Alaska Energy Authority
Emerging Energy Technology Grant Application

Abstract
for

Development of a High Efficiency Supercritical Carbon Dioxide Power Plant to take Advantage of Alaska's Northern Climate and Indigenously Available Fuels

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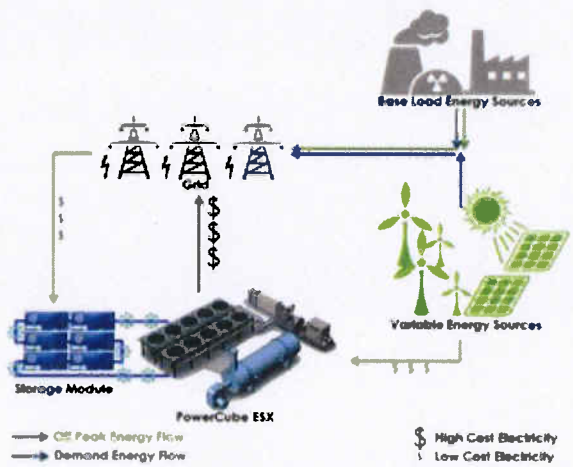

Partners:
University Mechanical Contractors, Inc.
Alaska Business License # 216722 Exp: 12/31/13
Alaska Contracting License # 2920 Exp: 12/31/14
SuperCritical Technologies, Inc.
Barber Nichols, Inc.

Total Project Costs: $900,000
Requested amount: $750,000
Match Committed: $150,000

No Previous Projects
No Previous Applications

Development of a High Efficiency Supercritical Carbon Dioxide Power Plant to take Advantage of Alaska's Northern Climate and Indigenously Available Fuels

1) Project Summary

Project Description: This proposal will execute the initial development of a power plant that uses northern climate ambient air/water temperatures and indigenous fuel sources to reduce the electrical energy costs for Alaskan customers. It will accomplish this by evaluating the development of a supercritical carbon dioxide (SCO2) power plant that thermally provides bulk energy storage, improves power plant efficiency by using ice to reduce the heat rejection temperature, lowers capital costs by using the lower heat rejection temperature to increase power produced by the plant in peak output scenarios, and provides waste heat to residential or industrial users.

The current Technology Readiness Level for SCO2 power systems is considered to be TRL3/4, this proposal will advance the state of readiness for deployment into Artic climates to TRL6. University Mechanical, SuperCritical Technologies, and its partners intend to advance this technology to a TRL of 8/9 within the next 4 years through a combination of public and private investment. There are long term implications for the State of Alaska and the University of Alaska system to play a pivotal role in this development.

Project Innovation: The power plant uses natural gas, diesel fuel, or other combustible indigenous fuels, including biomass fuels, to operate a supercritical CO2 (SCO2) power plant with co-generation capabilities. Because CO2 is a natural refrigerant, it is capable of operating at very low temperatures (-56 C) allowing the working fluid to directly make ice. Likewise CO2 can be heated in a low pressure combustor to high temperature (1100-1400 F) allowing for high power plant efficiency. Because the combustion takes place at low pressure the power plant is capable of operating with multiple fuel types including biomass base, liquid and gaseous fuels, and even waste heat.

The plant will be configured to operate in two modes; an energy storage mode (ice making) and an electrical power production mode (ice melting). The operating modes are selected by opening and closing valves to select the number of pump stages or turbine stages used and to select flow paths through heat exchangers and expansion valves.

During the energy storage mode, the plant will be designed to make the best use of excess renewable power and cold ambient temperatures that are available during off-demand power times. In this mode the plant consumes off peak energy and operates as a transcritical CO2 heat pump to make the ice, and to provide hot water (at ~146 F). The heat will be stored in stratified thermal cline water tanks for later distribution to residential or industrial customers, and the ice is stored in specifically designed tanks or ponds. If the environmental conditions are not optimal, the plant can use mechanical power from the power production operating mode to make and store ice. This configuration allows energy to be consumed from renewable or other variable sources, stored in the ice energy storage platform, and redistributed to the electrical grid at times of peak use when energy costs are highest.

During the day and evening, at times of peak power demand, the plant is operated in its power production mode (a transcritical CO2Rankine cycle). In this mode the power plant uses the stored ice as the heat sink which melts the ice. This lowers the waste heat rejection temperature from 88°F to near40°F which increases the efficiency of the power plant by up to 10% (to 41-43%). Depending on the size of the ice storage unit, the plant can operate in this mode for up to 6-8 hours. When the ice is not used as the heat sink, the power production mode is capable of operating at high efficiencies (~34-37%) indefinitely. When the ice is available, the lower heat rejection temperature also lowers the power plant pump inlet pressure which in turn increases the pressure ratio through the turbines to increase the power production by about 73%. This ensures the plant, which is designed for 5 MWe, is capable of producing 8.8 MWe in peaking mode, which effectively lowers the capital cost of the plant and increases the efficiency as the fuel utilization is decreased from 11,700 kJ/kWh to about 9700 kJ/kWh.

Project Site and Demonstration Environment: Clearly, the optimum strategy will vary throughout the seasons and will also depend on location. The combined optimization effort and design is what provides lower electrical power cost for Alaskans and is made possible by the SCO2 power plant. We intend to engage with the University of Alaska Fairbanks and the Alaska Center for Energy and Power to complete a cursory study of deployment locations and environments in which this system will have the highest impact on community energy costs. Funding for this study in conjunction with the University has been included in the budget for this proposal.

Upon completion of final plant design and collection of testing results, SuperCritical Technologies and its partners will seek to build a full scale facility in Alaska at the site identified in this study. This demonstration will prove the technology for application in rural and developing communities across the globe. Alaska's high energy costs, logistical complications, and abundant selection of indigenous fuels make it an ideal demonstration environment for this technology.

