

Exhibit No. 4:

Avista 2019 Idaho Research and Development Report



AVISTA UTILITIES

SELECTED RESEARCH AND DEVELOPMENT EFFICENCY PROJECTS - IDAHO

Annual Report

March 31, 2020

**THE FOLLOWING REPORT WAS
PREPARED IN CONFORMANCE WITH
IDAHO PUBLIC UTILITIES COMMISSION (IPUC)**

CASE NO. AVU-E-13-08

ORDER NO. 32918

March 31, 2020

**ANNUAL REPORT
SELECTED RESEARCH AND DEVELOPMENT EFFICENCY PROJECTS
IPUC CASE NO. 32918**

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On August 30, 2013 Avista applied for an order authorizing it to accumulate and account for customer revenues that will provide funding for selected electric energy efficiency research and development (R&D) projects, proposed and implemented by the state of Idaho's four-year Universities. On October 31, 2013 Order No. 32918 was granted to Avista. Avista now recovers up to \$300,000 per year of revenue for research from the Company's Schedule 91 Energy Efficiency Rider tariff.

This program provides a stable base of research and development funding that allows research institutions to sustain quality research programs that benefit customers. It is also consistent with the former Idaho Governor's Global Entrepreneurial Mission "iGem" initiative in which industry would provide R&D funding to supplement funding provided by the State of Idaho.

B. Background

In the 1990s, with the prospect of electric deregulation, utilities reduced or eliminated budgets that would increase costs not included by third-party marketers for sales of power to end-users. Research and development was one of those costs. This has led to the utility industry having the lowest R&D share of net sales among all US industries.

Research and development is defined as applied R&D that could yield benefits to customers in the next one to four years.

In 2010, the former Governor announced Idaho would support university research as a policy initiative with some funding provided by the state and supplemental funding expected from other sources. This project provides additional funding to selected research.

II. KEY EVENTS

A. Request for Proposal

The Request for Proposal (RFP) for projects funded in the 2018/2019 academic year was prepared and distributed to all three Idaho Universities in March 2018. A full copy of the RFP is included in **Appendix B**.

On April 21, 2018, Avista received 10 proposals from the University of Idaho, 2 proposals from Boise State University, and 1 proposal from Idaho State University. Following is a list of the proposals received:

University of Idaho

1. Asset Health Management for Avista System
2. Designing and Evaluating an Energy Trading System for Prosumers
3. Develop New Sustainable Planning Process to Provide Non-wire Solutions to Capacity Planning
4. Energy Interdependency Risk Analysis
5. Energy Use at Clearwater Paper: Evaluating the Potential for Innovations with an Integrated Approach to Energy
6. Fluid Flow Electric Load Scheduling and Demand Side Management in Smart Districts
7. High Energy Efficient Aerogel-Glazing Coupled with Aerogel-Insulated Walls in Residential
8. Proof of Concept All-Iron Battery with Carbon Electrodes
9. Optimizing Energy Modeling of Dedicated Outdoor Air Systems in Cold and Dry Climate Zones
10. Using IR Cameras in Building Controls

Boise State University

1. Demand-Side Management of Non-Critical Residential Loads Using Power Electronic Modulators and/or Electric Springs
2. Analytics Toolkit for Interval Data from Aggregate Loads

Idaho State University

1. LED Street Light Technology

B. Selection of Projects

Avista prepared an evaluation matrix for the 13 proposed projects. A team of individuals representing Distribution, Transmission Planning, Generation and Demand Side Management, co-filled out the matrix to rank each of the projects. The following criteria, in no particular order, were considered in the ranking process.

- Research Areas Already Being Done (EPRI, WSU, AVA)
Complement/Redundant/New
- Potential Value to Customers kwh/KW/\$ (1-10)
- CO₂ Emission Reduction (Y/N)
- Market Potential (1-10)
- Are Results Measurable (Y/N)
- Aligned with Avista Business Functions (Y/N)
- New or Novel (Y/N)
- Ranking (1 -10)

C. Description of Selected Projects

Following is a brief description of each of the four selected projects from the 2018/2019 academic year. Project teams compiled “Two-Page Reports” which summarized and highlighted project details. These Two-Page Reports are included in **Appendix A**. Additional details are included in the final project reports in **Appendix D**, **Appendix E**, **Appendix F**, and **Appendix G**.

High Energy Efficient Aerogel-Glazing Coupled with Aerogel-Insulated Walls in Residential Buildings: Phase II (referred to as Aerogel Phase II)

Summary of Phase I

The main objective of this project was to investigate the thermal efficiency of Aerogel insulation blankets as a new insulation material for future implementation in the exterior walls of residential buildings. The research tasks were conducted using laboratory experiments, field measurements and computer simulations. The computer simulation tools included the EnergyPlus software, which is available to users through the U.S. Department of Energy, and the computational fluid dynamics (CFD) tool; FLUENT in ANSYS Multiphysics. The field measurements were collected from a room in a real apartment before and after the walls were insulated with the Aerogel blankets.

Project Description for Phase II

The goal of Phase II was to develop the means of implementing new energy-efficient aerogel glazing systems in residential buildings for Avista customers to combine with the aerogel insulated walls evaluated in Phase I.

The objectives of the project’s second phase were to: 1) determine the thermal properties of aerogel-based glazing systems, 2) develop and validate a numerical model using computational fluid dynamics to predict heat transfer performance of these systems, and 3) apply this model to a simulated, scaled 3D single-family house with walls and windows insulated with aerogel.

Ultimately, the feasibility of using aerogel blankets for walls and windows as a super insulator was verified using small scale laboratory testing, and high-fidelity computer simulations.

Proof of Concept All-Iron Battery with Carbon Electrodes (referred to as All-Iron Battery)

The objective of the project was to scale-up and refine the all-iron battery. The all-iron battery uses inexpensive and safe chemistry to store electrical energy. Through the scaling of the battery, the research demonstrated that the energy storage capacity is close to the theoretical limit. The research also showed that the power delivered by the cell can be increased to a practical level using carbon additives.

Designing and Evaluating an Energy Trading System for Prosumers (referred to as Energy Trading Phase I)

The objective of this project was to analyze and develop a prototype system that would enable Avista prosumers and consumers to trade power on-demand with utility oversight or with the utility while also ensuring the utility's network resilient operation with respect to the enablement of such prosumer-consumer transactions. A prosumer for this project is any retail customer that who may both consume and produce energy. A prototype software system was designed and developed that enabled the request of prosumer-consumer energy transactions through an online web and/or application interface. In addition, a system for evaluating the feasibility of the proposed transactions within the Avista distribution network was developed.

Integrated Design Lab (IDL): Using IR Cameras in Building Controls (referred to as IR Camera Phase I)

This project demonstrated the feasibility of using a low-cost infrared camera to estimate the mean radiant temperature in a room. This radiant temperature information was used to more effectively heat and cool buildings. The team set up a camera in an experimental chamber and collected data from various scenarios. Once collected, the team processed the data into a comfort prediction and sent that information as a standard control signal. Energy models were used to estimate the potential energy savings of incorporating an infrared camera into building's thermostats.

D. Project Manager and Related Communications

Avista set out to find an independent third-party project manager based in Idaho. On September 26, 2014 Avista entered into an agreement with T-O Engineers as this independent third-party project manager. T-O Engineers is a company based in Idaho, with offices in Boise, Coeur d'Alene, Meridian and Nampa, Idaho, as well as Cody, Wyoming, Heber City, Utah, and Spokane, Washington.

T-O is tasked with providing project management, organizational structure, milestone setup, milestone tracking, and incidental administrative services. The project manager for T-O Engineers is JR Norvell, PE and the deputy project manager is Natasha Jostad, PE. JR and Natasha are based out of the Coeur d'Alene and Spokane offices, respectively.

E. Agreements

By July 16, 2018 Avista executed individual task orders for each of the University of Idaho research projects selected. The agreements are included in **Appendix C**.

F. Project Milestones

The following graphics identify the overall research and development milestones, as well as the milestones for each project. Final reports from each Principle Investigator were submitted in the fall of 2019. In addition to the written report, each research team presented their findings in person to Avista. The Aerogel Phase II and IR Camera Phase I teams both presented their findings to Avista on August 19, 2019, and the All-Iron Battery and Energy Trading Phase I teams presented their findings on August 28, 2019.

Milestones/Deliverables All Projects												
Task Description	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19	Apr/19	May/19	Jun/19	Jul/19	Aug/19
	Fall Semester				Spring Semester				Summer Semester			
1. Project Kickoff	█											
2. Follow on Proposal to Avista								█				
3. Final Report and Presentation to Avista												█
4. IPUC Deliverables												█

Aerogel Phase 2												
Task Description	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19	Apr/19	May/19	Jun/19	Jul/19	Aug/19
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Literature Survey	█	█	█	█								
Task 2: Aerogel Window Samples Acquisition	█	█	█	█								
Task 3: Computer Validation of Aerogel-Based Glazing								█	█	█	█	
Task 4: Simulation of a Single-Family House as a case study					█	█	█	█	█	█	█	█
Task 5: Energy simulation for annual savings											█	
Task 6: Cost Analysis												█

All-Iron Battery												
Task Description	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19	Apr/19	May/19	Jun/19	Jul/19	Aug/19
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Collect final data on 20 mL Cell	█	█										
Task 2: Construct 200 mL Cell		█	█	█	█							
Task 3: Characterize 200 mL Cell					█	█	█	█	█			
Task 4: Build 1L Battery							█	█	█			
Task 5: Characterize and Present 1L Cell									█	█	█	
Task 6: Prepare Follow-up Proposal												█

Energy Trading Phase I												
Task Description	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19	Apr/19	May/19	Jun/19	Jul/19	Aug/19
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Gather system requirements and understand information interchange interfaces												
Task 2: Design and model the system using modern system modeling tools												
Task 3: Develop the database architecture and schema and select a DBMS												
Task 4: Analyze security risks and design and implement security mechanisms												
Task 5: Develop a simulated model of the power distribution network.												
Task 6: Design and sketch Web and/or App interfaces: User and Administration												
Task 7: Build the prototype software using a fourth-generation application development tool												
Task 8: Integrate the transaction control system prototype with the distribution model												
Task 9: Design and perform tests for: Functionality, Usability, and Security												
Task 10: Produce user and administrator usage guides												
Task 11: Create test cases for OpenDSS												

IR Camera Phase I												
Task Description	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19	Apr/19	May/19	Jun/19	Jul/19	Aug/19
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Project Planning and Reporting												
Task 2: Literature Review												
Task 3: Deploy IR Camera in Chamber												
Task 4: Collect Operational Data												
Task 5: Develop Algorithm to Process Measurements												
Task 6: Translate IR camera files to BACnet Signals												
Task 7: Estimate Savings												
Task 8: Develop Workflow for Practitioners												

III. ACCOUNTING**A. Schedule 91 Available Funds**

Effective November 1, 2013, Avista can fund up to \$300,000 per year of R&D from revenue collected through Avista's Schedule 91, Energy Efficiency Rider Adjustment. At the end of each year, any monies not allocated toward payment on R&D projects roll over as available resources for the next year. A summary of the balance for Schedule 91 from the beginning of Order No. 32918 is shown in the table below.

Academic Year	New Funding	Balance from Previous Year	Total Funds Available	Contracted Amount	Actual Expenditures	Balance
2014/2015	\$300,000.00	\$0.00	\$300,000.00	\$287,941.00	\$243,467.32	\$56,532.68
2015/2016	\$300,000.00	\$56,532.68	\$356,532.68	\$252,493.00	\$235,809.03	\$120,723.65
2016/2017	\$300,000.00	\$120,723.65	\$420,723.65	\$372,665.16	\$358,641.82	\$62,081.83
2017/2018	\$300,000.00	\$62,081.83	\$362,081.83	\$317,074.89	\$313,757.29	\$48,324.54
2018/2019	\$300,000.00	\$48,324.54	\$348,324.54	\$299,463.00	\$265,826.86	\$82,497.68
2019/2020	\$300,000.00	\$82,497.68	\$382,497.68	\$287,400.00		

B. Funds Authorized for R&D Projects in 2018/2019

Contracts for 2018/2019 are as follows:

Agency	Project	Contract Amount	Point of Contact
University of Idaho	Aerogel Phase II	\$ 82,873.00	Dr. Ahmed Ibrahim
University of Idaho	All-Iron Battery	\$ 48,141.00	Dr. Peter Allen
University of Idaho	Energy Trading Phase I	\$ 89,771.00	Dr. Yacine Chakhchoukh
University of Idaho	IR Camera Phase I	\$ 48,678.00	Dr. Damon Woods
T-O Engineers	Project Manager	\$ 30,000.00	James R. Norvell
Total		\$ 299,463.00	

C. Funds Expended and Remaining Balance

Following is the final budget summary for 2018/2019 FY R&D Projects.

Agency	Project	Contract Amount	Total Expended	Budget Remaining
University of Idaho	Aerogel Phase II	\$ 82,873.00	\$ 83,916.10	See below
University of Idaho	All-Iron Battery	\$ 48,141.00	\$ 30,529.55	\$ 17,611.45
University of Idaho	Energy Trading Phase I	\$ 89,771.00	\$ 83,037.16	\$ 6,733.84
University of Idaho	IR Camera Phase I	\$ 48,678.00	\$ 48,678.00	\$ 0.00
T-O Engineers	Project Manager	\$ 30,000.00	\$ 19,666.05	\$ 10,333.95
	Totals	\$ 299,463.00	\$ 265,826.86	\$ 33,636.14

Aerogel Phase II was a continuation of Phase I, conducted in FY 2017/2018. Due to the extension of the project, the research team finalized their Phase I work concurrent with the kick-off of their Phase II work and therefore, requested the budget total be evaluated as the contract amounts for Phases I and II. The following table outlines the contract amounts and funds expended for Phases I and II of the Aerogel project.

Project	Contract Amount	Total Expended	Budget Remaining
Aerogel Phase I	\$ 88,777.00	\$ 87,710.49	\$ 1,066.51
Aerogel Phase II	\$ 82,873.00	\$ 83,916.10	-\$1,043.10
Totals	\$ 171,650.00	\$ 171,626.59	\$ 23.41

D. Cost-Recovery

The costs associated with R&D are funded from revenue collected through Avista's Schedule 91 – Energy Efficiency Rider Adjustment. The outstanding balance was rolled over to the current year's R&D budget, as seen in the table in **Section III A**. All R&D projects are invoiced on a time and materials basis with an amount not to exceed. The costs would be included in Avista's annual tariff filing in June if the rider balance requires a true-up.

IV. PROJECT BENEFITS

A. Aerogel Phase II

Many buildings in the United States were constructed before energy efficiency was a concern. Therefore, a strong incentive exists to renovate existing buildings to meet minimum energy requirements as mandated by the federal and state governments. Aerogel is a transparent insulating material that meets this need to improve energy efficiency in residential buildings because of its extremely low thermal conductivity, high solar factor, and high daylight transmittance.

Experimental data and computer simulations were used to show that the overall yearly savings using 1 layer of window aerogel insulation is 39%. The overall yearly savings using 1 layer and 4 layers of wall aerogel insulation coupled with window aerogel insulation is 13.3% and 38.3%, respectively for a single-family house, compared to traditional insulation. The use of aerogel insulation in retrofitting existing structures and in new construction would result in energy savings for Avista customers.

B. All-Iron Battery

Expansion of renewable energy capability has resulted in periods of oversupply; when more energy is generated than can be used generators are forced to shut down. In sunny locations like Mexico, solar energy can cost as little as \$14 per megawatt hour. Prices in the Pacific Northwest are approximately \$30 per megawatt hour. This represents an economic opportunity in energy arbitrage: if oversupply of renewable energy could be stored and sold during peak demand, it would provide a new revenue source. In the long term, this will also increase overall demand for the expansion of wind and solar energy. However, there is no stationary battery technology that is sufficiently safe and inexpensive to make a practical grid storage solution. Cost is the critical factor for a stationary battery. Weight and volume are less important (unlike in mobile applications). The extremely low-cost, non-toxic, non-flammable all-iron battery can help meet this need. The team estimates that a shipping container sized all-iron battery could store approximately one megawatt-hour and deliver 1 MW of peak power for a total cost of \$0.09 per watt-hour stored.

C. Energy Trading Phase I

The adoption of consumer-level electric energy production and storage and of smart consumer appliances is accelerating. Examples of technologies leading this rapid adoption are photovoltaics, small wind, electric vehicles, and smart water heaters and freezers, among other technologies. Within such a new prosumer-enabled Smart Grid, enabling the managed but timely and selective trading and transmission of power between prosumers (producer-consumer) and with the utility, with utility oversight may enable a more efficient use of the Power Grid as well as provide utility savings on generation and transmission.

Such type of integrated system would enable Avista to develop a new market for prosumer-consumer power trading and also to plan, manage, and control such market and the flow of power through its network.

D. IR Camera Phase I

The research proved that it is possible to use an inexpensive thermal camera to predict comfort and occupancy in an office and run a thermostat based on those comfort predictions. The energy models showed net energy savings for Avista customers. The goal is to commercialize this device so that Avista customers may benefit from its development. During Phase II (in progress), the project is incorporating glare detection into the algorithm so that the device may serve multiple functions and eliminate superfluous sensors and wiring in buildings.

V. RESEARCH IN-PROGRESS

A. Summary of Research In-Progress

There are currently three projects in progress for the 2019/2020 academic year. Project kick-off meetings were held on-site at each University of Idaho location or via web conference in early fall 2019. Two stage gate meetings will be held throughout the academic year where the teams have an opportunity to showcase their research and plan upcoming work with input from Avista. Two-Page Reports were prepared in the spring of 2020 and describe the project objectives, business value and industry need. Additionally, the individual project tasks are summarized. Two-Page Reports are included in **Appendices H through J**. Each team will present their research and findings to Avista in the fall of 2020, as well as prepare a final research report. Final reports will be filed with the 2021 Annual Report.

