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1. Title: Alaska Sewage Sludge Energy Conversion Plant Demonstration

2. Applicant: Lammergeier CleanTech
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3. Partners: City and Borough of Juneau (Benefitting Municipal Government)
University of Alaska Fairbanks (Scientific Oversight and Energy Research)
Wilson Engineering (Site Build-Out Engineering)
Supercritical Fluids International Group (AquaCritox® Fabrication Engineering)
Parsons Engineering, Ltd. (AquaCritox® Design Engineering)
Rockwell Automation (AquaCritox® Controls and Integration Engineering)

4. Financials:

Total Project Funding	**$10,377,320**	**100.00%**
Grant Funds Requested	**$1,500,000**	**14.45%**
Total Match	**$8,877,320**	**85.55%**
Match Breakdown		
Lammergeier CleanTech	**$5,349,820**	**51.56%**
City and Borough of Juneau	**$3,527,500**	**33.99%**

5. Juneau SuperCritical Water Oxidation Sewage Sludge To Energy (no match overlap) submitted to REF
6. No previous EETF submissions

1. Project Summary

a. Description: The project will design, build, and demonstrate the continuous operation of a supercritical-water thermochemical conversion plant that captures excess energy from wet sewage sludge oxidation. The plant will bolt-on to an existing wastewater treatment facility in Juneau, Alaska. The process uses supercritical water and oxygen (SCWO) to exothermically oxidize all organic compounds in the sludge with minimal dewatering and pretreatment. The system generates enough pressurized steam and hot water to be used in process heat and distributed energy systems. The proposed project will generate process-heat and power for the Juneau Wastewater Utility Division, and in doing so, achieve a marked reduction in operating costs. The proposed SCWO plant is professionally engineered using off-the-shelf components, commonly found in the petroleum industry, with minor modifications. The design and engineering will be based on the AquaCritox® system licensed by Supercritical Fluids International Group (Figure 1).

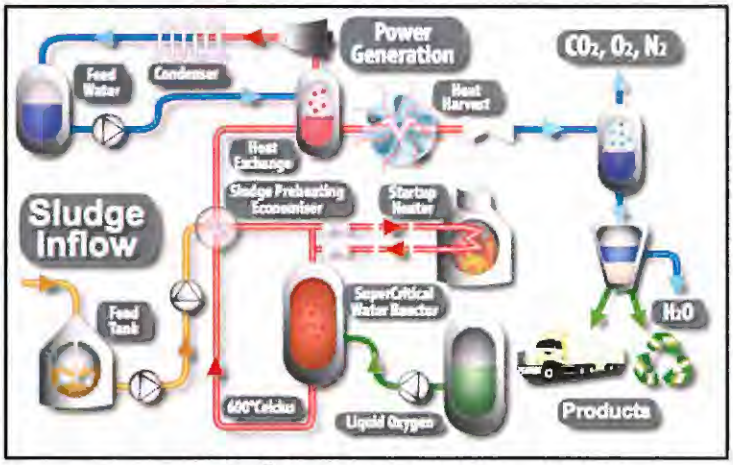


Figure 1. AquaCritox® System Schematic

b. Eligibility: Extensive pilot runs of the AquaCritox® system have been successfully completed in Europe and have reliably demonstrated energy recovery from municipal sewage sludge. This project, as the first North American demonstration, will test, *in-situ*, the energy conservation and production capabilities of AquaCritox® on Juneau's sewage sludge. The successful Alaskan demonstration of a net-plus-energy, AquaCritox® plant will poise the AquaCritox® system at a Technology Readiness Level (TRL) 7, ready for commercialization as an energy-saving option for municipalities charged with operating wastewater treatment facilities.