Priority: The primary goal of this proposal is to determine the optimized design and operating strategy that provide the greatest benefit to the Alaskan power customers. The design must do this by minimizing the cost of electricity generated while maximizing fuel utilization and district heating capabilities. The operating strategy provides this optimum by taking advantage of available excess renewable power and cold nighttime or winter like weather to make ice. By providing energy storage (in the form of ice) we can shift renewable energy output to timeframes where it is most useful, and provide higher efficiency peak power generation at times of peak demand, which lowers overall energy costs.

2) Technology Validation and Data Collection

a. SuperCritical Technologies, Inc. (SCT) and its partners University Mechanical Contractors, Inc. and Barber Nichols, Inc. will develop a small scale ($1/10^{th}$ flow) supercritical recirculation loop to study the key technologies incorporated in the energy storage concept. The recirculation loop will contain supplementary refrigeration hardware as well as other hardware and test sections to perform risk reduction testing for key components such as bearings, seals, and materials ($400 k, one year).

b. SCT will perform a feasibility study to determine the optimized design based on the environmental conditions and expected variations throughout the year. This study will determine the expected mix of excess renewable energy, off-peak power, and cold air temperatures available for heat rejection, the appropriate size of heat exchangers and storage tanks that will be capable of operating over the expected environmental variations. ($50k, 6 months)

c. SCT will perform a feasibility study utilizing the University of Alaska System to determine appropriate sites by evaluating the local environmental annual temperature distributions and use the results of the feasibility study to determine the performance and optimal design of the power plants.($50k, 6 months)

d. SCT will advance the state of development of SCO2 power plants from its current preliminary design level through the point of first final design review (~80% complete), including design drawings, cost quotations, design performance and off-design performance estimates for an energy storage and high efficient power plant optimized for the Artic. Supercritical Technologies and its partners have already invested over $250k of seed funding to develop a preliminary design for a generic SCO2 power system including obtaining budget quotes for all components; we will leverage this work to tailor a design for Alaskan environments. ($400k, one year).

3) Project Schedule and Budgets	End of Quarter
a. Circulation Loop:($400k)	
i. Proposed PID drawing of circulation loop and report	1
ii. Status reports on assembly and operations	2 and 3
iii. Summary report of performance testing of loop	4
b. Feasibility Study ($50k)	
i. Summary reports of feasibility study	1,2,3
ii. Final feasibility report	4
c. Site Selection Study ($50k)	
i. Status of site selection study	1,2,3
ii. Final site selection study report	4
d. Final Design Task ($400k)	
i. Short status reports	1,2,3
ii. Drawings, request for quotes, quote responses	2
iii. Designs specs and PID drawings	3
iv. Final Report	4

4) **Project Team Qualifications**

Chal S. Davidson, P.E. was born and raised in Alaska, attended Kodiak High School, and served as a page in the Alaska State Senate. He has since worked in technical and managerial leadership positions at Lockheed Martin, Bechtel Corporation, TerraPower, and Intellectual Ventures. He holds a BS degree in Engineering from the Oregon State University, an MS degree in Engineering from Rensselaer Polytechnic Institute, and an MBA from the University of Washington Foster School of Business. Chal is also a licensed Professional Engineer in the states of New York, Washington, and Oregon.

Steven A. Wright, PhD was a distinguished member of technical staff at Sandia National Laboratories (Sandia) with 35 years of experience. He holds BS, MS, and PhD degrees in Engineering from the University of Washington. Steven retired from Sandia in November of 2011 and is now the Chief Scientist for SuperCritical Technologies. At Sandia National Laboratory, Steven was the Principle Investigator on the development of two small supercritical power systems, and is one of the major leaders in this field.

University Mechanical Contractors, Inc. is one of the largest, most trusted, and experienced mechanical contractors in the western United States. UMC has completed numerous large scale construction projects in Alaska, such as the Kodiak Island Hospital Expansion, and continues to hold both an Alaska Business License and an Alaska Contracting License.

Barber Nichols, Inc. is a world recognized engineering firm specializing in the design and production of turbomachinery for aerospace, cryogenic, defense, energy, and a variety of commercial applications. BNI has completed energy projects in Alaska that look to provide less expensive electricity for Alaskan communities, such as the geothermal Organic Rankine Cycle installation at Chena Hot Springs.

5) **Discussion of Commercialization of Funded Technology**

Supercritical carbon dioxide power systems are an emerging technology that offer revolutionary solutions to a variety of modular power plant applications including combustion heated electrical power generation with flexible fuels, waste heat utilization, co-generation technology, bulk energy storage, efficient high temperature Concentrated Solar Power (CSP), military applications, plus more advanced power plants that use oxy-combustion heating methods that offer solutions for carbon capture and sequestration at power conversion efficiencies exceeding 50%.

Supercritical CO2 (SCO2) power systems offer these benefits because they use a gas turbine based power plant operating in a closed loop utilizing high pressure CO2 as the working fluid. The supercritical working fluid offers very high power density due to the high fluid density, and high efficiency at modest temperatures due to non-ideal fluid properties that occur near the CO2 working fluid critical point. This means the turbomachinery is very small (typically a factor of 30x smaller than a steam turbine and 6 times smaller than a gas turbine). The balance of plant is also reasonably small because of advanced technologies used for heat exchangers and the high fluid density. (See ASME Mechanical Engineering Magazine, January 2012 for an introduction to SCO2 power systems, a copy is included for information).

The market for a modular power system utilizing SCO2 as the working fluid is immense and has long term implications for not only Alaskan energy projects at the community level, but also globally for industrial power production.

By signature on this application, I certify that we are complying and will comply with the amount of matching funds being offered.

Jerry Bush, CEO UMC

Chal Davidson, PE