The individual project tasks for the current IPUC funding projects are presented below.

Energy Trading Phase II												
Task Description	Sep/19	Oct/19	Nov/19	Dec/19	Jan/20	Feb/20	Mar/20	Apr/20	May/20	Jun/20	Jul/20	Aug/20
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Meet with Avista representatives to gather system requirements												
Task 2: Review of the literature on prioritization and pricing strategies at the distribution level												
Task 3: Evaluate options for revenue or objective prioritization and pricing functions												
Task 4: Enhance the simulated model of the power distribution network developed in Phase I.												
Task 5: Implement the prioritization algorithm in a modern programming language												
Task 6: Integrate the transaction control system prototype with the updated distribution model												
Task 7: Analyze the power grid condition and economic benefits for different scenarios												
Task 8: Design and perform tests for: Functionality, Usability, and Security												
Task 9: Produce user and administrator usage guides												

Gamification of Energy Use												
Task Description	Sep/19	Oct/19	Nov/19	Dec/19	Jan/20	Feb/20	Mar/20	Apr/20	May/20	Jun/20	Jul/20	Aug/20
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Research: Survey development												
Task 2: Research: Mockup												
Task 3: Research: Second Mockup												
Task 4: Research: Gaming applications; other attempts												
Task 5: Research: Incentive systems identified; user model prepared												
Task 6: Sampling: Deploy survey												
Task 7: Sampling: Analyze & interpret data												
Task 8: Sampling: Create profile template												
Task 9: Prototyping: Screens, navigation, access points												
Task 10: Prototyping: Integration, social feeds, notifications												
Task 11: Prototyping: Usability, user experience; final reports												

IR Camera Phase II												
Task Description	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19	Apr/19	May/19	Jun/19	Jul/19	Aug/19
	Fall Semester				Spring Semester				Summer Semester			
Task 1: Project Planning and Reporting												
Task 2: Set up HVAC Equipment												
Task 3: Automate IR Signal Processing												
Task 4: Develop Glare Detection Algorithm												
Task 5: Develop Business Case												
Task 6: Run comparison with old Thermostat												
Task 7: Document Results												

B. Other Relevant Activity

A progress meeting is held twice monthly for each project. These meetings typically take 0.5 hours and include a review of schedule, bi-monthly progress reporting, invoicing, Avista comments, and action items for the next meeting. The meetings are organized and led by the Independent Program Manager, T-O Engineers. Attendees for each meeting include the Principal Investigator, Co-Investigators, Student Researchers, Avista personnel, and the Independent Program Manager.

Contracts for these projects total \$287,400.00 and are summarized below.

Agency	Description	Contract Amount	Point of Contact
University of Idaho	Energy Trading Phase II	\$ 96,164.00	Dr. Yacine Chakhchoukh
University of Idaho	Gamification of Energy Use	\$ 108,736.00	Richard Reardon
University of Idaho	IR Camera Phase II	\$ 52,500.00	Dr. Damon Woods
T-O Engineers	Project Manager	\$ 30,000.00	James R. Norvell
Total		\$ 287,400.00	

Funds expended, and additional budget details will be summarized in the 2021 Annual Report.

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APPENDIX A

Two-Page Reports

High Energy Efficient Aerogel-Glazing Coupled with Aerogel-Insulated Walls in Residential Buildings: Phase II

Project Duration: 12 months

Project Cost: Total Funding \$82,873

OBJECTIVE

The PIs validated the thermal conductivity of the aerogel blankets in Phase I and found it to be very low as close to $0.014 \text{ Wm}^{-1}\text{K}^{-1}$, which confirms that aerogel blankets could be considered a super insulator. The proposed work will be based on experimental laboratory testing (Dr. Ahmed Ibrahim), ANSYS Multiphysics simulation including computational fluid dynamics (CFD) (Dr. Xing and Dr. Sean Quallen), and EnergyPlus (Drs. Ibrahim, Xing and Johnson). The team is proposing to develop full detailed 3D single family house simulation to capture the thermal performance of walls insulated with aerogel blankets and aerogel-based window panes. A practical tool for energy **consumptions' alternatives will be developed.**

BUSINESS VALUE

It is anticipated that the use of Aerogel-based window panes reduces the heat transfer across building envelopes and therefore will significantly reduce the annual heat loss compared to the currently used window material(s). In addition, a life cycle cost analysis with a full consideration of service life-cost will be performed and compared to the performance of conventional insulation materials.

Benefits to Avista: 1) Huge projected energy saving; the team performed a preliminary analysis on the proposed aerogel-based glazing and found that heating saving is estimated to be 15% when using one layer (0.4-inch) of aerogel insulation in a window and a wall of a typical building, and 2) Tool to assess energy consumption and potential saving and that will be based on parametric studies using the validated numerical simulations to quantify the various energy

leakage sources and optimize the design of the windows and walls.

INDUSTRY NEED

Energy sustainability is a crucial issue for the **humanity's** development in modern era, which can significantly impact future quality of life and the environment. The industry is moving towards the construction of sustainable-energy efficient buildings. The outcomes of the current research will have a direct impact on Avista customers saving energy, reducing need for natural gas and electricity. The Aerogel-based windows will be efficiently used in retrofitting existing structures and in new constructions as well.

BACKGROUND

The investigators have conducted a comprehensive literature survey for the up-to-date studies related to the performance and implementation of aerogel-based glazing insulation in residential buildings. Representative publications are listed below:

1. Ghoshala, S., Neogi, S. (2014). Advance Glazing System – Energy Efficiency Approach for Buildings a Review, Energy Procedia 54 (2014) 352 – 358
2. Cinzia Buratti, Elisa Moretti Transparent insulating materials for buildings energy saving: experimental results and performance evaluation, Third International Conference on Applied Energy - 16-18 May 2011 - Perugia, Italy
3. High Energy-Efficient Windows with Silica Aerogel for Building Refurbishment: Experimental Characterization and Preliminary Simulations in Different Climate Conditions

SCOPE

The scope of this project is mainly focused on evaluating the ability of the Aerogel-based windows to save energy through:

Task 1: Literature Survey

Various studies have reported on the characterization of Aerogel, along with preliminary investigation of its implementation as a super insulator, (Ghoshala, S., Neogi, S. (2014)., Cinzia et al. (2011).

Task 2: Aerogel Acquisition

The team has purchased 54 ft² of the Aerogel based glazing. The panes have a 16mm thickness. The team also purchased a computer workstation for the CFD simulations.

Task 3: Experimental Study

Dr. Ibrahim has started field data collection. Twenty thermocouple sensors have been attached to the cubical scaled room as shown in Figure 1. The scaled room was completely sealed and the internal temperature was raised up to 95°F and then the decay in temperatures was measured. Figure 2 shows Temperature vs. time for the vertical walls. The results will be used to verify the computer simulations.

Task 4: Modeling and Simulation

Dr. Tao Xing, and Dr. Sean Quallen are using computational fluid dynamics (CFD) to simulate a cubical scaled room built using the Aerogel panes.



Figure 1: View of cubical scaled room

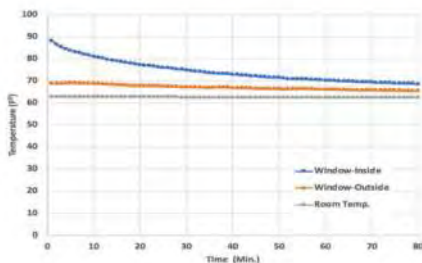


Figure 2: Temperature versus time for the south wall

The results of the CFD simulations have helped to determine an expected convection transfer coefficient inside our experimental domain as well as helping to determine ideas

for temporal and spatial discretization for future simulations. These results also demonstrate that the transition to a natural top-to-bottom temperature gradient happens rapidly, especially relative to the 1-2-hour experimental timeframe (see Figure 3).

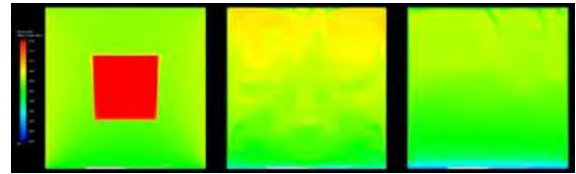


Figure 3: 2D simulation showing temperature distribution at t = 0s (left), t = 30s (middle), and t = 90s (right)

Task 5: Energy Simulation: will start on 5/2019

Task 5: Cost Analysis: will start on 6/2019

DELIVERABLES

The main deliverable of this project will be a final report includes all the experimental data the data and the computer simulations, cost analysis to compare the cost saving of the insulation panes.

PROJECT TEAM

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SCHEDULE

TASK	TIME ALLOCATED	START DATE	FINISH DATE
{Task 1: Literature review}	{ 5 Months}	{9/2018}	{12/2018}
{Task 2: Material purchasing}	{2 Months}	{9/2018}	{11/2018}
{Task 3: Computer Validation}	{3 Months}	{12/2019}	{2/2019}
{Task 4: Simulation}	{6 Months}	{2/2019}	{5/2019}
{Task 5: Energy simulation}	{1 Months}	{5/2019}	{6/2019}
{Task 6: Cost Analysis}	{2 Months}	{6/2019}	{8/2019}

Proof of Concept All-Iron Battery with Carbon Electrodes

Project Duration: 10 months

Project Cost: Total Funding \$48,141

OBJECTIVE

This project objective is to refine an extremely low-cost, non-toxic, non-flammable battery chemistry. This battery stores energy using an iron anode and an iron salt cathode. A new carbon electrode material developed in the Cheng lab at the University of Idaho is being used to increase performance. The primary advantage of the iron/carbon design is a low price per Watt-hour of storage. Our current results suggest that this chemistry will be economical for stationary applications. We are building a demonstration battery and are planning to spin out a company to commercialize its production.

BUSINESS VALUE

A safe and inexpensive battery could help expand the use of low-cost renewable energy. Energy storage also enables energy arbitrage.

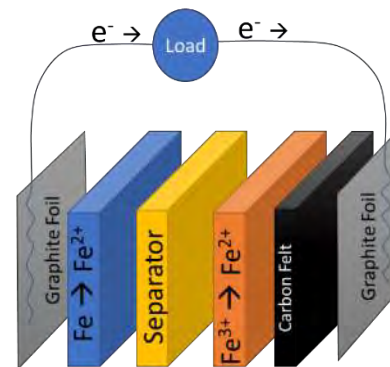
INDUSTRY NEED

Expansion of renewable energy capability has resulted in periods of oversupply; when more energy is generated than can be used generators are forced to shut down. In sunny locations like Mexico, solar energy can cost as little as \$14 per megawatt hour. Prices in the Pacific Northwest are approximately \$30 per megawatt hour. This represents an economic opportunity in energy arbitrage: if oversupply of renewable energy could be stored and sold during peak demand, it would provide a new revenue source. In the long term, this will also increase overall demand for the expansion of wind and solar energy. However, there is no stationary battery technology that is sufficiently safe and inexpensive to make a practical grid storage solution. Cost is the critical factor for a stationary battery. Weight and volume are less important (unlike in mobile applications). The extremely low-cost,

non-toxic, non-flammable all-iron battery can help meet this need.

BACKGROUND

Prior to Avista funding, the Iron battery was a crowdfunded effort **to make an "Open Source"** energy storage solution. The Allen lab screened iron salts and separator materials for low cost and high reliability. Avista funds have allowed for optimization and scale-up of the preliminary cell.



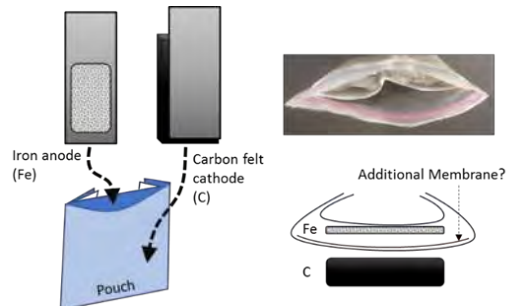
The overall cell is shown above. An iron anode is oxidized at the left. This produces electrons that flow to the right and react with iron (III) sulfate. We started with a 20 ml cell made from iron, iron (III) sulfate, and a polymer separator.

SCOPE

Task 1: Collect data on 20ml cell

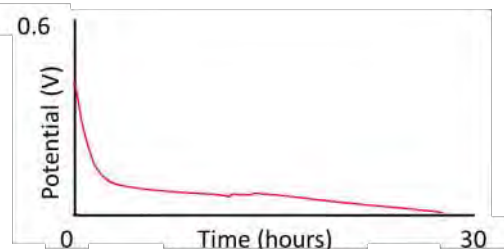
The project started with a prototype 20 ml cell which was not fully characterized. We replaced the inexpensive polymer (sodium polyacrylate) with Nafion (a commercial separator). We also refined assembly methods to make a sealed cell that lasted far longer than our original design. We characterized the resulting cell and found that it delivered ~10 mW of peak power. It also could be charged and discharged dozens of times with little loss in capacity.

Task 2: Construct 200 ml cell



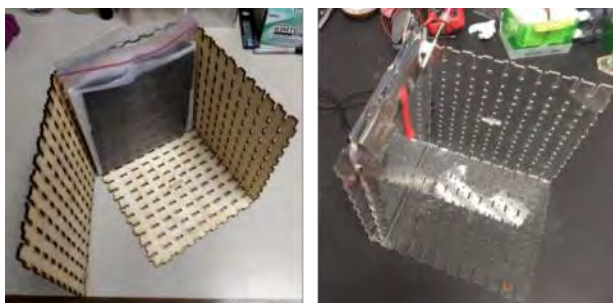
The 200 ml cell is a scaled version of the 20 ml cell. A plastic bag holds the “pouch” separator membrane. The pouch separates the interior (anode) from the exterior (cathode) electrolyte. The diagram above shows an assembled prototype. The first assembly procedure produced pinhole leaks in the plastic. The current assembly procedure produces a cell without leaks.

Task 3: Characterize 200 ml cell



The initial characterization of the 200 ml cell produced close to the desired total energy capacity but a low total power. The discharge of the cell takes 24 hours (as above) or longer. Cell improvements to meet the desired power requirements (1W) include alternative membranes and conductive additives (e.g. GUITAR carbon) to the electrolyte solutions.

Task 4: Build 1L battery



The 1 L battery will consist of five of the 200 ml cells connected in series. We have constructed a housing to contain the cell stack. Images of the prototype (left) and final acrylic (right) are shown above.

Task 5: Characterize 1L battery

The performance of the 200 ml stack will yield performance benchmarks for the 1L cell. The

performance objectives are a 15 Wh capacity and 15 watts of peak power.

Task 6: Prepare follow-up proposal

Options in the table include SBIR funding and private capital. We need to reach our goals for power and energy capacity.

DELIVERABLES

- Construct a 0.2 L cell (complete)
- 0.2 L cell stores 0.4 Wh (goal 1.5 Wh)
- 0.2 L cell delivers 40 mW (goal 1W)
- Construct a 1L battery (in progress)
- 1 L cell should store 15 Wh of energy
- 1 L cell should deliver >5 W peak power
- Apply for SBIR and/or propose venture funding for commercial production
- Report on appropriate path to market

PROJECT TEAM

PRINCIPAL INVESTIGATOR(S)	
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Organization	University of Idaho
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Email	
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Email	
Name	Depak Koirala
Organization	University of Idaho
Email	
Name	
Organization	University of Idaho
Email	

SCHEDULE

TASK	TIME ALLOCATED	START DATE	FINISH DATE
Collect data on 20ml cell	1	9/18	10/18
Construct 200 ml cell	3	10/4	1/19
Characterize 200 ml cell	2	1/19	3/19
Build 1L battery	2	3/19	5/19
Characterize 1L battery	2	5/19	7/19
Prepare follow-up proposal	1	7/19	8/19

Designing and Evaluating an Energy Trading System for Prosumers

Project Duration: 12 months

Project Cost: Total funding \$89,771

OBJECTIVE

The objective of this project is to analyze and develop a prototype system that would enable Avista prosumers and consumers to trade power on-demand with utility oversight or with the utility while also **ensuring the utility's** network resilient operation with respect to the enablement of such prosumer-consumer transactions. A prototype software system will be designed and developed that enables the request of prosumer-consumer energy transactions through an online web and/or application interface. In addition, a system for evaluating the feasibility of the proposed transactions within the Avista distribution network will be developed and integrated. Such type of integrated system would enable Avista to develop a new market for prosumer-consumer power trading and also to plan, manage, and control such market and the flow of power through its network.

BUSINESS VALUE

Avista will benefit from such prototype in the following ways:

- Provide a platform for testing new technologies and algorithms that would enable larger scale implementations of such customer-driven trading markets
- Enable the collection of data on sharing behaviors and trading patterns,
- Enable data analytics that may lead to increased efficiency in the distribution system,
- Enable data analytics that may lead to adequate and profitable electric power pricing strategies for prosumers and smart-grid enabled consumers and Avista power transaction fee structure.

INDUSTRY NEED

The adoption of consumer-level electric energy production and storage and of smart consumer appliances is accelerating. Examples of technologies leading this rapid adoption are photovoltaics, small wind, electric vehicles, and smart water heaters and freezers, among other technologies. Within such a new prosumer-enabled Smart Grid, enabling the managed but timely and selective trading and transmission of power between prosumers (producer-consumer) and with the utility, with utility oversight may enable a more efficient use of the Power Grid as well as provide utility savings on generation and transmission. For example, a temporary increase in demand from a smart-grid-enabled customer could be served from a grid-near prosumer with stored capacity or current wind or solar generation.

BACKGROUND

The following is an example of how the proposed prosumer-consumer power trading may work. **One of Avista's customers installs** solar panels or has a storage system such as an electric vehicle and generates or stores electricity. To sell some of this prosumer's excess electricity, this prosumer goes to an Avista-managed website and enters the amount of energy that they want to sell, the target price, its nature, and other constraints such as timing. An Avista customer needs some additional electricity at a given or scheduled time. Such customer goes to the same website and indicates an interest in buying energy under certain conditions, pricing, and time period. The proposed system then creates a match between the prosumer energy offers, requests, restrictions, timing, and pricing, informs the customers, enables and records the business transaction.

