minnesota water-treatment systems. The enclosed SISG prototype, PFAS mass-balance data, and cold-climate operating guidelines developed in this work will support pilot-scale evaluation with Minnesota utilities, environmental engineers, and partners working on PFAS treatment for surface and groundwater systems. Project results will provide a technical foundation for integrating solar concentration management with existing PFAS capture technologies. Follow-on funding will be pursued through the NSF, the US Environmental Protection Agency, and through industry partnerships supporting advanced water treatment technologies.

Project Manager and Organization Qualifications

Project Manager Name: Xiaojia Wang

Job Title: Professor in Mechanical Engineering

Provide description of the project manager's qualifications to manage the proposed project.
Professor Xiaojia Wang will lead the project. She has significant experience in advancing the frontiers of thermal transport science and energy conversion technologies. At the U of MN, she leads an interdisciplinary research group that bridges innovative experiments with advanced modeling to investigate thermal energy transport in functional materials, across interfaces, and within integrated devices. By combining materials science, nanotechnology, and device engineering, her work addresses the global challenges in energy efficiency and renewable technologies, driving advancements in applications such as solid-state energy conversion, electronic cooling, thermal switching devices, and next-generation computing architectures.

Prof. Wang has established a high recognition in thermal science and energy research. Her group has published ~60 research articles in top-tier journals, many of which have been featured as Editor's Picks and Highlighted Articles. She

has secured research funding from federal agencies (NSF, DARPA), industry (3M, ASRC, and Seagate), and foundations. She has advised ~10 graduate and 10+ undergraduate students, many of whom have received prestigious fellowships and secured positions at national labs and leading companies (e.g., Intel, Lam Research, and Seagate). Professor Wang has a proven track record of translating fundamental discoveries into real-world solutions through partnerships with leading Minnesota-based industrial corporations, including Seagate, Medtronic, and 3M.

Organization: U of MN - College of Science and Engineering

Organization Description:
The University of Minnesota, Twin Cities (U of MN) is a premier public land-grant research university located in Minneapolis and Saint Paul, recognized as one of the most comprehensive research universities in the nation. The College of Science and Engineering (CSE) is a global leader in research, education, and technological innovation, with 12 departments spanning engineering, physical sciences, computer science, and mathematics. Home to over 8000 students and many cutting-edge research centers, CSE drives technological innovation and breakthroughs in energy, artificial intelligence, nanotechnology, climate, biomedical engineering, quantum computing, and sustainability. The college consistently ranks among the top public STEM institutions in the US. CSE is also committed to excellence in education, providing hands-on learning, interdisciplinary collaboration, and entrepreneurial opportunities to its students. The Department of Mechanical Engineering is a world leader in thermal science and engineering research, known for its impactful areas in renewable energies, environment & sustainability, next-generation manufacturing, robotics, and biomedical engineering. The Department of Chemical Engineering and Materials Science is a top-tier, internationally competitive department, leading advancements in fluid mechanics, transport, catalysis, bioengineering, renewable energy, polymer synthesis and processing, and advanced semiconductor research.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Xiaojia Wang		Principal Investigator			8.16%	0.16		$35,185
Graduate Student (1)		Research Assistant			45.52%	1		$133,380
							Sub Total	**$168,565**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	The requested budget for materials and supplies supports the construction and operation of laboratory-scale solar-driven interfacial steam generation (SISG) systems and the execution of controlled PFAS concentration experiments relevant to Minnesota water protection. These supplies fall into three main categories. (1) SISG device construction materials, including photothermal absorber materials (e.g., carbon-based coatings), hydrophilic wicking materials such as cotton fabrics, floating insulation layers, polymer foams, bubble wrap covers, structural holders, and laboratory glassware used to assemble floating evaporation modules that localize solar heat at the water-air interface. (2) Illumination and experimental operation supplies, including components for calibrated light exposure (solar simulator specified under Capital Expenditures), thermocouples, temperature sensors, and consumables required to perform controlled evaporation experiments and quantify solar-driven water removal under laboratory conditions. (3) PFAS testing and sample handling supplies,	These materials and supplies are essential for constructing solar-driven evaporation systems and performing systematic studies of PFAS concentration and mass balance under environmentally relevant conditions. The SISG modules will enable controlled laboratory experiments to evaluate heat localization, evaporation rates, and PFAS partitioning during solar-driven concentration processes. Experiments will be conducted using synthetic solutions and water chemistries representative of PFAS-contaminated water in Minnesota, ensuring that the results are directly applicable to regional remediation challenges. Major laboratory instruments required for thermal characterization and solution analysis are already available in the PI's laboratory and shared university facilities. PFAS concentration					$16,160