c. Innovation: This innovative AquaCritox® system will decrease operating costs of the Juneau-Douglas Wastewater Treatment Facility (JD Facility) in two ways: 1) through energy conservation and 2) by generating renewable energy. First, energy will be conserved through reduced water removal from sewage sludge. Sludge dewatering is expensive, with the JD Facility currently expending about 290 MWh annually (≈29% of JD Facility's total electrical consumption) to reduce the sludge water content by 15% prior to landfilling or incinerating. Juneau is not the only community faced with dewatering costs. Nationwide, municipalities spend $6 billion annually just on energy to remove water from sewage sludge prior to its disposal, consuming 120 billion KWh. This Juneau demonstration project will reduce the JD Facility's dewatering-equipment duty cycle by approximately 50%, saving Juneau almost 145 MWh annually (worth ≈$12K). Dewatering will be reduced at the JD Facility, because the AquaCritox® plant will simultaneously expose the water entrained in sewage sludge to elevated pressures and temperatures (>3,210 psi and >374°C), thereby raising the water to supercritical conditions (Figure 2). The supercritical water will dissolve all organic materials in the sludge at high destruction efficiencies (>99.99%) with short residence times (e.g., <1 minute). The disposal of dewatered sewage sludge is also expensive, with the JD Facility expending an average of $125K annually on incineration and/or landfilling. Nationwide, many communities rely heavily on incineration for sewage sludge disposal, but incineration operates at an energy deficit of greater than 15 million BTUs per ton of sludge processed, with the vast majority of that energy spent simply boiling off water. It is because of energy-negative disposal methods like incineration that the U.S spends $10 billion in energy annually to dewater and dispose of sewage sludge. Second, renewable energy will be generated from the hydrothermal destruction of wet sewage sludge at the JD Facility. The AquaCritox® plant will produce an excess of 16 million BTUs for every ton of sludge processed, for an energy savings of 21 times that of incineration. The chemical energy in the JD Facility's sewage sludge (19KJ/Kg, estimated from bomb calorimetry performed in 2011) will be converted into heat at a rate of about 18 million BTUs per dry ton equivalent via AquaCritox®'s exothermic reactions. The reactions are exothermic because, when oxidants are added to supercritical water, enough energy is released to internally heat the working fluid itself (i.e., water), thereby perpetuating self-sustaining reactions. These exothermic reactions create high efficiencies for heat-transfer inside

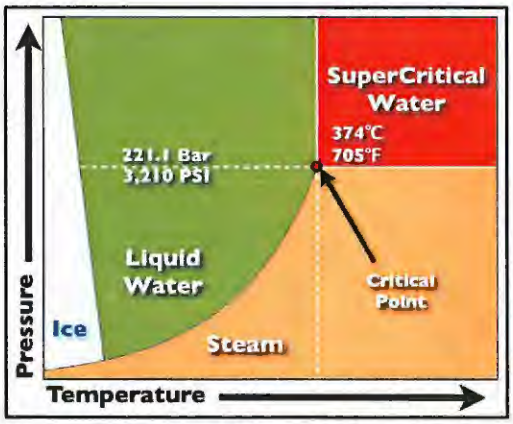


Figure 2. States of Water

the AquaCritox® reactor. The AquaCritox® plant will convert the heat into steam and convey that heat (at about 825K BTUs per hour) into electrical energy via small, 10%-efficiency, organic Rankine turbines (e.g., Infinity Turbine® or equivalent), annually producing about 170 MWh of surplus renewable energy (≈$15K) at the JD Facility.

Current rough-order-of-magnitude, economic estimates for a larger, AquaCritox® plant versus replacement of Juneau's sludge incinerator put the absolute savings at $46 million and net-present-discounted (5%) cost savings at $36 million with most of the savings due to energy efficiency improvements. Thermoeconomic net-present-value of the energy savings, including the annual elimination of 110K gallons of diesel fuel and 990 MWh of electrical usage for Juneau's sludge incinerator, parallels the monetary remunerations at an absolute savings of 1.6 trillion BTUs (over 20 years) and a net-present-value of 675 billion BTUs saved. These surplus BTUs (at the larger scale) could produce about 2 GWh of renewable energy in Juneau with larger, higher-efficiency, steam turbines. This electrical production could power Juneau's three wastewater treatment facilities and provide a surplus. Widespread use of AquaCritox® to destroy sewage sludge in the U.S. could eliminate up to $16 billion in energy costs nationwide, power all of the country's wastewater treatment facilities, and still likely generate more than $2 billion in surplus electricity sales.

d. Priority: The project addresses all four priorities. First, the applicant and project manager, Lammergeier CleanTech, is an Alaska-based business. Local engineering will be performed by Alaska-based Wilson Engineering. The project will be demonstrated at a City and Borough of Juneau wastewater facility. Second, the applicant has solidified a partnership with Dr. Juan Andres Soria of the University of Alaska Fairbanks. Dr. Soria will be the project's principal investigator for scientific and technology oversight. Third, significant matching funds and in-kind contributions (≈85.6% match, ≈$8.9 million) have been committed to this project. Fourth, the project will demonstrate a net-plus-energy, emerging technology that is suitably scalable to different-sized Alaskan communities with wet organic wastes, including sewage sludge.