TASKS and STATUS:

Task 1: System Requirements

Research has been completed in determining the desired system architecture and modeling packages. OpenDSS will be used for modeling the power system.

Task 2: Database Design

Design and model the system using modern system modeling tools such as ERD. Completed design an implementation to support transactions. Refinements are needed to fully support the Power System Model interaction.

Task 3: Database Architecture

Develop the database architecture and schema and select a DBMS. Completed as needed for initial prototype. Refinements are ongoing.

Task 4: Security Risks

Analyze security risks and design and implement security mechanisms. Ongoing as implementation proceeds.

Task 5: Simulation Model

The IEEE 13 bus distribution model will be used for testing functionality. A model has been modified to include Photovoltaics, battery storage, electric vehicles, wind, and switch gear. This model will be used along side test cases for PV to test the application software.

Task 6: Web Interface

Design and sketch Web and/or App interfaces: User and Administration. Prototype system is complete. Enhancements are ongoing as needed.

Task 7: Prototype Software

Build the prototype software. Prototype system is complete. Enhancements are ongoing as needed.

Task 8: Transaction Control

The communication between the web application and OpenDSS has started and is being interfaced through a SQL query and Python. The team has the individual parts: SQL query, OpenDSS, and Python in the testing phases.

Task 9: Functionality Testing

The team has started testing individual pieces of the software. Communication between python and OpenDSS has been established, and the next steps are to incorporate the SQL query and database transactions.

Task 10: Usage Guides

This task will be performed after Task 9.

Task 11: OpenDSS Test Case

Three test cases are being explored for

implementation in OpenDSS. These cases are primarily for different time scales such as: one day, one week, one month data sets to provide enough Solar and customer data for testing.

DELIVERABLES

The deliverables on successful completion in this project including the software prototypes will be:

- Written final report of the results of these studies in the format approved by Avista.
- Interim reports and online conferences with Avista. Mid-term report.
- Proof-of-concept software and user and administrative documentation.
- Proof-of-concept evaluation within a small-scale simulated transmission and distribution system.
- Outlines of proposals for follow-on funding to further develop and refine the prototype.

PROJECT TEAM

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SCHEDULE

Task Item	Start Date	Finish Date	% Completion
Task 1	09/ 01/18	11/01/18	100%
Task 2	09/ 01/18	11/01/18	100%
Task 3	09/ 01/18	01/01/19	100%
Task 4	09/ 01/18	01/01/19	30%
Task 5	09/ 01/18	01/01/19	100%
Task 6	09/ 01/18	01/01/19	60%
Task 7	09/ 01/18	03/01/19	40%
Task 8	01/01/19	06/01/19	10%
Task 9	01/01/19	08/01/19	5%
Task 10	08/01/19	08/31/19	0%
Task 11	01/14/19	02/14/19	70%



Using IR Cameras in Building Controls

Project Duration: 12 months

Project Cost: Total Funding \$46,678

OBJECTIVE

This project will demonstrate the feasibility of using a low-cost infrared camera to estimate the mean radiant temperature in a room. This radiant temperature information is used to more effectively heat and cool buildings. Over the course of this study, the team will set up a camera in an experimental chamber and collect data from various scenarios. Once collected, the team aims to process the data into a comfort prediction and send that information as a standard control signal. Energy models will be used to estimate the potential energy savings of incorporating an infrared camera into building thermostats.

BUSINESS VALUE

Managing office temperatures by factoring in the surface temperatures would allow for wider air temperature setpoints, thus saving energy each year. Increasing the cooling setpoint by 5°F has been shown to reduce total HVAC energy by 27%. If the IR camera can successfully detect both surface temperatures and occupancy, then the need for additional occupancy sensors could be eliminated and this device can serve both purposes. If it is successful in detecting glare in a room, it could potentially serve in the role of a photosensor as well. The adoption of IR-enhanced thermostats provides a holistic sense of occupant comfort that enables offices to maintain efficient environments that improve worker productivity.

INDUSTRY NEED

Most buildings manage their heating or cooling based solely on zone air temperature. Even when the thermostats are kept within a narrow band of 4°F, occupant complaints persist (Arens, et al., 2010). A large factor of human comfort is being missed in conventional thermostats: the inclusion of the mean radiant

temperature. While surface temperatures are widely used for predicting human comfort, rarely are they directly used in building controls. A control system that incorporates the surface temperatures of a zone would allow for a wider range of supply air temperatures and better meet the needs of occupants. The wider range of air temperatures would reduce energy consumption and help to capitalize on operational features such as natural ventilation, night-flush and optimized set-points.

BACKGROUND

Many previous studies have established that the surrounding surface temperatures are more important to human comfort than the air temperature (Olesen 2007). Standard comfort predictions require both the air and surface temperatures, yet surfaces are rarely used in building controls. Surface temperatures can be measured with globe sensors, IR beams, or thermocouples, each of these methods has drawbacks of cost and complexity. With the recent reduction in cost of IR technology, low-cost cameras could provide an alternative.

SCOPE

The research team has set up an experimental chamber with an IR camera that has been able to accurately estimate surface temperatures to within 1°F. These readings have been used to calculate the impact that each surface's temperature might have on a hypothetical occupant. Energy models of the test chambers have been created to estimate energy savings of enhanced thermostat controls. At the end of the project, the research team will have developed a method to take a photo of a room using a low-cost IR camera and from that data, predict occupant comfort. That information will be sent out as a standard control signal which could be read by a typical HVAC system.

Task 1: Project Planning and Reporting

Conduct team meetings and ongoing project updates, reports and deliverables as required by Avista staff, project management contractors, and the PUC. This task continues throughout the project.

Task 2: Set up Experimental Chamber

The team will deploy instruments in a test chamber at the U of I IDL site to monitor all surface temperatures, air temperatures, light levels, and CO₂ levels.

Task 3: Deploy IR Camera in Chamber

IDL will set up the camera to take pictures at different angles and send the digital files to a computer for analysis to determine the ideal settings and method for MRT measurement.

Task 4: Collect Operational Data

The research team will use different setpoints for the HVAC system and occupy the room at different times over a period of several weeks to establish baseline data.

Task 5: Develop Algorithm for Processing Measurements

In parallel with Task 4, IDL will use the ongoing operational data collection to correlate the IR camera files to readings of temperatures, lighting, and occupancy.

Task 6: Translate IR Camera Files to BACnet Signals

The IDL team will develop a process to translate IR measurements into a BACnet signal that could be used by any controller.

Task 7: Estimate Savings

The team will use energy simulation results to compare the energy impacts of using an IR camera to manage controls versus traditional control signals (air temperature and CO₂) over a sample period.

Task 8: Develop Workflow for Practitioners

The final task will be to detail the methods of how to set up an IR camera for monitoring occupancy and surface temperatures and how those signals can be translated into building control networks. This will ideally inspire further commercialization of this concept and result in energy savings once implemented. This documentation will be submitted to an academic journal.

DELIVERABLES

- The team has completed a current literature review of the relevant technology in this sector.
- The team has prepared a test chamber for data collection with a mounted IR camera that is able to read the surface temperatures to within 1°F of accuracy.
- The camera and chamber have been used to collect a set of data that includes variations in the following categories: air temperatures, surface temperatures, occupancy, and lighting.
- The team has determined a set of equations that will allow the IR camera to estimate the mean radiant temperature at a location in the room.
- The next deliverable (not yet complete) is the ability to send a measurement of predicted occupant comfort as a standard control signal.
- The team will estimate energy savings for typical small commercial office buildings in the Pacific Northwest
- Documentation will be written on how to use an IR camera to record surface temperatures and provide an overall verification of the proof of concept for this technology.

PROJECT TEAM

PRINCIPAL INVESTIGATOR(S)	
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RESEARCH ASSISTANTS	
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Email	jubi5312@vandals.uidaho.edu

SCHEDULE

TASK	TIME ALLOCATED (Months)	START DATE	FINISH DATE
Project Planning	12	09/01/18	08/30/19
Set up Exp Chamber	2	09/01/18	10/26/18
Deploy IR Camera	2	10/01/18	11/16/18
Collect Data	2	12/01/18	01/25/19
Develop Algorithm	4	01/25/19	05/24/19
Translate Ctrl Signal	3	03/01/19	06/21/19
Estimate Savings	3	04/29/19	06/26/19
Develop Workflow	2	07/01/19	08/16/19



APPENDIX B

Request for Proposal

Request for Proposal (RFP)

Contract No. R-41895

for

Avista Energy Research (AER) Initiative

INSTRUCTIONS AND REQUIREMENTS

Proposals are due by 4:00 p.m. Pacific Prevailing Time (PPT), April 21, 2018 (the “Due Date”)

Avista Corporation is an energy company involved in the production, transmission and distribution of energy as well as other energy-related businesses. [Avista Utilities](#) is our operating division that provides electric service to 378,000 customers and natural gas to 342,000 customers. Its service territory covers 30,000 square miles in eastern Washington, northern Idaho and parts of southern and eastern Oregon, with a population of 1.6 million. Alaska Energy and Resources Company is an Avista subsidiary that provides retail electric service in the city and borough of Juneau, Alaska, through its subsidiary [Alaska Electric Light and Power Company](#). Avista stock is traded under the ticker symbol "AVA." For more information about Avista, please visit www.myavista.com.

**Avista Corporation (“Avista”)
RFP Confidentiality Notice**

This Request for Proposal (“RFP”) may contain information that is marked as confidential and proprietary to Avista (“Confidential Information” or “Information”). Under no circumstances may the potential Bidder receiving this RFP use the Confidential Information for any purpose other than to evaluate the requirements of this RFP and prepare a responsive proposal (“Proposal”). Further, Bidder must limit distribution of the Information to only those people involved in preparing Bidder’s Proposal.

If Bidder determines that they do not wish to submit a Proposal, Bidder must provide a letter to Avista certifying that they have destroyed the Confidential Information, or return such Information to Avista and certify in writing that they have not retained any copies or made any unauthorized use or disclosure of such information.

If Bidder submits a Proposal, a copy of the RFP documents may be retained until Bidder has received notice of Avista’s decision regarding this RFP. If Bidder has not been selected by Avista, Bidder must either return the Information or destroy such Information and provide a letter to Avista certifying such destruction.

Avista and Bidder will employ the same degree of care with each other’s Confidential Information as they use to protect their own Information and inform their employees of such confidentiality obligations.

Instructions and Requirements

1.0 PURPOSE

in response to the Idaho Public Utilities Commission Order No. 32918, Avista Corporation will fund up to \$300,000 per year of applied research that will further promote broad conservation goals of energy efficiency and curtailment. Specifically, Avista is seeking a qualified four year institution in the state of Idaho to provide such applied research (the “Services”). In light of the rapidly changing utility landscape, Avista would be interested in funding research projects which are forward thinking and would assist the utility in the development of product and services which provide an energy efficient commodity to its customers. The applied research and development projects can be one or multiple years and can be used to support university research programs, facility and studies.

The following institutions are eligible to submit Avista Energy Research (AER) initiative proposals.

1. University of Idaho
2. Boise State University
3. Idaho State University

Persons or institutions submitting a Proposal will be referred to as “Bidder” in this RFP; after execution of a contract, the Bidder to whom a contract is awarded, if any, will be the name of the university (“Institution”).

2.0 STATEMENT OF WORK

The attached Statement of Work (“SOW”) specifies the activities, deliverables and/or services sought by Avista. This SOW will be the primary basis for the final SOW to be included under a formal contract, if a contract is awarded.

3.0 RFP DOCUMENTS

Attached are the following RFP Documents:

- Appendix A – Proposal Cover Sheet
- Appendix B – Sponsored Research and Development Project Agreement

4.0 CONTACTS / SUBMITTALS / SCHEDULE

- 4.1** All communications with Avista, including questions (see Section 5.1), regarding this RFP must be directed to Avista’s Sole Point of Contact (“SPC”):

Russ Feist
Avista Corporation
1411 East Mission Avenue
PO Box 3727, MSC-33
Spokane, WA 99220-3727
Telephone: (509) 495-4567
Fax: (509) 495-8033
E-Mail: russ.feist@avistacorp.com

- 4.2** Proposals must be received no later than 4:00 PM Pacific Prevailing Time (“PPT”), on April 23, 2018 (“Due Date”). Bidders should submit an electronic copy of their Proposal to bids@avistacorp.com. In addition to an electronic copy, Bidders may also fax their Proposal to 509-495-8033, or submit a hard copy to the following address:

Avista Corporation
Attn: Greg Yedinak Supply Chain Management (MSC 33)
1411 E. Mission Ave
PO Box 3727
Spokane, WA 99220-3727

No verbal or telephone Proposals will be considered and Proposals received after the Due Date may not be evaluated.

4.3 RFP Proposed Project Schedule

<u>March 20, 2018</u>	Avista issues RFP
<u>April 9, 2018</u>	Bidder's Questions/Requests for Clarification Due
<u>April 13, 2018</u>	Avista's Responses to Clarifications Due Date
<u>April 23, 2018</u>	Proposals Due
<u>May 7, 2018</u>	Successful Bidder selection and announcement
<u>June 1, 2018</u>	Contract and Statement of Work Executed

5.0 RFP PROCESS

5.1 Pre-proposal Questions Relating to this RFP

Questions about the RFP documents (including without limitation, specifications, contract terms or the RFP process) must be submitted to the SPC (see Section 4.1), in writing (e-mailed, faxed, or addressed in accordance with Section 4.2, by the Due Date. Notification of any substantive clarifications provided in response to questions will be provided via email to all Bidders.

5.2 Requests for Exceptions

Bidder must comply with all of the requirements set forth in the documents provided by Avista as part of this RFP (including all submittals, contract documents, exhibits or attachments). Any exceptions to these requirements must be: (i) stated separately, (ii) clearly identify the exceptions (including the document name and section), and (iii) include any proposed alternate language, etc. Failure by Bidder to provide any exceptions in its Proposal will constitute full acceptance of all documents provided by Avista as part of this RFP. While Avista will not consider alternate language, etc. that materially conflicts with the intent of this RFP, Avista may consider and negotiate the inclusion of terms that would be supplemental to the specific document if such terms reasonably relate to the scope of this RFP.

5.3 Modification and/or Withdrawal of Proposal

5.3.1 By Bidder: Bidder may withdraw its Proposal at any time. Bidder may modify a submitted Proposal by written request provided that such request is received by Avista prior to the Due Date. Following withdrawal or modification of its Proposal, Bidder may submit a new Proposal provided that such new Proposal is received by Avista prior to the Due Date and includes a statement that Bidder's new Proposal amends and supersedes the prior Proposal.

5.3.2 By Avista: Avista may modify any of the RFP documents at any time prior to the Due Date. Such modifications will be issued simultaneously to all participating Bidders.

5.4 Proposal Processing

5.4.1 Confidentiality: It is Avista's policy to maintain the confidentiality of all Proposals received in response to an RFP and the basis for the selection of a Bidder to negotiate a definitive agreement.

5.4.2 Basis of Any Award: This RFP is not an offer to enter into an agreement with any party. The contract, if awarded, will be awarded on the basis of Proposals received after consideration of Bidder's ability to provide the services/work, quality of personnel, extent and quality of relevant experience, price and/or any other factors deemed pertinent by Avista, including Bidder's ability to meet any schedules specified in the Statement of Work.

5.4.3 Pre-award Expenses: All expenses incurred by Bidder to prepare its Proposal and participate in any required pre-bid and/or pre-award meetings, visits and/or interviews will be Bidder's responsibility.

5.4.4 Proposal Acceptance Term: Bidder acknowledges that its Proposal will remain valid for a period of 60 days following the Due Date unless otherwise extended by Avista.

5.5 Contract Execution

The successful Bidder shall enter into a contract that is substantially the same as the Sponsored Research and Development Project Agreement governing the performance of the Services/Work applicable under this RFP included as Appendix B. However, those Universities that have prior written agreements with Avista, may mutually agree to utilize those agreements with an extension and some modifications to the documents.

6.0 PROPOSAL REQUIREMENTS AND SUBMITTALS

Bidder's Proposal must conform to the following outline and address all of the specified content to facilitate Avista's evaluation of Bidder's qualifications; approach to performing the requested Services/Work; and other requirements in the SOW. Proposals will be evaluated on overall quality of content and responsiveness to the purpose and specifications of this RFP, including the information set forth in Section 6.5 below.

6.1 Proposal Process

Each eligible institution will be limited to **TEN** specific proposal submittals. One representative of the eligible institutions will be responsible for submitting all of the proposals.

The proposal must **not exceed 6 pages** not including the appendices. The proposal shall be in 11 point font, 1.5 spaced and one inch margins. The original and one electronic copy of the proposal (PDF – Form) must be provided to Avista's point of contact listed herein.

6.2 Proposal Submittals The following items are required with Bidder's Proposal. Each proposal shall contain the following project elements.

1. Name of Idaho public institution;
2. Name of principal investigator directing the project;
3. Project objective and total amount requested (A general narrative summarizing the approach to be utilized to provide the required services);
4. Resource commitments, (number of individuals and possible hours for services);
5. Specific project plan (An outline of work procedures, technical comments, clarifications and any additional information deemed necessary to perform the services);
6. Potential market path;
7. Criteria for measuring success;
8. Budget Price Sheet / Rate Schedule;
9. Proposal Exceptions to this RFP (if any);
10. Appendix A – Proposal Cover Sheet (last 2 pages of this document)
11. Appendix C: Facilities and Equipment
12. Appendix D: Biographical Sketches and Experience of the principle investigators and / or primary research personnel for each project (if different individuals for each project submitted)

6.3 Proposal Cover Sheet

Bidder must fill out, sign and date the attached Proposal Cover Sheet. The signatory must be a person authorized to legally bind Bidder's company to a contractual relationship (e.g. an officer of the company).