		including PFAS reference standards (e.g., PFOA, PFOS, PFBS), PFAS-free containers and tubing, filtration materials, aerosol filters, sorbent tubes for vapor-phase sampling, and solvent extraction materials required to conduct PFAS mass-balance measurements and determine whether PFAS compounds partition into residual concentrates, condensate water, or vapor pathways during evaporation. The budget for Year 2 includes a 2% inflation adjustment to account for rising material and supply costs.	measurements will be conducted through campus analytical facilities using LC-MS instrumentation, with associated costs included under Scientific Services.					
							Sub Total	**$16,160**
Capital Equipment								
		(SCISUN-AM1.5G) SciSun Solar Simulator, AM1.5G, Class AAA, 50 × 50 mm, for solar flux simulation. Intensity: 150 W, quantity: 1; Air mass filter (included), quantity: 1; Xenon arc lamp (included), quantity: 1. Corresponding data acquisition system (included); Software for imaging processing, visualization, and data reduction (included); Mounting accessories (included). The total price excluding tax is ~$11,000.	As part of the experimental testing of the solar-driven interfacial steam generation (SISG) system, a solar simulator is required to provide controlled 1-sun illumination (~1000 W/m^2) to drive and evaluate the solar-driven interfacial steam generation (SISG) system under reproducible laboratory conditions. Stable and calibrated illumination is essential for accurately measuring evaporation rates, heat localization, and PFAS concentration performance, independent of weather variability.	X				$12,000
							Sub Total	**$12,000**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Conference Registration Miles/ Meals/ Lodging	An annual travel budget of $3,000 is allocated to support conference attendance and industry engagement for the team (totaling $6,000 for two years). The requested travel budget will cover one	Expanding research impact through broader dissemination of research knowledge, findings, and products. Enhancing student professional					$6,060

		conference trip per year for the PI and her students ($3,000). Estimated expenses include conference registration of $400 (for one student) and $900 (for PI), ground transportation $200 × 2 = $400, and meals $200 × 2 = $400. The budgets for Year 2 include a 2% inflation adjustment to account for rising travel costs.	development to strengthen Minnesota's future workforce. Building connections with potential collaborators and industry partners to drive innovation and commercialization.					
							Sub Total	**$6,060**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publication cost in open-access journals; potential cover-image highlighting.	We would like to maximize the visibility of our research outcomes by publishing in several open-access journals, ensuring free and unrestricted access for all readers.					$3,095
							Sub Total	**$3,095**
Other Expenses								
		Scientific Services	To successfully evaluate and optimize the proposed solar-driven interfacial steam generation (SISG) system for PFAS concentrate management, this project will utilize advanced analytical and characterization tools available through on-campus shared facilities. These services are essential for accurate quantification of PFAS concentrations, characterization of materials, and verification of PFAS mass balance during solar-driven concentration experiments. On-campus facilities at the Characterization Facility (CharFac) will be used for several key material characterization tasks. These include: (1) optical characterization of					$12,120

			photothermal absorber materials using UV-Vis-NIR spectroscopy to determine solar absorptance and reflectance; (2) structural characterization using SEM to examine the pore structure, morphology, and surface texture of absorber materials and insulating layers; and (3) additional surface characterization techniques, such as profilometry or AFM to evaluate surface structure and coating uniformity. In addition, PFAS concentration measurements and mass-balance analysis will be conducted through university analytical laboratories equipped with liquid chromatography-mass spectrometry (LC-MS) systems capable of detecting PFAS compounds at environmentally relevant concentrations. These services will be used to quantify PFAS concentrations in initial feed solutions, concentrated brines, condensed water samples, aerosol filters, and vapor-phase sorbent samples collected during evaporation experiments. These analyses are critical for determining whether PFAS compounds remain confined to the residual concentrate or partition into vapor or aerosol pathways during the solar-driven concentration process. The estimated service fees are approximately $6,000 per year, including. $3,500 for CharFac characterization services, and $2,500 for PFAS analytical measurements through university mass spectrometry facilities. The budget for Year 2 includes a 2% inflation adjustment to account for potential increases in service costs.					

							Sub Total	**$12,120**
							Grand Total	**$218,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Equipment		(SCISUN-AM1.5G) SciSun Solar Simulator, AM1.5G, Class AAA, 50 × 50 mm, for solar flux simulation. Intensity: 150 W, quantity: 1; Air mass filter (included), quantity: 1; Xenon arc lamp (included), quantity: 1. Corresponding data acquisition system (included); Software for imaging processing, visualization, and data reduction (included); Mounting accessories (included). The total price excluding tax is ~$11,000.	The solar simulator provides controlled 1-sun illumination to drive and evaluate the solar-driven evaporation process in the SISG system. The solar simulator will be used throughout the project to perform repeatable evaporation experiments and compare SISG materials and device configurations under standardized solar conditions. This capability is critical for generating reliable data needed to assess the effectiveness of the proposed solar-driven PFAS concentration approach. **Additional Explanation :** This is a one-time purchase to be made at the beginning of the project. We have already contacted the vendor (ScienceTech Inc.) to provide a quote (submitted as an attachment). The solar simulator will be used throughout the project to perform repeatable evaporation experiments and compare SISG materials and device configurations under standardized solar conditions.

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	Unrecovered F&A calculated at 54% MTDC	Support of ME facilities where research will be conducted.	Secured	$89,795
			Non State Sub Total	**$89,795**
			Funds Total	**$89,795**

Total Project Cost: $307,795

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 952366a4-e78.pdf

Alternate Text for Visual Component

This visual illustrates current PFAS concentration methods (activated carbon and ion exchange) and their limitations, including high cost and centralized processing. We propose a solar-driven near-zero-liquid-discharge strategy to reduce waste volume and concentrate PFAS. The strategy enables decentralized, low-cost, and safer management while enhancing downstream PFAS destruction efficiency....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
UMN SPA Support Letter	776d7b54-d71.pdf
Sciencetech Quotation for 1-Sun Solar Simulator	3d52c573-56e.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care,

treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

ME proposal staff (Alexandra Sullivan <sull1129@umn.edu>) and UMN SPA (Josh Gates <gates191@umn.edu>) for budget preparation and approval.

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A