2. Technology Validation and Research Methodology

a. Objectives: This project will demonstrate the technical feasibility and commercial potential of efficiently capturing energy from wet sewage sludge as heat and electricity via the AquaCritox® system. The objectives of this project are to construct and deploy, in Juneau, Alaska, a fully automated AquaCritox® A4 plant with a sustainable hydraulic load of 250 liters/hour that demonstrates how the system:

1) *reduces energy consumption in the wastewater treatment process by avoiding water removal;*
2) *produces renewable energy from wet sewage sludge via hydrothermally driven electrical generation;*
3) *destroys wet organic waste at net-plus-energy via supercritical water oxidation; and*
4) *performs as an integrated system in terms of reliability, maintenance, and ease of operation.*

b. Methodology: The robust evaluation of these four objectives will be incorporated into decisions about integrating the AquaCritox® system into other wastewater treatment facilities in Juneau, other cities in Alaska, and outside of the State. First, reductions in energy consumption will be reported in units of electricity and fuel. Electrical energy used in the processing and destruction of the sewage sludge will be measured, displayed, stored, and analyzed in real-time by Rockwell Automation's integrated monitoring software. Calculated reductions in energy consumption will include reduced electrical consumption, trucking fuel, and incinerator fuel. Second, the production of renewable energy from sludge destruction will be reported in units of heat and electricity. Energy data will be measured, displayed, stored, and analyzed in real-time by system telemetry and monitoring software. Third, energy savings resulting from sludge destruction efficiencies will be reported in chemical and thermoeconomic terms. Sludge destruction efficiencies will be assessed chemically, in part, through periodic analyses of organics and inorganics present in the sludge before and after supercritical water oxidation. Organics will be measured for total organic carbon, elemental analysis, and energy content. Inorganic measurements will use multiple analyses, including high performance liquid chromatography, carbon-hydrogen-nitrogen elemental, total organic carbon, gas chromatography, and caloric content. Organic and inorganic analyses will be performed at the UAF Palmer Center for Sustainable Living. Exergic destruction efficiency of the process will be assessed primarily via measurements of chemical oxygen demand, total organic carbon, and caloric content in the effluent. In addition, throughput exergy will be continuously monitored via ultrasonic calorimeter telemetry on the system itself. Net exergy output from the system will be measured in terms of electrical power produced and surplus heat available for harvest or recycling, with an adjustment for overall system efficiency [Formula 1]. Gross, system-wide efficiency will be calculated by comparing the energy content of the sludge feedstream to the net energy captured and the theoretical system efficiency. Theoretical system efficiency will be simulated using AspenPlus® modeling software. Total thermoeconomic inputs to the system will be calculated by adding energy measurements to the lifecycle exergy of the oxygen used to drive the reaction and other operational energy measurements. Efficiency results from