6.4 Institution Information

- Institution Qualifications

Bidder shall provide information on projects of similar size and scope that Bidder has undertaken and completed within the last five years. Please include a list of references on Appendix A that could be contacted to discuss Bidders involvement in these projects.

- Institution Resources

Identify any unique or special equipment, intellect, hardware, and software or personnel resources relevant to the proposed Services that Bidder's firm possesses(list in Appendix D).

- Project Personnel Qualifications

Provide a proposed organization chart or staffing list for a project of this size and scope and identify the personnel who will fill these positions. If applicable, identify project managers who will be overseeing the Services and submit their resume identifying their work history, (please see Section 6.2, question #4).

- Approach to Subcontracting

If Bidder's approach to performing the Services will require the use of subcontractors, include for each subcontractor: (a) a description of their areas of responsibility, (b) identification of the assigned subcontractor personnel, (c) resumes of key subcontractor personnel, (d) a summary of the experience and qualifications of the proposed subcontracting firms in work similar to that proposed, and (e) a list of references for such work.

6.5 Evaluation Criteria

Avista will evaluate each proposal based upon the following criteria:

6.5.1 Project Requirements

- Strength of Proposal
- Responsiveness to the RFP
- Creativity in Leveraging Resources
- Samples of Work Products
- Overall Proposal (Complete, Clear, Professional)

6.5.2 Strength & Cohesiveness of the Project Team

- Overall ability to manage the project
- Technical ability to execute the Services
- Research/analysis ability
- Project milestones with clear stage and gates (annually)
- Overall team cohesiveness

6.5.3 Qualifications and Experience

- Experience working with electric utilities
- Project management and multi-disciplined approaches
- Experience working with organizations in a team atmosphere

7.0 RESERVATION OF AVISTA RIGHTS:

Avista may, in its sole discretion, exercise one or more of the following rights and options with respect to this RFP:

- Modify, extend, or cancel this RFP at any time to obtain additional proposals or for any other reason Avista determines to be in its best interest;
- Issue a new RFP with terms and conditions that are the same, similar or substantially different as those set forth in this or a previous RFP in order to obtain additional proposals or for any other reason Avista determines to be in its best interest;
- Waive any defect or deficiency in any proposal, if in Avista's sole judgment, the defect or deficiency is not material in response to this RFP;
- Evaluate and reject proposals at any time, for any reason including without limitation, whether or not Bidder's proposal contains Requested Exceptions to Contract Terms;
- Negotiate with one or more Bidders regarding price, or any other term of Bidders' proposals, and such other contractual terms as Avista may require, at any time prior to execution of a final contract, whether or not a notice of intent to contract has been issued to any Bidder and without reissuing this RFP;
- Discontinue negotiations with any Bidder at any time prior to execution of a final contract, whether or not a notice of intent to contract has been issued to Bidder, and to enter into negotiations with any other Bidder, if Avista, in its sole discretion, determines it is in Avista's best interest to do so;
- Rescind, at any time prior to the execution of a final contract, any notice of intent to contract issued to Bidder.

[END OF REQUEST FOR PROPOSAL INSTRUCTIONS AND REQUIREMENTS]



APPENDIX A - Proposal Cover Sheet
Bidder Information

Organization Name: _____

Organization Form: _____
 (sole proprietorship, partnership, Limited Liability Company, Corporation, etc.)

Primary Contact Person: _____ Title: _____

Address: _____

City, State, Zip: _____

Telephone: _____ Fax: _____ Federal Tax ID# _____

E-mail Address: _____

Name and title of the person(s) authorized to represent Bidder in any negotiations and sign any contract that may result (“Authorized Representative”):

Name: _____ Title: _____

If classified as a contractor, provide contractor registration/license number applicable to the state in which Services are to be performed. _____

Provide at least three references with telephone numbers (please verify numbers) that Avista may contact to verify the quality of Bidder’s previous work in the proposed area of Work.

REFERENCE No. 1: Organization Name: _____ Contact Person: _____ Project Title: _____	Telephone: _____ Fax: _____ Email: _____
REFERENCE No. 2: Organization Name: _____ Contact Person: _____ Project Title: _____	Telephone: _____ Fax: _____ Email: _____
REFERENCE No. 3: Organization Name: _____ Contact Person: _____	Telephone: _____ Fax: _____ Email: _____



Project Title:	
----------------	--

By signing this page and submitting a Proposal, the Authorized Representative certifies that the following statements are true:

1. They are authorized to bind Bidder's organization.
2. No attempt has been made or will be made by Bidder to induce any other person or organization to submit or not submit a Proposal.
3. Bidder does not discriminate in its employment practices with regard to race, creed, age, religious affiliation, sex, disability, sexual orientation or national origin.
4. Bidder has not discriminated and will not discriminate against any minority, women or emerging small business enterprise in obtaining any subcontracts, if required.
5. Bidder will enter into a contract with Avista and understands that the final Agreement and General Conditions applicable to the Scope of Work under this RFP will be sent for signature under separate cover.
6. The statements contained in this Proposal are true and complete to the best of the Authorized Representative's knowledge.
7. If awarded a contract under this RFP, Bidder:
 - (i) Accepts the obligation to comply with all applicable state and federal requirements, policies, standards and regulations including appropriate invoicing of state and local sales/use taxes (if any) as separate line items;
 - (ii) Acknowledges its responsibility for transmittal of such sales tax payments to the taxing authority;
 - (iii) Agrees to provide at least the minimum liability insurance coverage specified in Avista's attached sample Agreement, if awarded a contract under this RFP.
8. If there are any exceptions to Avista's RFP requirements or the conditions set forth in any of the RFP documents, such exceptions have been described in detail in Bidder's Proposal.
9. Bidder has read the "Confidentiality Notice" set forth on the second page of these "INSTRUCTIONS AND REQUIREMENTS" and agrees to be bound by the terms of same.


Signature: _____ Date: _____

*** THIS PAGE MUST BE THE TOP PAGE OF BIDDER'S PROPOSAL ***



APPENDIX C
University of Idaho Agreements

PROJECT TASK ORDER for SERVICES

Master Agreement No.	Task Order No.	Modification No.	Modification Date
MA, UI/Avista R-39872	3 for 2018-2019	1	
<p>This Task Order is made and entered into this 16th day of May, by and between Avista Corporation, herein called SPONSOR, and the Regents of the University of Idaho, herein called UNIVERSITY. The Task Order describes activities to be conducted by UNIVERSITY for SPONSOR. Any deviation from the work outlined in this Task Order and Attachment A must first be approved in writing by SPONSOR. In addition, work performed under this Task Order is subject to the provisions of the Master Services Agreement. The Master Agreement, and this Task Order and Attachment A constitute the entire agreement for the Work/ Services applicable under this Task Order. The terms and conditions of this Task Order may not be modified or amended without the express written agreement of both parties.</p>			
<p>Title of Services: High Energy Efficient Aerogel-Glazing Coupled with Aerogel-Insulated Walls in Residential Buildings: Phase II</p>			
<p>Start Date: 06/15/2018</p>	<p>Duration (number of months) 14 months</p>	<p>Estimated completion date: 09/14/2019</p>	
<p>UI PI: Ahmed Ibrahim</p>		<p>SPONSOR Representative: Randy Gnaedinger</p>	
<p>Consideration and Payment: UI agrees to perform the Services set forth in Attachment A, Scope of Services, and SPONSOR agrees to pay for said Services listed as budgeted amounts upon performance by UI. The obligation and rights of the parties to this Task Order shall be subject to and governed by terms and conditions of this Task Order and the Master Agreement.</p>			
<p>Funding Amount (\$): (Per Attachment A, Budget) \$82,873</p>			
<p>Deliverables: <input checked="" type="checkbox"/> Progress Reports: <input checked="" type="checkbox"/> Final Report: <input type="checkbox"/> Other:</p>			
<p>IN WITNESS WHEREOF, the parties hereto have set their hands on the day and year first written above:</p>			
<p>UI Representative Signature</p>		<p>Agency Representative Signature</p>	
<p>Deborah Shaver, AVP Research Administration Date:</p>		<p> Heather Rosentrater VP Date: 6-20-18</p>	

Attachment A

Scope of Work:

Performance of pioneering aerogel-based glazing systems will be investigated for energy saving in residential buildings. Aerogel is a promising transparent insulating material, with low thermal conductivity, high solar factor, high daylight transmittance and remarkable lightweight. A reduction of energy consumption for heating and electric energy saving in residential buildings could be implemented by using aerogel as a transparent glazing insulating material. In the USA, energy performance of buildings' administration encourages renovation of existing buildings to meet the minimum energy performance requirements since most existing buildings were built before energy efficiency regulations were a concern, and most of these buildings will still be functioning until 2050. The PIs are currently conducting a phase I project with Avista testing a real apartments' walls insulated with aerogel blankets. The results of the active project are promising for a major reduction in the energy consumption. The team is also conducting computer simulations to investigate various key parameters to lead to more accurate predictions of energy consumption reduction. The PIs validated the thermal conductivity of the aerogel blankets and found it to be very low as close to $0.014 \text{ Wm}^{-1} \text{ K}^{-1}$, which confirms that aerogel blankets can be considered a super insulator. The proposed work will be based on experimental laboratory testing (Dr. Ahmed Ibrahim), ANSYS Multiphysics simulation including computational fluid dynamics (CFD) (Dr. Xing), and EnergyPlus, THERM/WINDOWS (Drs. Ibrahim, Xing and Johnson). The team is proposing to develop a coupled THERM and CFD model to more accurately capture the thermal performance of windows assemblies' thermal and global building energy savings for the room/apartment under investigation. A practical tool for energy consumptions' alternatives will be developed. OBJECTIVES: The proposed idea is a continuation of the current project (aerogel insulation for buildings) to be coupled with a new implementation of new energy-efficient aerogel glazing systems in residential building envelopes. The proposed work will be closing the research gap for using aerogel in a whole residential building envelop to verify energy saving capabilities which will have a great positive impact for Avista customers. The main objectives of the proposed work are: 1) Investigate experimentally the thermal properties of aerogel-based glazing systems, 2) with the aid of the experimental data, develop and validate a comprehensive numerical analysis (coupled CFD and THERM) aerogel-glazing panels for 2 | Page predicting the heat transfer performance of windows' components, 3) use the validated coupled CFD and THERM approach to project savings for a whole typical residential single-family house as a case study with aerogel-insulated walls (active project) and aerogel-based windows under typical summer and winter conditions, and (4) same as objective (3) except using EnergyPlus to predict annual energy savings. BENEFITS TO AVISTA: B1) Huge projected energy saving: the team performed a preliminary analysis on the proposed aerogel-based glazing and found that heating saving is estimated to be 15% when using one layer (0.4-inch) of aerogel insulation in a window and a wall of a typical building, and B2) Tool to assess energy consumption and potential saving and that will be based on parametric studies using the validated numerical simulations to quantify the various energy leakage sources and optimize the design of the windows and walls. RESOURCE COMMITMENTS: Research team time up to 10% commitment as normal academic duties plus 270 hours during summer for all the PIs. One graduate student as a funded research assistant to run simulations, analyze data, and supervise and mentor an undergraduate student. One

undergraduate will help the graduate student during the project course. Students will be involved in every aspect of this project. The research team has been employed at the university of Idaho for number of projects in the past with great success. Potential students are majoring in Civil, and Mechanical Engineering. RESEARCH METHODOLOGY: Energy sustainability is a crucial issue for the human's sustainable development in the modern era which is greatly dependent on electricity for maintaining high quality of life. Per the statistics, buildings use about 41% of the consuming energy every year, which results in a large amount of wastes and affects the air quality, [1]. Therefore, it is imperative to promote energy efficiency of residential buildings. Currently, thermal insulation in modern buildings has become a crucial way to meet the demands of energy efficiency codes, by reducing the conduction of heat through walls and windows effectively. The following sections present the tasks to achieve the objectives of the proposed research. Task 1: Literature Survey-(1-month): The investigators will conduct a comprehensive literature survey for the up-to-date studies related to the performance and implementation of aerogel-based glazing insulation in residential buildings. Task 2: Experimental Testing-(3-months): It is proposed to build prototypes (Three aerogel-based windows with different thicknesses) with typical aluminum frames. The system will be assembled in the laboratory based on the test set up shown in Figure 1a, where all the proposed windows will be installed in all box sides. Figure 1a shows the existing laboratory test setup, where a cubical room with aerogel blanket walls being tested under internal heating source (current phase I project). Figure 1b shows 3 | Page comparison between the inner wall temperature profiles from existing CFD simulations and the experimental testing. A heater will be used to increase the inner temperature of the box to a certain degree and then it will be turned off and thermal properties will be measured with the help of thermocouples and heat flux sensors. The three prototypes will have a double-glazing unit with aerogel in interspace. The results of the three-proposed aerogel-based windows will be compared to one control typical window that is used in residential houses. So, in total the PIs will have four windows to be tested. The team will utilize the existing experimental set up system from the current aerogel Avista project to study the efficiency (thermal properties and energy consumption) of the developed aerogel windows. Figure 1: a) Experimental testing for an Aerogel cubical box, b) inner wall temperature profiles from CFD and experimental data (data from current Avista active project). Task 3: Computer Validation of Aerogel-Based Glazing -(4-months): The main goal from this task is to use the experimental results obtained from Task 1 to validate computer simulations using both THERM/WINDOW and ANSYS Multiphysics including CFD. THERM [2] is a state-of-the-art computer program used to model heat transfer and thermal performance of building components, and simulates the thermal bridging effect in building components such as windows and walls, and doors. The THERM program will be used together with another LBNL program named WINDOW [3]. The combination of the two programs will help determine the total window product U-factors and solar heat gain coefficients that is consistent with ASHRAE SPC142, ISO15099, and the national fenestration rating council. A third software tool, ANSYS Multiphysics including CFD, will be used to model airflows, heat convection between the air and walls, heat conduction through the wall layers, and heat radiation. This will allow the team to accurately model the 3D heat transfer phenomena of the aerogel windows' assemblies and visualize and validate the effectiveness of the proposed window types in a single-family house under typical winter and summer conditions. Aerogel blanket 4 | Page Task 3.1: Validation of Windows Assembly using THERM/WINDOW In this task, the first step is to develop materials and construction for the three prototypes of aerogel glazed windows, such as the glass cross section, frame materials and construction.

Different elements of the window (e.g. typically the center glass, and the frames) will be modeled separately in the THERM program to obtain the 2D heat transfer performance through windows thickness. In the next step, the 2D simulation results will be transferred to the WINDOW program to compose the overall 3D window performance of the whole assembly (glass, frames, etc.), which typically includes the U-value and solar heat gain coefficient, which are of most importance in energy simulation analysis and savings estimations. The performance values will be compared to a standard window (e.g. double pane) and the performance enhancement of the newly developed aerogel windows will be evaluated. Task 3.2: Validation of the coupled THERM/WINDOW and ANSYS Multiphysics including CFD This task aims to use the experimental data collected in Task 1 to validate the coupled THERM/WINDOW and ANSYS Multiphysics software. ANSYS Multiphysics has been validated in the current/active project. In this proposed project, the coupled software will be used to predict the transient temperature profiles at various locations (e.g. inner surface of the window, inner surface of the wall) and compare with the measurements (Task 1). Task 4: Simulation of a Single-Family House as a case study-(5-months in parallel with task 3): In this task, a scaled typical single-family house will be simulated using the validated THERM/WINDOWS-CFD coupling. The proposed model will have walls insulated with aerogel and with the aerogel-based windows included in the house envelop. The simulation results will be validated using measurements for the same geometry and environmental conditions including typical summer and winter operation circumstances. The airflow patterns, temperature gradient, and heat flux across the wall and windows will be simulated and the impact of the new aerogel on the overall thermal environment will be evaluated. Task 5: Energy simulation for annual savings-(1 month): EnergyPlus [5] which is a widely used state-of-the-art building energy simulation program sponsored by Department of Energy, will be used to predict the energy saving potentials of the building enveloped with aerogel windows. In the EnergyPlus simulations, the tested and validated windows performance's results will be used to estimate the savings using the proposed new windows. To achieve this, a baseline model will be developed and calibrated to serve as a reasonable base benchmark point. Part of this analysis has been developed in the Phase I project using one student residence unit located on the Moscow campus. In Phase II, the same case will be selected as the baseline case. Since multiple years of energy consumption data are available, new comparisons will be made to gain better confidence in the baseline model. 5 | Page The proposed new model will first consider the combined effects of using the aerogel window (to be developed in Phase II) alone for savings estimations. A method to properly use the validated heat transfer performance data (such as the overall U-value and the solar heat gain coefficient) validated performance data obtained in task 3.1 and then integrate the resulting data into the EnergyPlus model. Further, the proposed new model will incorporate the combined effects of both the aerogel wall (developed in Phase I) and the aerogel windows (to be developed in Phase II) to estimate the performance enhancement of the total aerogel enclosure. Since windows are considered typically significant heat transfer elements in modern buildings, it is believed that insulating windows with an aerogel product will allow heat loss from the building to be reduced much further down. Task 6: Parametric Study and Cost Analysis (4-month): The proposed parametric study will include various parameters such as number of glazing layers, aerogel layers, aerogel thicknesses, aerogel wall insulation thickness, etc. The amount of energy leakage through windows and walls for each case will be reported concurrently with the projected savings for Avista customers. The PIs will develop a cost analysis tool (excel spreadsheet) that

help Avista personnel to compare between the energy consumption of various walls and windows' configurations.

POTENTIAL MARKET PATH: The annual heat loss is expected to significantly decrease compared to the currently used insulation materials. If the technology appears to become feasible in a short-term time horizon, then recommendations for developing it further will be made so it can be applied to various types of residential buildings as a first step to transfer this knowledge. The results may also suggest commercially available technologies that can instead be implemented in the system. In that case, an implementation plan for moving forward to benefit the system ratepayers will be suggested.


CRITERIA FOR MEASURING SUCCESS: The deliverables for success in this project will include the following: 1. Report comparing current state-of-art windows' insulation schemes to the proposed aerogel glazing insulation system for providing energy savings and more efficient cooling/heating systems. 2. Report on the testing and analysis of energy saving resulted from Phases I and II. 3. Report on life cost analysis of the proposed windows' configurations with a tool to be provided to Avista personnel to assess aerogel-based walls and windows performance.

Budget

Salaries \$13,379
Temporary/Irregular Help \$19,656
Fringe Benefits \$4,625
Travel \$400
Supplies/Services \$9,500
Equipment \$
Other Direct Costs \$11,390
Total Direct Costs \$58,950
Indirect Costs @50.3%: \$23,923
Total Costs \$82,873

Budget Narrative: BUDGET: Salaries: Ahmed Ibrahim, Tao Xing, and Brian Johnson will provide advice to the undergraduate and graduate students hired in this project. Ibrahim will also teach and identify literature as well as administrative coordinator. Ibrahim requests 80 hours of summer salary. Xing requests 80 hours of summer salary, and Brian Johnson requests 40 hours of summer salary. Fringe benefits for faculty is 26.5%. 6 | Page One graduate student will work as a research assistant during the academic year of 2018-2019. The graduate student will be employed 780 hours at \$16.5 per hour during the academic year and 220 hours during summer 2019 at \$16.5 per hour with a fringe rate of 3.8%. The student will be involved in collecting laboratory data, data analysis, and develop and test simulation. One undergraduate student will be employed for 220 hours during the summer at a rate of \$12 during summer 2019. Student benefits: Student fringe rates are 3.8% academic year/8.7% summer session. Tuition and insurance: The estimated fiscal year 2019 academic year graduate student in state tuition per student is \$4788 and health insurance is \$907 per semester. All salaries and tuition fees have been adjusted for an annual increase for 2018- 19. Materials: The team requests \$5,000 to cover the cost of Aerogel windows and \$4,500 to cover the software license fees. Any money not spent on materials may be spent as student or faculty salaries and benefits. Travel: Two trips to Avista in Spokane to present results and to consult with Avista engineers and management. F&A / Overhead: Assessed at the rate of 50.3% of project direct costs excluding student tuition fees

PROJECT TASK ORDER for SERVICES

Master Agreement No.	Task Order No.	Modification No.	Modification Date
MA, UI/Avista R-39872	18705		
<p>This Task Order is made and entered into this 16th day of July, by and between Avista Corporation, herein called SPONSOR, and the Regents of the University of Idaho, herein called UNIVERSITY. The Task Order describes activities to be conducted by UNIVERSITY for SPONSOR. Any deviation from the work outlined in this Task Order and Attachment A must first be approved in writing by SPONSOR. In addition, work performed under this Task Order is subject to the provisions of the Master Services Agreement. The Master Agreement, and this Task Order and Attachment A constitute the entire agreement for the Work/ Services applicable under this Task Order. The terms and conditions of this Task Order may not be modified or amended without the express written agreement of both parties.</p>			
<p>Title of Services: Proof of Concept All-Iron Battery with Carbon Electrodes</p>			
Start Date: 08/01/2018	Duration (number of months) 24	Estimated completion date: 07/31/2020	
UI PI: Peter Allen		SPONSOR Representative: Randy Gnaedinger	
<p>Consideration and Payment: UI agrees to perform the Services set forth in Attachment A, Scope of Services, and SPONSOR agrees to pay for said Services listed as budgeted amounts upon performance by UI. The obligation and rights of the parties to this Task Order shall be subject to and governed by terms and conditions of this Task Order and the Master Agreement.</p>			
Funding Amount (\$): (Per Attachment A, Budget) \$48,141			
<p>Deliverables: <input checked="" type="checkbox"/> Progress Report Date: <input checked="" type="checkbox"/> Final Report Date: <input type="checkbox"/> Other:</p>			
<p>IN WITNESS WHEREOF, the parties hereto have set their hands on the day and year first written above:</p>			
UI Representative Signature		Agency Representative Signature	
Deborah Shaver, ASP Research Administration Date:		 Heather Rosentrater VP Date: 7-16-18	

Attachment A

Scope of Work proposal: Proof of Concept All-Iron Battery with Carbon Electrodes

1. Name of Idaho public institution:

University of Idaho

2. Name of principal investigator directing the project;

PI: Peter Allen, Co-Is: Francis Cheng, and Dean Edwards

3. Project objective and total amount requested:

Total budget: \$48,141

Project Objective: We propose to refine a prototype of an extremely low-cost, non-toxic, non-flammable battery chemistry based on iron and a new carbon electrode material developed in the Cheng lab at the University of Idaho. The price per kilowatt hour of storage will be economical immediately for stationary applications. A grant from Avista would allow us to build a demonstration battery and spin out a company to commercialize its production over the next year.

4. Resource commitments, (number of individuals and possible hours for services):

PI will commit 0.25 month (43 person-hours).

1 Student assistant will run experiments at 50% time (6 months, 2080 hours)

Institution Qualifications: Project Personnel Qualifications: PI will manage project with advice and mentorship from Co-Is (see Appendix D for biosketches). One research assistant will report to PI and whole team meetings will be held weekly to discuss progress. **Subcontracting:** This project will not include subcontracts.

5. Specific project plan:

Overview:

The Pacific Northwest is a leader in renewable energy. Expansion of the wind energy capability has resulted in periods of oversupply; more energy was generated than could be used and wind turbines were forced to shut down. This represents an economic opportunity in energy arbitrage: if oversupply of renewable energy could be stored and sold during peak demand, it would provide a new revenue source. In the long term, this will also increase overall demand for the expansion of wind and solar energy. However, there is no stationary battery technology that is sufficiently safe and inexpensive to make a practical grid storage solution. The needs of a stationary battery are very different than for mobile applications: weight and volume are less

important than cost. We propose to refine and scale a prototype of an extremely low-cost, non-toxic, non-flammable all-iron battery chemistry. The electrodes will be made from a new material developed at the University of Idaho. The price per kilowatt hour of storage will be economical immediately for stationary applications. A grant from Avista would allow us to scale up our current prototype battery and spin out a company to commercialize its production.

The mismatch between renewable energy supply and grid demand is a persistent problem. To meet peak demand, renewable sources of power will need to be highly redundant. Such redundancies also result in over-generation. During off-peak hours, renewable sources can generate excess energy. There is no effective way to collect and store that energy. This problem is going to grow. Solar energy is now being sold at \$20 per MWh. More than 50% of new power generation capacity added worldwide in 2016 was renewable. With prices dropping for new solar and wind generation, new renewable energy is likely to see the fastest growth (see *Global Trends in Renewable Energy Investment 2017* by Frankfurt School of Finance & Management). A large, inexpensive battery would provide a new economic opportunity. Excess energy that would otherwise be wasted can be purchased at a discount (on already low prices). That energy can then be sold back into the grid during peak demand at a significant profit. This ability to meet high demand can help with load balancing and add to overall grid stability and help the Pacific Northwest take advantage of new developments in solar energy even when the solar generation is located in more favorable climates.

The risk of fire is a deep concern for grid scale batteries. Battery storage facility fires have occurred in Kauai and in Japan. The Hawaiian facility built by Xtremepower ended in a fire at the Kahuku wind farm facility. A NGK facility in Japan also burned and the sodium-sulfur batteries made firefighting very difficult. Such storage projects were economical first for island locations with high fossil fuel costs. As the price falls for both solar power and lithium ion batteries, it will become economical in more areas and as part of home rooftop solar installations. Lithium ion batteries and all batteries with an organic electrolyte carry a fire risk. Non-flammable, non-polluting iron batteries can help solve these problems.

Iron batteries have a long history but have not been widely adopted. The Edison cell was invented in 1901 and uses iron and nickel-based electrodes. Nickel is prohibitively expensive at these scales. Iron production is five orders of magnitude larger than lithium and represents a far more ubiquitous material for extreme scale energy storage solutions. The iron-air battery and

iron flow battery have both been explored and tested extensively but must contend with sufficiently high voltages for hydrogen outgassing. The GUITAR material developed in the Cheng lab is a solution to this problem.

The University of Idaho Battery Group:

I Francis Cheng: Electrochemist and inventor of the GUITAR electrode material. Prof. Cheng's lab has the equipment and expertise necessary to synthesize GUITAR, assemble cells and perform performance tests. This includes potentiostats for characterizing electrodes and an Arbin battery test instrument for measuring the performance of finished cells.

Dean Edwards: Chemical engineer with decades of experience in battery formulation and production. This includes electrode additives and formulations that increased lead-acid battery performance.

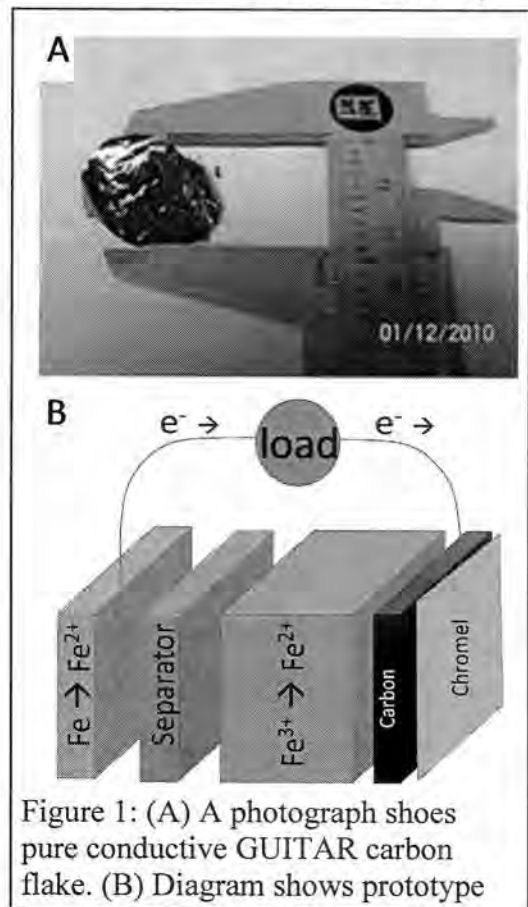
Peter Allen: Analytical chemist and rapid prototyping expert including experience in 3D printing, laser cutting, and microfluidics. Over 2017, Prof. Allen produced an iron battery prototype and video series with 100,000 views. A 2017 crowdfunding campaign raised \$5,000 to support initial battery testing. The Allen lab will assemble the prototype battery and develop cost effective, easily manufactured housings and separator membranes.

Technology details:

We propose to build a battery using inexpensive all-iron chemistry and an electrode made of Graphenic/graphitic material from the University of Idaho Thermolyzed Asphalt Reaction (GUITAR, see **Figure 1 A-B**). Batteries based on iron have a high price-performance ratio (Wh/\$). Iron is far more

abundant than current battery materials like lithium or lead. GUITAR is synthesized by thermal decomposition of low-cost carbon materials such as tire waste or asphalt.

We will build the battery from GUITAR powder saturated in a solution of iron salts (cathode) and iron metal (anode) in water. Aqueous batteries are inexpensive, but are prone to



hydrogen and oxygen outgassing. The GUITAR electrodes are an excellent solution to this problem. This carbon-based material is highly conductive and produces no hydrogen at the charging voltages of an iron battery. GUITAR is also resistant to corrosion.

Preliminary results and projections:

We have already shown that the iron chemistry can function reproducibly over many charge-discharge cycles. One example is shown in **Figure 2C**. A small pouch cell constructed with an iron anode and iron sulfate as the cathode ($\text{Fe}|\text{Fe}^{2+}||\text{Fe}^{3+}, \text{Fe}^{2+}|\text{C}_{\text{graphite}}$). The cell gave an open circuit potential of $\sim 1\text{V}$. The coulombic efficiency was $>90\%$ (**Figure 2D**). The capacity of the cell was $\sim 12\text{ J}$ or 0.3 kJ/kg . This cell contained only .2 % iron by mass which limited the total capacity of the battery.

Based on these results, we can extrapolate the storage capacity of a battery with increased iron content.

At 10% iron by mass, the battery will store a modest 15 watt-hours per liter. Commercial lithium ion batteries can store 500 watt-hours per liter. However, the iron, plastic, and separator for an iron battery costs a few cents per liter.

Assembly is inexpensive, simple, and requires no special equipment.

Estimates of material costs associated with a 1L iron batterie

are approximately \$0.5 for GUITAR, \$0.05 for ferric chloride and \$0.06 for iron plus a few cents for the plastic container and separators. This works out to about \$1 for a 1 liter, 15 watt-hour battery or \$70 per kWh. Even paying retail prices for the components, this is significantly better than any competing commercial technology.

Using a more soluble form of iron (e.g. iron EDTA or an iron-sugar complex) we have already shown iron content of 5%. With modest improvements and optimizations, we are confident that we can reach 10% iron by mass. With further developments over this coming year,

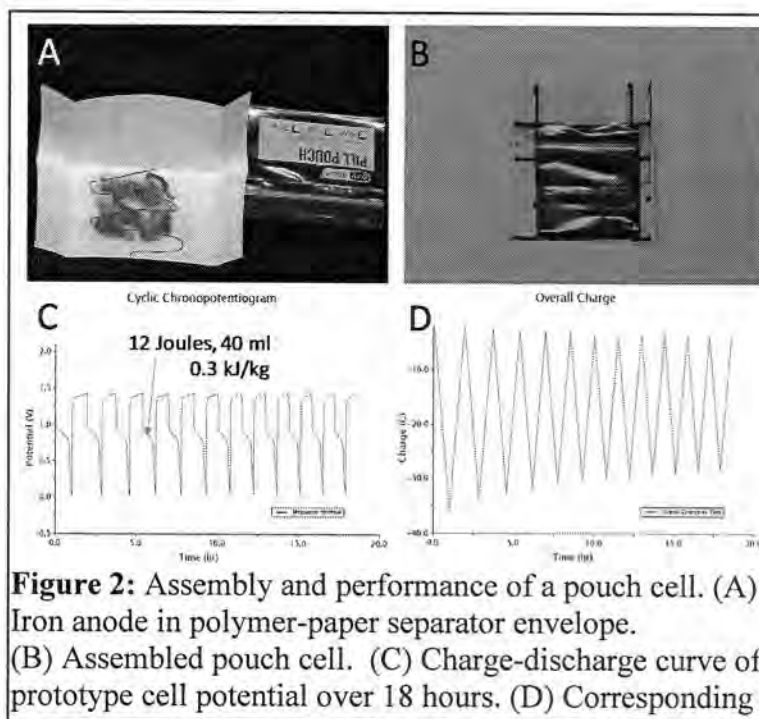


Figure 2: Assembly and performance of a pouch cell. (A) Iron anode in polymer-paper separator envelope. (B) Assembled pouch cell. (C) Charge-discharge curve of prototype cell potential over 18 hours. (D) Corresponding

we can refine the chemistry and assembly to achieve the desired performance. This will include optimization of pH, electrode additives, and iron solubility enhancers to minimize the cost per kWh stored.

With adequate iron content, the performance of the battery will be determined by the electrodes and separator. GUITAR is a highly conductive and corrosion resistant carbon that can be used at both electrodes to improve charge transfer and limit coulombic losses due to hydrogen and oxygen outgassing (current prototypes mitigate these problems by operating at pH 8). GUITAR electrode production has scaled from milligram- to 10-gram scale over the last 4 years. Senior Design Teams in Chemical and Materials Engineering along with graduate students in Chemistry helped develop the present methods for producing the GUITAR coated electrode materials in sufficient quantities to test in battery cells. In 2016, a team of senior Chemical Engineering students successfully coated GUITAR on glass microspheres. This makes a conductive powder that increases both the electrolyte storage and porosity in our battery. GUITAR can now be coated on the surfaces of glass, halloysite, and ceramic powders and carbon sheet. We have plans to move from a batch process in a tube furnace to a continuous process in a fluidized bed reactor. With support from Avista, GUITAR-coated electrode material will be generated at the kilogram scale, sufficient to produce a 1L battery and evaluate cost-performance of GUITAR electrode materials produced by different synthesis conditions.

Tasks or Deliverables:

We will expand our preliminary results to construct a 0.1 L cell with 1.5 Wh of energy storage capacity and >1 W peak power. We will use this to springboard development of a 1L, 15 Watt-hour cell with >10 W peak power (suitable for pallet scale 1 m³ array with 15 kWh and 10 kW performance). We will use this demonstration to solicit further investment. We will seek SBIR and venture funding for commercial production. We will determine the most appropriate path to market (e.g. in collaboration with a business school team and discussions with prospective investors).

6. Potential market path:

Plans to scale-up battery to a 1L test cell by 8/31/19.

GUITAR production will be scaled from batch to continuous production. Student engineering teams working in the Edwards lab have built a continuous reactor for synthesizing

GUITAR material. We will test and optimize protocols for GUITAR synthesis in this new continuous process.

We will scale our battery design to take advantage of larger quantities of GUITAR. Our current design is a plastic “pouch cell” approximately 20 milliliters in volume. We will scale this basic design to 1 L pouch cell batteries. These will be large enough for module-level performance and reliability tests. Once single modules are tested, they can be assembled into larger arrays. This follows the example of Tesla’s 2170 battery cell, which is 21 milliliters in volume. These small cells are manufactured and tested then assembled into battery larger packs. For the lower energy density iron cell, a larger size is needed.

We anticipate that GUITAR will be necessary to suppress hydrogen generation. Using the scaled production of GUITAR (currently in-progress) we will produce ~1 kg of GUITAR to build and test the 1L cell. We will optimize the production of GUITAR in terms of synthetic efficiency, and material properties. The key properties are conductivity and porosity. GUITAR gives our spin-out company two competitive advantages: 1.) the GUITAR material was invented at the University of Idaho and the necessary expertise to synthesize it is here; 2.) this material uniquely suppresses water hydrolysis and resists corrosion.