$$\eta_{Ex} = \frac{\dot{W}_{Net}}{\dot{m}_{fuel} ex_{fuel}}$$

Formula 1. Net Exergy

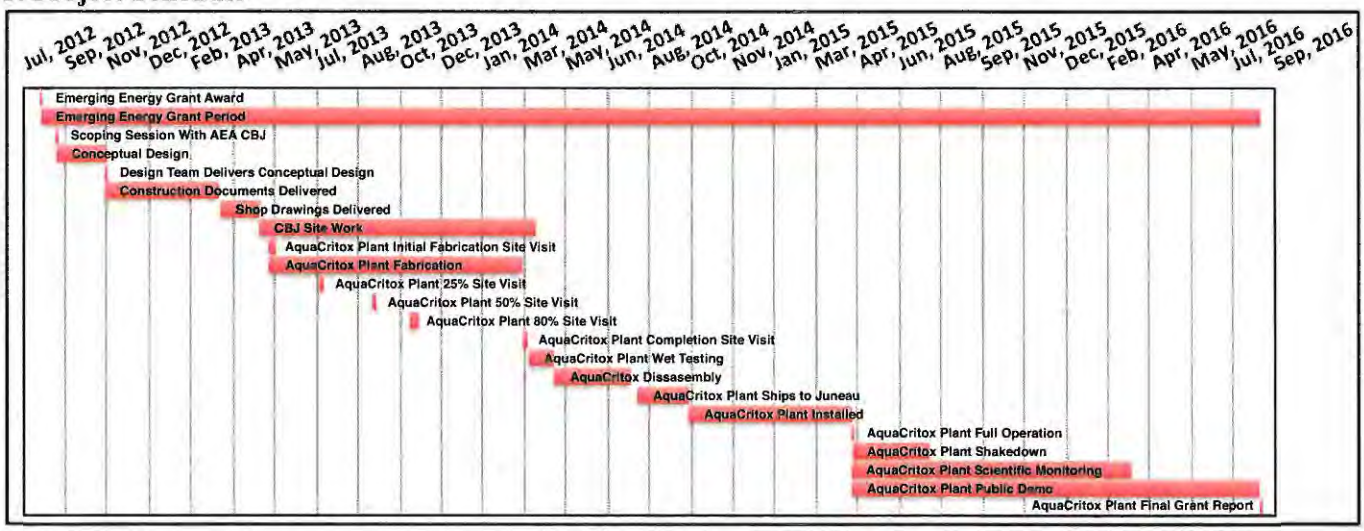
European pilot runs of the SCWO technology are shown in Table 1 in a comparison with typical incineration estimates. The expected efficiencies of a larger AquaCritox® plant will be calculated based on the net-captured-energy of the demonstration system plus additional capturable energy with the use of higher-efficiency heat exchangers and steam turbines suitably available only on larger systems. The exergic efficiency of sewage-sludge destruction and the energy captured from that biomass using the AquaCritox® plant will be compared to that of traditional incineration methods. Fourth, maintenance and operation conditions will be reported. The integrated Rockwell Automation controls and condition monitoring software will allow for real-time collection of operational data on the AquaCritox® plant. Data on frequency and type of system breakdowns, including in-service time as a percentage of operating hours, will be analyzed. In addition, system integrity will be assessed periodically via corrosion and scaling analyses by an outside laboratory. The above-mentioned technical and thermoeconomic methods are structured to provide an objective evaluation of the AquaCritox® system. Long-term savings will be calculated in two ways: 1) the simple, economic net-present-value of the savings in actual operating and capital costs will be compared to rough-order-of-magnitude, pre-deployment estimates, and 2) the thermoeconomic, exergic net-present-value of the energy savings. Economic indicators including calculated and projected accumulated cash flow at the end of the expected project life, payback period, and net-present-value will also be used to evaluate the economic viability of AquaCritox® as compared to incineration. The data will be used by Lammergeier CleanTech to develop commercialization strategies inside and outside of Alaska.

Technology Comparison	AquaCritox®	Incineration
Technology Status	Emerging	Established
Max Moisture	>95%	<60%
Sludge Energy (MBTU/Dry Ton)	17.9	17.9
Process Energy (MBTU/Dry Ton)	1.6	33.2
Net Energy (MBTU/Dry Ton)	16.3	(15.3)

Table 1. Thermoeconomic Comparisons

For this project, an AquaCritox® A4 system will be deployed as skid-mounted modules in a total of four to six shipping containers (i.e., 20-foot and 40-foot "CONEX boxes"). Modifications will be made to the containers (e.g., roll-up side doors) to improve viewing, demonstration, and maintenance of the system. The containers will be sited and arranged inside a soft-sided structure (ClearSpan® or equivalent) next to the sludge-pressing building at the JD Facility near downtown Juneau. The modular AquaCritox® system will be connected with specified wiring, plumbing, and piping and then intertied into the JD Facility's electrical, plumbing, and sludge delivery systems. Switching equipment will be installed to deliver surplus power from the organic Rankine turbines to the JD Facility. This full integration of the AquaCritox® plant and the JD Facility will enable on-site use of the energy contained in the sludge while simultaneously avoiding waste storage and transportation costs.