Seek investment for production facilities and equipment by 8/31/19

We will sponsor a student team in the Idaho Entrepreneurs and Entrepreneurship program at the University of Idaho, to help develop a marketing/business plan. This program sends teams to an annual business plan competition. Our team will evaluate the market and compare different paths to investment including the manufacture of batteries, battery packs or home-energy storage solutions.

We will evaluate two possible paths to market: 1) contract with utilities like Avista for shipping-container scale batteries for deployment at substations or 2) work with solar kit manufacturers and/or crowdfunding to supply pallet-scale batteries to back up home solar installations. Based on the evaluation of the market sizes, we will proceed to seek federal (SBIR, ARPA-E) and private funding to equip a factory. Participation in the business plan competition will also put our team in contact with an investor network who can help us find an experienced CEO to help find further investment.

7. Criteria for measuring success; Timelines:

We will optimize a GUITAR electrode synthesis protocol for large scale production. At 3 months, we will have 0.1 L cell with 1.5 Wh of energy storage capacity and >1 W peak power. At 9 months, we will finish constructing a 1 liter test cell and performance data will be collected (total capacity, degradation over multiple cycles). Our goal is a 15 Wh cell with >10 W peak power (suitable for pallet scale 1 m³ array with 15 kWh and 10 kW performance). We will use this cell to show construction costs of \$70 per kWh of storage capacity. At the end of 1 year, we will seek investors who can help us find a CEO with expertise in hardware startup companies. We will also seek Department of Energy Small Business Innovation Research funding to fund travel and scale-up.

Budget

Salaries \$12,767
 Temporary/Irregular Help \$
 Fringe Benefits \$865
 Travel \$
 Supplies/Services \$12,500
 Equipment \$
 Other Direct Costs \$8,864
 Total Direct Costs \$26,132
 Indirect Costs @ 50.3%: \$13,145
 Total Costs \$48,141

Budget Narrative:


8. Budget Price Sheet / Rate Schedule;

	Year 1
Allen salary, .25 month	\$ 1,677
Fringe (0.265 of salary)	\$ 444
Student stipend (6 months effort)	\$ 11,090
Student Fringe 3.8%	\$ 421
Tuition and fees	\$ 8,864
Materials	\$ 12,500
Reagents including but not limited to: glassware, reagents, plastic prototypes	
Total Direct	\$ 34,996
Modified Total Direct (MTDC)	\$ 26,132
@ 50.3% Indirect/Overhead	\$ 13,145
Total Project Cost	\$ 48,141

9. Proposal Exceptions to this RFP (if any);

Per section 5.2 of the RFP, the University has described exceptions to RFP requirements and conditions in the letter dated April 10, 2018, and included with Appendix A.

PROJECT TASK ORDER for SERVICES

Master Agreement No.	Task Order No.	Modification No.	Modification Date
MA, UI/Avista R-39872	18706		
<p>This Task Order is made and entered into this 16th day of July, by and between Avista Corporation, herein called SPONSOR, and the Regents of the University of Idaho, herein called UNIVERSITY. The Task Order describes activities to be conducted by UNIVERSITY for SPONSOR. Any deviation from the work outlined in this Task Order and Attachment A must first be approved in writing by SPONSOR. In addition, work performed under this Task Order is subject to the provisions of the Master Services Agreement. The Master Agreement, and this Task Order and Attachment A constitute the entire agreement for the Work/ Services applicable under this Task Order. The terms and conditions of this Task Order may not be modified or amended without the express written agreement of both parties.</p>			
<p>Title of Services: Designing and Evaluating an Energy Trading System for Prosumers at the University of Idaho, Moscow</p>			
Start Date: 8/01/2018	Duration (number of months) 12 Months	Estimated completion date: 7/31/2019	
UI PI: Yacine Chakhchoukh		SPONSOR Representative: Randy Gnaedinger	
<p>Consideration and Payment: UI agrees to perform the Services set forth in Attachment A, Scope of Services, and SPONSOR agrees to pay for said Services listed as budgeted amounts upon performance by UI. The obligation and rights of the parties to this Task Order shall be subject to and governed by terms and conditions of this Task Order and the Master Agreement.</p>			
Funding Amount (\$): (Per Attachment A, Budget) \$89,771			
<p>Deliverables: <input checked="" type="checkbox"/> Progress Report Date: <input checked="" type="checkbox"/> Final Report Date: <input type="checkbox"/> Other:</p>			
<p>IN WITNESS WHEREOF, the parties hereto have set their hands on the day and year first written above:</p>			
UI Representative Signature		Agency Representative Signature	
Deborah Shaver, AVP Research Administration		 Heather Rosentrater VP Date: 7-16-18	

Attachment A

Designing and Evaluating an Energy Trading System for Prosumers

University of Idaho

Principal Investigator and Project Director: Dr. Yacine Chakhchoukh

Co-Principal Investigators and Project Manager: Drs. Daniel Conte de Leon, Herbert L. Hess, Brian Johnson, Lei Hangtian, Ms. Arvilla Daffin.

Total Amount Requested: **\$89,771**

Project Objective

We propose to design, develop, test, and evaluate a software application that would enable prosumers and consumers to trade power on-demand or semi-automatically between themselves, with utility oversight, or with the utility. Such system would enable prosumer-consumer power trading with some of the characteristics of sharing economies and markets. Furthermore, the goal is that such system would lead, in the long run, to semi-automated trading of power similarly to current financial high-speed trading systems between smart-grid-enabled consumers, prosumers, and the utility. We will evaluate and select the best software technologies and design and develop a prototype software system that enables these transactions through an online web and/or app interface. Such system will enable Avista to create a new market for prosumer-consumer power trading and to plan, manage, and control such market and the flow of power through its network.

Avista will benefit from such prototype in the following ways: (1) Provide a platform for testing new technologies and algorithms that would enable larger scale implementations of such customer-driven trading markets (2) Enable the collection of data on sharing behaviors and trading patterns, (3) Enable data analytics that may lead to increased efficiency in the distribution system, (4) Enable data analytics that may lead to adequate and profitable electric power pricing strategies for prosumers and smart-grid enabled consumers and Avista power transaction fee structure.

Resource Commitment

Resource commitments for this project include the following:

- PI and co-PIs research and student mentoring time as part of normal academic duties.
- One graduate student in computer science as a funded Research Assistant (in budget request). This student will develop the proposed prototype trading platform.
- One undergraduate student as a funded Research Assistant. This student will create a model of the distribution system to enable system simulation and testing (in budget request).
- Rental for a year of necessary computing equipment time and software licenses (in budget request).
- Use of University of Idaho space and facilities and academic and network resources (as F&A).

Student Involvement

This project involves students in every part of the research: project definition, modeling of the system and its components, specifying and developing the software prototype, performing the simulation studies, analyzing the results of those simulations, creating proof-of-concept prototypes, analyzing and testing these prototypes, and making recommendations for means to

further investigate and implement discoveries. We have successfully employed such student-based and faculty-led teams in many projects of similar scope and purpose in the past. Students are majoring in Computer Science and in Electrical Engineering with an expectation to be involved in the electrical power industry as professionals in the near future. Having a sponsor like Avista as the recipient of the proposed deliverables would enhance student engagement and performance. We have realized a great deal of success from teams of this composition and the combination of technical competence and multiple levels of seniority and experience.

Rationale and Advantages

The adoption of consumer-level electric energy production and storage and of smart consumer appliances is accelerating. Examples of technologies leading this rapid adoption are photovoltaics, small wind, electric vehicles, and smart water heaters and freezers, among other technologies. Within such a new prosumer-enabled Smart Grid, enabling the managed but timely and selective trading and transmission of power between prosumers (producer-consumer) and with the utility, with utility oversight may enable a more efficient use of the Power Grid as well as provide utility savings on generation and transmission. For example, a temporary increase in demand from a smart-grid-enabled customer could be served from a grid-near prosumer with stored capacity or current wind or solar generation.

The following is an example of how the proposed prosumer/consumer power trading may work. One of Avista®'s customers installs solar panels or has a storage system such as an electric vehicle and generates or stores electricity. To sell some of this customer's excess electricity, this customer goes to an Avista®-supervised website or app and enters the amount of energy that he wants to sell, the target price, its renewable nature, and the restrictions and timing for the sharing of excess produced power. Another Avista® customer needs some additional electricity at a given or scheduled time. Such customer goes to the same website or app and indicates an interest in buying energy under certain conditions, pricing, and time period. The proposed system then creates a match between the prosumer energy offers, requests, restrictions, timing, and pricing (similarly to AirBnB), informs the customers, enables and records the business transaction, and schedules the transfer of power between these two customers. In a future implementation the system would also verify that the customers effectively traded the electric power as scheduled and promised. All these transactions facilitated and controlled by Avista®. Avista® provides the matching and transactions platform, the electrical path to exchange the energy, and the transaction verification, and charges a fee for such services.

The proposed project will contribute to the concretization of the "transactive energy" vision where power flows directions could be reversed (i.e., from customer to the grid) motivated by financial gains through competitive pricing of electricity. The utility is paid for enabling the power flow through distribution and transmission systems and its enabled the planning, management, and control of the distribution of prosumer generated energy.

Avista® has interest in making this happen among many of its customers. In fact, when one of this project's PIs presented Avista® engineers with an idea that addressed only the electrical issues of such a system, the engineers suggested adding the customer-initiated transactions to the project. Avista® currently has a proposal under review for funding with the Clean Energy Fund of the Washington State Department of Commerce to develop such an interactive energy exchange among individual customers. Avista®'s engineers indicated that this proposed project would nicely complement the Department of Commerce effort by providing advanced research capabilities to solve the technical issues to make such a system possible while Avista® addresses the regulatory structure.

Technical Approach

The software components for the proposed project will be constructed using leading modern technologies and application development tools for online-enabled transaction processing. The customer and administrative interfaces will be Web and/or App-based. Data storage and analytics will be enabled by using modern database technologies. We plan on using a

Fourth-Generation application development tool that enables rapid system prototyping and implementation. A critical aspect will be to ensure future interoperability with Avista® systems.

Modeling small generation facilities, home and buildings management systems, storage technologies and the local network is the first step in an electrical framework. We propose to model the electrical behavior of small generation, such as home solar panels or wind turbines, and the issues of electrical compatibility to the distribution network. Simulation of this model will provide an appropriate technical electrical understanding of the seller's electrical side of the energy trading system. Issues of safety for people and equipment, capacity to supply what has been agreed upon, availability of energy from the means at hand (solar energy deals for nighttime delivery may not work well), and interface to the distribution network must be investigated and appropriate methods to ensure technical capability established.

Once the electrical energy is produced, it must be metered and documented as it enters the electrical distribution network. Appropriate metering must be installed, if not already in place, to document the quantity and timing of energy flow. Such things as demand and power factor, as well as energy delivery, must be measured and recorded. Interface to the distribution grid in accordance with rules established by appropriate authority must be enforced. In the long term, designing and programming the means to allow or inhibit energy transfer based on compliance must be assessed and enforced at the metering interface. We propose to develop models of a typical electric grid in coordination with Avista engineers. We will simulate these using rented computing resources and the university's Analog Model Power System. Appropriate supervision based upon grid conditions must be communicated to the producer. Modeling of the grid provides understanding of how to deliver the purchased energy through the distribution system. When the energy arrives, the same instrumentation and metering issues apply. The customer must have capacity and appropriate protection. From the customer's point of view, this process is similar to the service that the public utility already provides, but perhaps a little more information intensive. Services necessary to transport the energy must be documented. For example, reactive power is necessary to stabilize the voltage. If the public utility produces this, then a fee may be in order. The same is true for grid management services. Methods to establish a fee structure for these services are certainly important, but they are considered beyond the scope of this investigation.

If this investigation is successful, it will provide concrete avenues for solving one of the most important problems for incorporating prosumers as providers within the public utility system. Within this proposed system, the price of shared power will be established by the seller, buyer, and AVISTA in a private commercial transaction, negotiated by these parties. With many producers and consumers making these transactions, the price gets established in the same manner as prices for commodities in competitive markets have been determined for many centuries. As time permits, packaging and marketing this as software will be investigated. After project end, further enhancements to the software prototype by Avista or a third party will require purchasing of commercial licenses for the fourth-generation application development tools. In the context of the work done so far, these products will likely consist of software and methods for integrating photovoltaic assets into a system to reduce expenditures on additional distribution capacity into areas on the periphery of a public utility's system.

Specific Project Plan

The proposed tasks for the software effort are:

- T1: Meet with Avista® representatives to gather system requirements and understand information interchange interfaces such as to the Advanced Metering Infrastructure.

- T2: Design and model the system using modern system modeling tools such as ERD.
- T3: Develop the database architecture and schema and select a DBMS. T4: Analyze security risks and design and implement security mechanisms.
- T5: Develop a simulated model of the power distribution network.
- T6: Design and sketch Web and/or App interfaces: User and Administration.
- T7: Build the prototype software using a fourth-generation application development tool.
- T8: Integrate the transaction control system prototype with the distribution model.
- T9: Design and perform tests for: Functionality, Usability, and Security.
- T10: Produce user and administrator usage guides.

Proposed Project Schedule

01 September 2018	Project Kickoff. T1, T2, T3, T4, T5, T6, T7 start.
01 November 2018	T1, T2 complete. Initial prototype I.
01 January 2019	T3, T4, T5, T6 complete. T8 starts. Prototype refinement II.
01 March 2019	T7, T8 complete. T9 starts. Prototype refinement III.
01 June 2019	T8 complete. Prototype refinement IV.
01 August 2019	T9 complete. T10 starts. Final prototype refinement V.
31 August 2019	T10 complete and Final report.

Potential Market Path

This project will develop the technology to enable individuals entering the business of producing and marketing power on a very small scale. Results from this project provide a path on how to proceed with this technology for enabling the proposed trading market. Meanwhile, the software prototype could be further evolved and tested by enlarging the simulations and small-scale pilot projects. Studies will identify and address issues of software and electrical distribution to eventually create a useful product for marketing electrical power. Engaging energy development resources, for example through US Department of Energy or State of Idaho innovation and entrepreneurial funding could follow. Creating a business plan would be appropriate at that point in the development process, when nearing completion of such follow-on projects. At the pace that similar products have been developed, it is reasonable to estimate that a working system may be available within five years. The savings to ratepayers and the utility will depend upon prices that are negotiated and on the fee structure for public utility support services.

Criteria for Measuring Success

Success of this project will be measured by the on-time achievement of the proposed project schedule and deliverables, including the software prototypes.

1. Written final report of the results of these studies in the format approved by Avista.
2. Interim reports and online conferences with Avista. Mid-term report.
3. Proof-of-concept software and user and administrative documentation.
4. Proof-of-concept evaluation within a small-scale simulated transmission and distribution system.
5. Outlines of proposals for follow-on funding to further develop and refine the prototype.

Budget

Salaries \$43,802
 Temporary/Irregular Help \$
 Fringe Benefits \$3,725
 Travel \$600
 Supplies/Services \$4,000
 Equipment \$
 Other Direct Costs \$11,424
 Total Direct Costs \$52,127
 Indirect Costs @ 50.3%: \$26,220
 Total Costs \$89,771

Budget Narrative:**Budget Price Sheet and Budget Justification**

	Expense Category	Year 1
A	Project Director, Principal Investigators, and Prog. Manager Salaries	\$5,894
B	Project Director, Principal Investigators, and Prog. Manager Fringe	\$1,665
C	Graduate and Undergraduate Student Researcher Salaries	\$37,908
D	Graduate and Undergraduate Student Researcher Fringe Benefits	\$2,060
E	Supplies, Software, and Computing Equipment Rental	\$4,000
F	Travel to Avista Headquarters in Spokane, WA	\$600
G	Graduate Student Tuition and Health Insurance	\$11,424
H	<i>Modified Total Direct Cost (MTDC) (A+B+C+D+F)</i>	<i>\$52,127</i>
I	<i>Facilities and Administrative Costs (50.30%)</i>	<i>\$26,220</i>
J	<i>Other Direct Costs (No F&A, Row G)</i>	<i>\$11,424</i>
K	Total Amount of Request (H+I+J)	\$89,771

Total Requested: \$89,771: MTDC \$52,127 + Student Supp. \$11,424 + Indirect 50.3% / MTDC \$26,220

Senior Personnel Salaries and Fringe Benefits: \$7,559: *Salaries \$5,894 + Fringe Benefits \$1,665*. Just: Senior personnel roles are: architectural design, manage, direct, administer project, and mentor students.

Student Salaries and Fringe Benefits: \$39,968: *Salaries: \$37,908 + Fringe benefits \$2,060*.

Justification: One graduate student at \$20.40/hour for 20 hours/week * 39 weeks during the academic year plus 30 hours/week * 13 weeks during summer 2019. Undergraduate student(s) at \$12/hour for 20 hours/week * 39 weeks during the academic year plus 30 hours/week * 13 weeks during summer 2019. Student fringe benefit rate is 3.80% in the academic year and 8.70% in the summer.

Student Tuition and Health Insurance: \$11,424: Academic year in-state tuition for graduate student \$9,756 plus yearly health insurance \$1,848; Summer health insurance is included. Not subject to F&A.

Services, Supplies, and Other Expenses: \$4,000: Cover costs of 4th generation application development tools and server licenses plus rental of time and space of computing, networking,

and storage from Center for Secure and Dependable Systems or cloud provider. Background checks required by university policy.

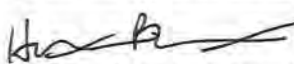
Travel: \$600: Two trips to Avista in Spokane to present results and to consult with Avista engineers and management.

Indirect Costs (F&A): \$26,220: Rate 50.3% of direct costs except tuition and health insurance (\$52,127).

Proposal Exceptions to this RFP

Per section 5.2 of the RFP, the University of Idaho has described exceptions to RFP requirements and conditions in the letter dated 10 April 2018 and included in Appendix A.

PROJECT TASK ORDER for SERVICES

Master Agreement No.	Task Order No.	Modification No.	Modification Date
MA, UI/Avista R-39872	18708		
<p>This Task Order is made and entered into this 16th day of July, by and between Avista Corporation, herein called SPONSOR, and the Regents of the University of Idaho, herein called UNIVERSITY. The Task Order describes activities to be conducted by UNIVERSITY for SPONSOR. Any deviation from the work outlined in this Task Order and Attachment A must first be approved in writing by SPONSOR. In addition, work performed under this Task Order is subject to the provisions of the Master Services Agreement. The Master Agreement, and this Task Order and Attachment A constitute the entire agreement for the Work/ Services applicable under this Task Order. The terms and conditions of this Task Order may not be modified or amended without the express written agreement of both parties.</p>			
<p>Title of Services: Using IR Cameras in Building Controls at the University of Idaho, IDL Boise</p>			
Start Date: 09/01/2018	Duration (number of months) 12 months	Estimated completion date: 08/30/2019	
UI PI: Elizabeth Cooper		SPONSOR Representative: Randy Gnaedinger	
<p>Consideration and Payment: UI agrees to perform the Services set forth in Attachment A, Scope of Services, and SPONSOR agrees to pay for said Services listed as budgeted amounts upon performance by UI. The obligation and rights of the parties to this Task Order shall be subject to and governed by terms and conditions of this Task Order and the Master Agreement.</p>			
Funding Amount (\$): (Per Attachment A, Budget) \$48,678			
<p>Deliverables: <input checked="" type="checkbox"/> Progress Report Date: <input checked="" type="checkbox"/> Final Report Date: <input type="checkbox"/> Other:</p>			
<p>IN WITNESS WHEREOF, the parties hereto have set their hands on the day and year first written above:</p>			
UI Representative Signature		Agency Representative Signature	
Deborah Shaver, AVP Research Administration Date:		 Heather Rosentrater VP Date: 7-16-18	

Attachment A

Scope of Work:

Objective

This research project will demonstrate how a thermal imaging camera can be incorporated into building controls for more efficient operation. Ideally, a building provides heating or cooling to maintain occupant comfort. Conventional thermostats fail to do so on two fronts: they do not measure occupancy and only manage the air temperature (a flawed proxy for comfort).. A new approach is to use an InfraRed (IR) thermal imaging camera to estimate the occupancy and surface temperatures of a space based on pixelated temperature grids.

Controlling a building based on both surface and air temperatures can reduce energy consumption and promote healthier buildings. People are almost twice as sensitive to surface temperatures as they are to air temperatures (Moe, 2010). Even so, the surrounding surface temperatures, sometimes known as the Mean Radiant Temperature (MRT) is rarely used in building controls. Instead, most thermostats manage a building's heating or cooling based solely on a zone's air temperature. This can result in excessive energy use and occupant complaints even when the thermostats are kept within a narrow band of 4°F (Arens, et al., 2010).

The team at IDL is currently engaged in a research project from last year's Avista Corporation R&D Funding to survey thermal conditions and controls at a number of offices in the same climate zones as Avista's service territory. To date, almost all measurements have shown conditions out of range of ASHRAE's thermal comfort criteria when the building's control signal (thermostat) does not incorporate the MRT. Preliminary findings suggest that incorporating MRT into the thermostat control would be particularly effective at reducing cooling costs in office buildings. IDL is working to estimate savings when controls incorporate MRT. The current study relies on temporary and unsightly surface temperature sensors. A better method is required for long term and continuous measurement of the MRT in a space.

The goal of this continuation project is to develop a method to quickly and inconspicuously measure the

surface temperatures and occupancy in an office using a thermal imaging camera and have the resulting measurements processed into a standard control signal.

Using an InfraRed camera to assess the surface temperatures in a space could significantly improve the efficiency of the HVAC system operation. However, the benefits don't end there. The IR camera can also register when the lights are on in a space and whether the space is occupied. These are two more signals that can be translated to BACnet objects and incorporated into building controls. The conventional method to detect occupancy and regulate HVAC systems is to use a CO₂ sensor, while simple IR motion sensors are used to manage lighting fixtures. An IR camera can serve both these functions and detect the MRT in a space. This would reduce the number of sensors needed in a space and could reduce installation costs. The recent dramatic reduction in the cost for IR cameras means they can now feasibly be used as a part of a building's control system. They are now at price parity with some CO₂ sensors. Some new building codes (particularly in the state of Washington) mandate occupancy sensors in many new buildings. Having a sensor that can serve three functions for the price of one is tremendously appealing. However, this concept needs to be proven.

IDL has several rooms on site that can serve as experimental chambers to test the functionality and accuracy of this approach. A proof of concept would significantly advance the building controls field in its assessment of occupancy, lighting, and MRT to improve building operation. It is the logical next step for continuing the operative temperature control development currently underway. A control system that incorporates the surface temperatures of a zone would allow for a wider range of supply air temperatures and better meet the needs of occupants. The wider range of air temperatures would reduce energy consumption and help to capitalize on operational features such as natural ventilation, night-flush and optimized set-points. Expanding just the air cooling setpoint by 5°F can save up to 27% of the total HVAC energy (Hoyt et al. 2014). However, expanded setpoints are only viable if occupant comfort is maintained. Up to \$330 per employee per year in lost productivity at work can be attributed to an office environment outside the bounds of ASHRAE 55's comfort setpoints (Tom 2008). Therefore, any temperature controller should factor in both occupancy and the MRT so that the space is comfortable when occupied.

This research would provide critical steps forward to advance control hardware and software to combine the measurement of occupancy and MRT in one device – a device that is rapidly coming down in price. This work sets up the necessary infrastructure to implement efficient control schemes that promote both comfort and energy efficiency.

Resource commitments, (number of individuals and possible hours for services):

Personnel	Hours estimate	Description
Elizabeth Cooper	60	Provide project guidance, support publication plan and market path approach
Damon Woods (TBC) – ME Faculty	240	Provide technical support, weekly management, and daily execution of tasks
TBD MS ME student	560	Execute daily tasks of this project

Specific project plan

The team will begin the research by setting up an experimental chamber. IDL has a room where thermocouples, CO₂ sensors, and humidity sensors can be installed to log data for an extended period of time. Team members will then set up an IR camera in the room so that it can be on continuously and send files to a computer either through Wi-Fi or a USB cable to a laptop in the room. Researchers will occasionally enter the room and adjust the thermostat that controls the ductless heat pump in the space to develop a range of occupancy and temperature scenarios. After at least one week, recordings of the data will be compared to the image files produced by the IR camera. The IR camera images can be broken down into a grid of pixels of different temperature values. These pixel temperature values will then be compared against the recordings from the other data loggers to verify their accuracy. The IDL has performed similar analyses in the past by using high resolution photographs to quantify the amount of glare from direct sunlight in a space. The challenge will be to compensate for the different reflectivity of various surfaces in the space and to correlate an occupant to a set of pixels of a certain temperature range. Once this algorithm is developed, the team will try this approach in a second experimental space on site to verify the method.

The IDL team will develop a script that can translate the processed IR image into a signal for building controls. The signal will be in the form of a BACnet object since this is a standard communication protocol that most new building controllers are required to use. IDL has done this in the past to send signals between energy models and controllers. Based on observed temperature and occupancy data, the team will estimate the potential energy impacts of using the IR camera MRT and occupancy signals to manage the heating and cooling of the space versus a traditional thermostat. The estimation will be carried out through the use of energy models of the space in the established, DOE software program, EnergyPlus.

The research team will document the process and establish a pathway for the controls industry to develop and commercialize the use of IR cameras as components of building controls. The research will highlight the potential savings and the value it could bring to consumers. The documentation will detail the methods and be pursued for publication in an academic journal to further the knowledge in the field. The project will be carried out in the following phases:

Task 1 Project Planning and Reporting – Conduct team meetings and ongoing project updates, reports and deliverables as required by Avista staff, project management contractor and the PUC. Ongoing throughout the project.

Task 2 Set up Experimental Chamber – The team will deploy instruments in a test chamber at the U of I IDL site to monitor all surface temperatures, air temperatures, light levels, and CO₂ levels; <1 month.

Task 3 Deploy IR Camera in Chamber – IDL will set up a platform that will enable the IR camera to take pictures at specified intervals and send the digital files to a computer for analysis. The team will test different angles and intervals to determine the ideal location and method for MRT measurement; 1 month.

Task 4 Collect Operational Data – The research team will use different setpoints for the HVAC system and occupy the room at different times over a period of several weeks to establish baseline data; 3-4 months.

Task 5 Develop Algorithm to Process Measurements – In parallel with Task 4, IDL will use the ongoing operational data collection to correlate the IR camera files to readings of temperatures, lighting, and occupancy; 5-6 months.

Task 6 Translate IR camera files to BACnet Signals – The IDL team will develop a process to translate IR measurements into a BACnet signal that could be used by any controller; 1 month.

Task 7 Estimate Savings – The team will use energy simulation results to compare the energy impacts of using an IR camera to manage controls versus traditional control signals (air temperature and CO₂) over a sample period; 1 month.

Task 8 Develop Workflow for Practitioners – The final task will be to detail the methods of how to set up an IR camera for monitoring occupancy and surface temperatures and how those signals can be translated into building control networks. This will ideally inspire further commercialization of this concept and result in energy savings once implemented. This documentation will be submitted to an academic journal such as Building Automation and Control; 1 month.

Potential market path

Building operations could benefit greatly from MRT and occupancy sensing controllers. Controls based on MRT would allow for wider air temperature setpoints in the summer, thus saving cooling energy each year. Increasing the cooling setpoint by 5°F has been shown to reduce total HVAC energy by 27%

(Hoyt et al. 2014). A study by the Pacific Northwest National Lab estimated slightly more conservative savings: a 2°F adjustment on both heating and cooling setpoints led to a fairly uniform HVAC energy savings of 12-20% (Fernandez et al. 2012). Nationwide, such savings would be equivalent to 370-615 trillion Btu saved annually (EIA 2012). For commercial office buildings in the Pacific Northwest, HVAC energy is typically 35% of the annual load (EIA 2012), an MRT thermostat implementation could result in total annual energy savings of 4-7% of annual energy consumption per building (Hoyt et al. 2014). A recent baseline study of buildings in the Pacific Northwest found average office building annual energy use to be 112 kBtu/ft² with an average office building size of 20,000 ft². (Baylon, et al., 2008). Given these assumptions, integrating an MRT controller could save 25,000 – 45,000 kWh/yr for an average office building. This represents only a general estimate, and firmer numbers will be established with the conclusion of the ongoing phase of this research this August. In addition to energy savings, an affordable MRT sensor could dramatically enhance occupant comfort, thus making it an attractive service to offer to clients.

This advance in controls coincides with Washington State’s latest energy code requiring occupancy sensors in many new commercial buildings that now must use Dedicated Outdoor Air Systems (DOAS) (Washington Administrative Code commercial buildings WAC 51-11C140360). Using IR cameras in lieu of CO₂ sensors could serve the same function of measuring occupancy with the added benefit of also measuring the MRT of a space. The report will provide a step-by-step methodology including a demonstration of how this sensor could be implemented at any site with code-compliant controls. As the new controller is integrated into the building’s energy management system, either building managers or utility companies could provide incentives for this type of controller. The market path may include the further development of this hardware and open source software for various private companies to develop their own IR camera controller.

Criteria for measuring success

- Project team has installed sensors and camera in experimental chamber recording measurements for intervals lasting at least one week.
- Project team has developed method to correlate IR camera files to MRT, occupancy, and lighting measurements.
- Project team has translated MRT, occupancy, and lighting readings to BACnet objects.
- Project team has built an energy model of the experimental chamber and contrasted simulation results of using IR camera control signals versus conventional thermostat control signals.
- Project team is able to articulate the process, measure the accuracy, and predict the energy savings of this approach to further commercialization.

Budget Price Sheet / Rate Schedule

Expense

PI/Faculty Salaries (Cooper and TBD ME)	\$ 13,244	
PI/Faculty Benefits (Cooper and TBC Woods)	3,509	
Graduate Student Salaries	8,960	
Student Benefits	340	
Graduate Student Tuition Remission (partial)	5,387	
Travel	2,250	
Equipment	500	
F&A / Overhead (Excludes Tuition)	<u>14,488</u>	
Total		\$ 48,678

Budget

Salaries \$22,204
 Temporary/Irregular Help \$
 Fringe Benefits \$3,849
 Travel \$2,250
 Supplies/Services \$
 Equipment \$500
 Other Direct Costs \$5,387
 Total Direct Costs \$28,803
 Indirect Costs @50.3 %: \$14,488
 Total Costs \$48,678

Budget Narrative:

Budget Justification

****All Hourly Rates are averages over CY18 and CY19*

Salaries -Support Requested from Elizabeth Cooper at 60 hours (\$56.93/hr), TBD ME at 240 hours (\$40.95/hr), and one graduate student at 560 hours (\$16.00/hr)

Fringe – Estimated based on the following rates: 26.5% Faculty, 3.8% Students

Tuition Remission –Partial tuition and fees for graduate student for Fall of 2018 and Spring of 2019 \$5,387 based on \$9.62/hour worked.

Equipment/Computers - Estimated for project period is \$500 for camera mounts and miscellaneous connectors.

Travel- Estimated travel expenses for project period \$2,250, to include: (1) trip to Spokane flying from Boise for project kick-off for PI, faculty and graduate student; (1) trip to Spokane flying from Boise for final presentation to Avista for PI, Faculty and graduate student.

F&A/Overhead - IDL is considered an on-campus unit of the University of Idaho with a federally negotiated rate of 50.33%.



APPENDIX D

Final Report: Aerogel Phase II

High Energy-Efficient Aerogel-Glazing Coupled with Aerogel-Insulated Walls in Residential Buildings: Phase II

Project Duration: 12 months

Project Cost: Total Funding \$82,873

OBJECTIVE

This project proposes a second phase for the aerogel insulation for buildings. The goal of Phase II is to develop the means of implementing new energy-efficient aerogel glazing systems in residential buildings for Avista customers to combine with the aerogel insulated walls evaluated in Phase I.

The objectives of the project second phase are to: 1) determine the thermal properties of aerogel-based glazing systems, 2) develop and validate a numerical model using computational fluid dynamics to predict heat transfer performance of these systems, and 3) apply this model to a simulated, scaled 3D single-family house with walls and windows insulated with aerogel.

BUSINESS VALUE

Using aerogel is expected to significantly decrease the annual heat loss in residential buildings compared to standard insulation materials. Recommendations for further development of aerogel systems will be made so it can be applied to various types of residential buildings and may also suggest ways to implement the use of aerogel in commercial buildings.

BACKGROUND

Many buildings in the United States were constructed before energy efficiency was a concern. Therefore, a strong incentive exists to renovate existing buildings to meet minimum energy requirements as mandated by the US and state governments. Aerogel is a transparent insulating material that meets this need to improve energy efficiency in residential buildings because of its extremely low thermal conductivity, high solar factor, and

high daylight transmittance. The material is also lightweight.

In Phase I of this project, the investigators validated the thermal conductivity of aerogel blankets and found them to be very low, close to $0.014 \text{ Wm}^{-1}\text{K}^{-1}$. Phase II of this project has included laboratory experiments and computer analysis using the ANSYS Multiphysics simulation tool; computational fluid dynamics (CFD) [1] to investigate the predicted energy savings when aerogel-glazed window panes are used with walls insulated with aerogel wall blankets.

The main deliverable of this project is a final report that includes the description of the methods used in the laboratory data collection and the computer simulations, and an analysis of the results.

SCOPE

The scope of Phase II is limited to residential buildings, but the findings may show promise for use in commercial buildings.

The project tasks are broken down as follows:

Task 1: Literature Survey

The investigators conducted a comprehensive literature survey related to the performance and implementation of aerogel-based glazing insulation in residential buildings.

Task 2: Experimental Testing

A prototype window wood frame has been built in the Civil Engineering Laboratory at the University of Idaho. The prototype consists of a cubical box with six aerogel window panes installed on all faces. The temperature gradient between the inside and outside of the box were measured using a heater/burner to increase the inside temperature relative to the outside.

More details about the experimental results will be discussed later in this report. The results were used to verify the accuracy of the CFD simulations, as will be explained later.

Task 3: Computer Validation of Aerogel-Based Glazing

The main goal of this task was to use the experimental results obtained from Task 2 to validate computer simulation results obtained using ANSYS Multiphysics including CFD. ANSYS was used to model air flows, heat convection between the air and walls, heat conduction through the wall layers, and heat radiation. This allowed the team to accurately model the 3D heat transfer phenomena of the aerogel windows assemblies. The results were used for visualizing and validating the effectiveness of the proposed window types in a simulated, 3D single-family house under typical winter and summer conditions.

Task 4: Simulation of a Single-Family House as a case study

In this task, a scaled 3D single-family house was simulated. It had walls insulated with aerogel and included aerogel-based windows in the house envelope. The simulation results were validated using measurements for the same geometry and environmental conditions for typical summer and winter weather conditions. The airflow patterns, temperature gradient, and heat flux across the wall and windows were simulated and the impact of the aerogel on the overall thermal environment was evaluated.

Task 5: Parametric Study

The proposed parametric study factors were the number of aerogel layers, aerogel thicknesses, aerogel wall insulation thickness, etc. The amount of energy savings for each case is reported in Section V.