3. Project Schedule



Project Budget

Line Item	Direct	Indirect	Total	% Total
AquaCritox® A4 Plant	$8,587,500	$707,500	$9,295,000	89.6%
UAF Scientific Oversight	$217,500	$72,500	$290,000	2.8%
Project Management	$424,320	$75,000	$499,320	4.8%
Juneau Engineering	$0	$90,000	$90,000	0.9%
Juneau OPEX	$203,000	$0	$203,000	2.0%
TOTAL	$9,432,320	$945,000	$10,377,320	100.0%

4. Team Qualifications: The assembled team brings considerable diversity and project management capabilities. These partners have extensive business, engineering, scientific, product development, and operations experience. **Lammergeier CleanTech**, specializing in bioenergy technology, is providing majority funding (***52%***), overall project management, partner coordination, and the technical and business expertise needed to develop and lead the commercialization strategy for AquaCritox®. The **City and Borough of Juneau** (CBJ) operates and maintains three wastewater treatment facilities. As part of an ongoing effort to find a long-term solution for sewage sludge disposal, the CBJ will provide this project with substantial funding (***34%***) and supervisory controls using staff engineers. **Wilson Engineering** has designed and built extensive infrastructure throughout Juneau and will provide engineering and project management for site preparation, local build-outs, and integration oversight for the deployment site. **University of Alaska Fairbanks** professor, **Dr. Juan Andres Soria**, teaches and conducts biomass-conversion-technology research of wastestreams using innovative approaches including supercritical fluids. Dr. Soria has served as a member of the National Academy of Science and worked for the World Bank Group and Fortune-500 companies on development, construction, and operation phases of large-scale (>30MW), renewable energy projects. Dr. Soria will provide technical support and scientific oversight for all phases of this project. **Supercritical Fluids International (SCFI) Group** is an Ireland-based company specializing in the supercritical water oxidation of industrial and municipal wet wastes. SCFI owns the intellectual properties of AquaCritox® and will provide overall process support and technical advice. **Parsons Engineering, Ltd.**, a $3-billion company with offices in all 50 states and 24 countries, actively partners with research and development pioneers to commercialize technologies. Parsons will provide overall AquaCritox® mechanical design and will coordinate construction engineering on this project. Parsons Vice President of Technology, **Dr. Ashok Rao**, will be the key engineering coordination liaison as well as commercialization and sustainability spokesperson on this project. **Rockwell Automation**, a $6-billion, Fortune-500 company with offices in 33 states and 80 countries, provides industrial automation products and services. Rockwell Automation will oversee AquaCritox® component fabrication and assembly, build the controls, and integrate all computer and mechanical systems.

5. Technology Commercialization: The AquaCritox® system holds great commercialization potential as a solution to global energy problems regarding wet waste treatment and disposal. AquaCritox®'s scalability, flexibility, and modular design broadens the technology's potential market penetration and deployment options. AquaCritox® is scalable in terms of volume capacity, meaning that it can serve individual sewage treatment facilities in small communities (such as this demonstration in Juneau) or serve all of the sludge-disposal needs of large cities. Specifically, the proposed demonstration plant will process 250 liters/hour, but the system can be scaled up to a single-plant capacity of 13,000 liters/hour. AquaCritox® is flexible in terms of feedstock. The system is designed for sewage sludge, but it can process any organic waste that has been macerated into very small pieces and slurried with water. Alternative feedstock markets include (but are not limited to) paper pulp, finely ground sawdust, waste motor and cooking oil, fish offal, and livestock manure. AquaCritox®'s modular design allows either a single, large-plant installation, or multiple smaller plants running run side-by-side. A multi-plant installation also allows for independent and simultaneous processing of multiple feedstocks. Any combination of large and small modular plants can be installed, offering scalability and expansion to any capacity. Given the system's breadth in capacity and acceptable feedstocks, the commercial market for AquaCritox® is enormous. A successful, North American TRL7 demonstration of an energy-conserving and energy-producing AquaCritox® plant, as proposed in this project, will foster consumer confidence in this technology. It is anticipated that this project will gain national attention and likely accelerate the technology to TRL8 and TRL9 within the next four years. If widely adopted as a result of this demonstration, Alaska will be in the rare and enviable position of exporting a technology to the rest of the country that could annually eliminate billions in wastewater energy costs, power wastewater facilities, and generate billions in surplus electricity sales.

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

Jonathan Kamler _____

Chief Operating Officer, Lammergeier CleanTech