PROJECT TEAM

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Organization	University of Idaho-Mechanical Engineering
Name	Conal Thie
Organization	University of Idaho-Mechanical Engineering

SCHEDULE

TASK	TIME ALLOCATED	START DATE	FINISH DATE
{Task 1: Literature review}	{ 4 Months}	{ 9/2018}	{ 12/2018}
{Task 2: Experimental Testing}	{ 1 Month}	{ 9/2018}	{ 11/2018}
{Task 3: Computer Validation}	{ 6 Months}	{ 12/2018}	{ 4/2019}
{Task 4: Simulation}	{ 10 Months}	{ 4/2019}	{ 7/2019}
{Task 5: Parametric Study}	{ 4 Months}	{ 7/2019}	{ 8/2019}

I. RESEARCH MOTIVATION

The chief objective of this research is to develop means of using aerogel to save energy for the largest number of Avista customers.

II. LITERATURE REVIEW

A limited set of studies have been done to report the behavior and efficiency of aerogel-based window glazing.

Buratti et al. (2017) [2] investigated the efficiency of high energy-efficient windows with silica aerogel used in buildings. Two types of aerogels were incorporated with two pes of glass layers. The investigation focused on measuring thermal transmittance and optical properties. The aerogel has decreased the U-value by 63% compared to conventional windows. In addition, a 30% reduction of light transmittance.

Ihara et al. (2015) and Cotanaet al. (2014) [3 and 4] reported the aerogel granulate glazing facades and their application potential from an energy saving perspective. The study concluded that a combination of aerogel and triple glazing systems may offer an energy efficient facade for cold climates. These findings may contribute to new architecture

techniques. Various other studies have also reported results, [5-11].

III. TECHNOLOGY UTILIZED

ANSYS Multiphysics CFD is the software tool used in this project. Thermocouple sensors and a data acquisition system were also used in the laboratory for data collection.

IV. ANALYSIS APPROACH

Thermal efficiency has always been a problem. Traditionally the higher the light transmittance levels, the lower the energy efficiency. Cellular Polycarbonate was the first breakthrough in window glazing systems because they offered good thermal efficiency and the light levels were better than almost all other materials [12]. Aerogel has proven to be the next big innovation. The six aerogel windows used in this project were acquired from Duo-Gard Industries Inc. under the commercial name of "Lumira aerogel" as shown in Figure 1.

The total thickness of each pane is 16 mm (10 mm aerogel enclosed by 6 mm polycarbonate panes). We investigated the ability of aerogel-based glazing to save energy as follows:



Figure 1: Aerogel glazing

a) Data Collection

The data was collected through laboratory testing by recording the data of a small-scale, aerogel-based glazing prototype, as shown in Figure 2a. The testing prototype measurement setup developed in Phase I was attached to panels and the thermocouple sensors were used to measure the temperature history inside and outside the window-glazed prototype at multiple locations.

One of the main goals of this project was to validate the aerogel glazing thermal conductivity and use the results in the computer simulations. A small-scale prototype was built first for verification under a controlled setting and to derive the heat conductivity of the aerogel glazing.

The prototype was a 3.0 x 3.0 x 3.0 ft. wood frame as shown in Figure 2a. The six walls of the cubical box were covered with glazing panes for the purpose of collecting a temperature versus time history. A conventional space heater/burner was positioned at the center of the cubical volume and 19 thermocouples were mounted in different places along the different faces of the cube as shown in Figure 2a.

Figure 2b is a schematic diagram showing the locations of sensors on one face (A). The sensors were mounted internally and externally on the six faces as shown in Figure 2c. The faces were given letters A to F with numbers referring to the location of the thermocouples relative to each face. As an example, A1 is the sensor located between the wall center and the cube center, A2 is mounted on the central point of the internal face of wall and A3 is the sensor mounted on the central point of the external face of the same wall.

In the experiments, the heater/burner was turned on until the temperature reached around 120° F and then the heater was turned off and data was recorded as the temperature decayed until it reached the outside room temperature. This process was repeated multiple times until the results became consistent and stable.

b) Modeling and Simulation

Computational fluid dynamics or CFD is a powerful tool that is used to capture fluid structure interactions, heat convection, heat flow and heat transfer. The team has continued using CFD as they moved forward from Phase I. The CFD tool has proven to be reliable in capturing the temperature time history responses, which is used to determine the amount of energy savings.

The Principal Investigator's (PIs) have used the data collected from the experiments to validate the computer model.

Computational and time costs have increased as we've moved into 3-dimensional simulations. Several grids representing our experimental setup were created—all of which are similar to Figure 3 with smaller grid spacings at corner edges to properly capture velocity gradients. A mesh sensitivity study was performed with this grid topology to determine the proper trade-off between grid resolution and required computational resources; the results of this study are presented in Figure 3. Decimating the grid from 2.89M points to 1.07M points (a reduction of 63%) provides very similar results beyond ~150 s into the simulation—we expect to run this simulation for over 2000 s. Decimation also decreased the required solution time by 77% allowing for longer simulations and allowed available time to be used to run a larger set of experiments.



Figure 2a: Cubical box with Aerogel glazing



Figure 2c: Cubical box with sensors attached

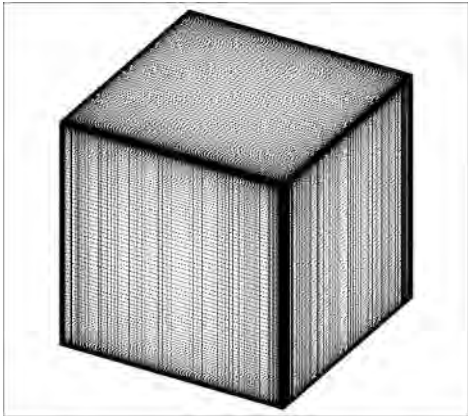


Figure 3: 3D Grid of Experimental Box

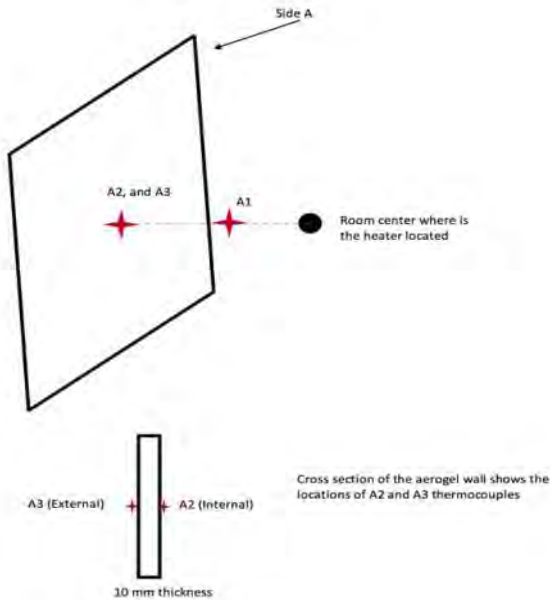


Figure 2b: Sensors locations across one of the box walls.

V. RESULTS

a) Laboratory Results

Figure 4 shows the average temperature decay through all of the scaled aerogel box walls. It can be seen that internal sensor has the highest temperature compared to the outside room temperature. This temperature data was used to validate the computer simulation and verify the thermal conductivity of the aerogel glazing. The temperatures recorded by all of the sensors have decayed with various rates over time depending on the sensor location as shown in Figure 4.

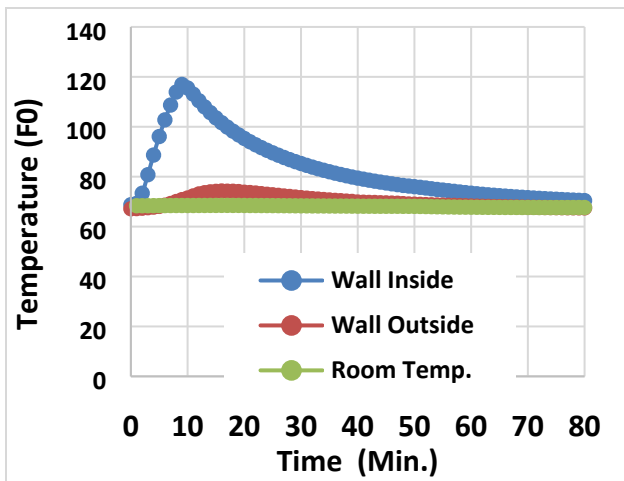


Figure 4: Average temperature-time history across all the four vertical walls of the prototype

CFD simulations were conducted on the small-scale aerogel box using a constant outer wall temperature, $T_o = 295^{\circ}\text{K}$ and a specified outer wall temperature profile based on the experimental data as (shown in Figure 4). Further, the thermal conductivity coefficient of the interspace aerogel was used as ($k=0.014$) (cited from Phase I results). Figure 4 shows the comparison of inner and outer wall temperatures.

Initial simulations have shown that natural convection inside the experimental box is significant and should be predicted and modeled in the simulations of the simulated house later in the project. Especially when considering taller vertical walls, which will see larger top-to-bottom temperature gradients.

Figure 5 shows a slice through the center of the box at 600 s. After a full 10 minutes, the air inside the box still shows considerable activity. Note the natural convection layers forming on the vertical sides and the swirling at top. Capturing this motion is critical to proper prediction of a convective heat transfer and will be a major feature of our future residential simulations.

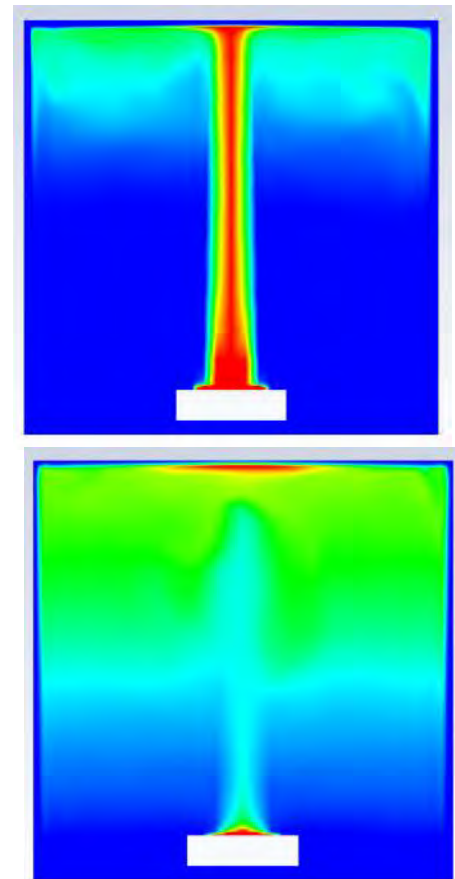


Figure 5: Temperature contour during heating period (top), and temperature as burner cools down (down)

A 3-layer panel grid (polycarbonate-aerogel-polycarbonate) was developed in the simulation model, which more accurately models the experimental box. After successfully logging quality experimental data, the simulations showed excellent agreement with the experimental data using a nominal convection room rate (see Figure 6). In addition, the team has included two additional gases in between the glazing panes (Air and Argon gases) to show the differences compared to the aerogel. It can be seen from Figure 6 that a very good agreement between the aerogel experimental and CFD results exist with a slower temperature variation versus time.

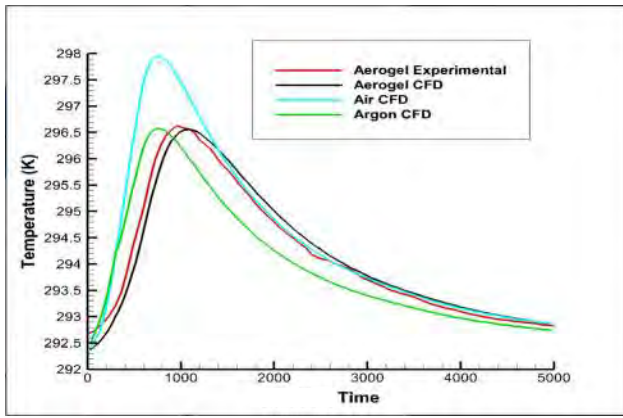


Figure 6: Comparison between experimental results and the CFD for temperature variation versus time

b) CFD Single-Room Results

The team developed a computer model for a single-room to test the mesh sensitivity and time needed for run the simulations. A 12'x10' single-room test grid has been developed as shown. This grid features a fully resolved multi-layer wall as well as multi-paned windows encased in 1-1/2 frames. A cross-section of the multi-layered grid is shown in Figure 7.

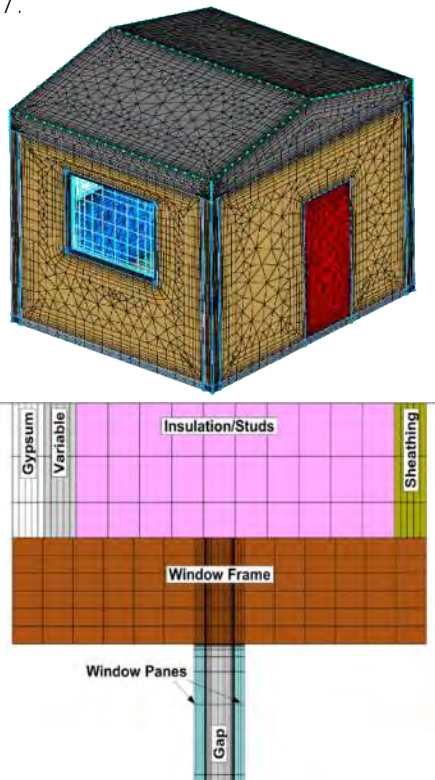


Figure 7: 3D mesh if the single-room (top) and wall cross section showing all wall elements (bottom).

Proper temperature or convection boundary conditions were assigned to this grid to solve for energy loss. These results include both net heat loss as well as local heat flux to compare losses through windows vs. walls or ceiling. The grid, as designed, allows for different configurations and types of insulation for comparisons. Figure 8 shows the results of the single room through conventional wall insulations, heat flux through standard insulation and windows, and heat flux through aerogel Windows.

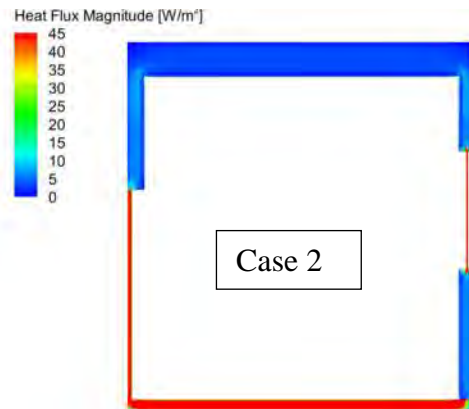


Case 1: Heat Flux through Aerogel Wall Insulation

The heat flux through a slice of the room shows a high rate of flux through the door (left of picture), window (right of picture), and the floor.

Case 2: Heat Flux through Standard Insulation and Windows

Here we still have high rates of flux through the door, window, and floor. However, the flux through the wall has increased about 12%.



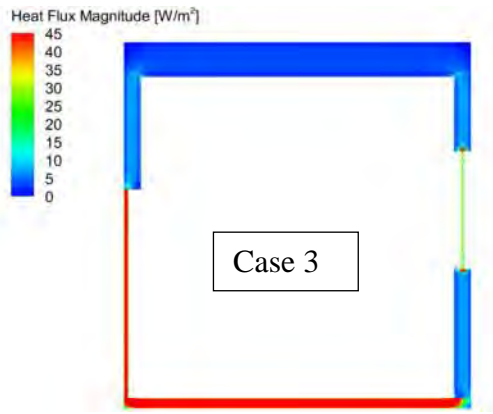


Figure 8: Heat flux in three different cases.

Case 3: Heat Flux through Aerogel Windows

Inserting aerogel between the two (2) window panes decreased the heat flux through the window by 36%.

In contrast to the air-gap window, the aerogel-insert window allows very little heat flux directly through the window. The heat flow from inside to out is forced more strongly through the window frame around the window as shown in Figure 9.

In conclusion, when a window with aerogel was used in the single room, the heat transfer was reduced by 10%, and that was for only one layer of aerogel used in between the polycarbonate layers.

c) Single-Family House Simulations

Next, a simulation of single-family house was developed for CFD simulation to evaluate savings for a typical house with the addition of aerogel windows. Figure 10 shows the 3D view of the CFD mesh of the single-family house. The house is a ranch style and has a floor plan area of 2000 ft².

The 3D CFD mesh of the house grid is shown in Figure 10. A multi-layer floor and external walls were modeled. The team decided to change the vaulted ceiling option to a flat one due to simulation complexities. The complete plans provide ample dimensions and details to ensure a high-fidelity simulation.

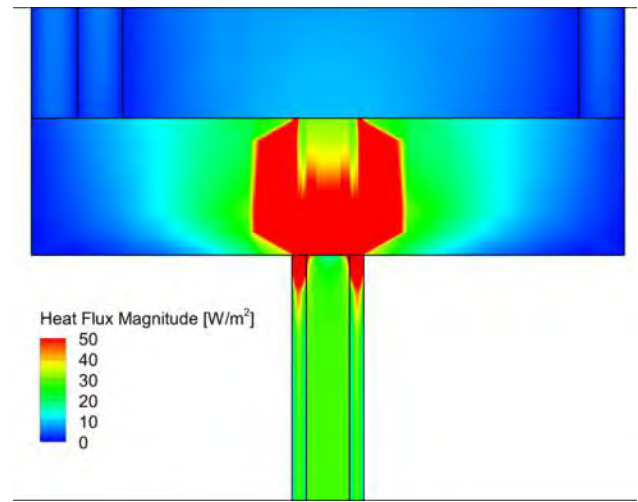


Figure 9: Heat flux through window with aerogel

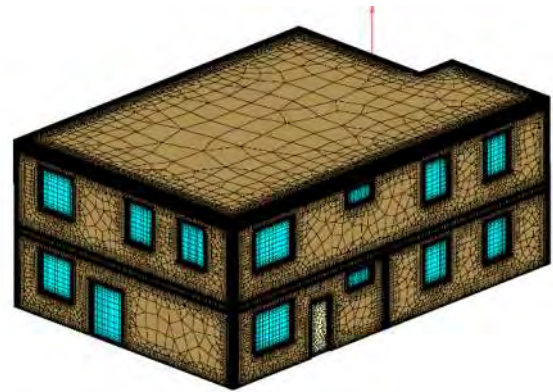
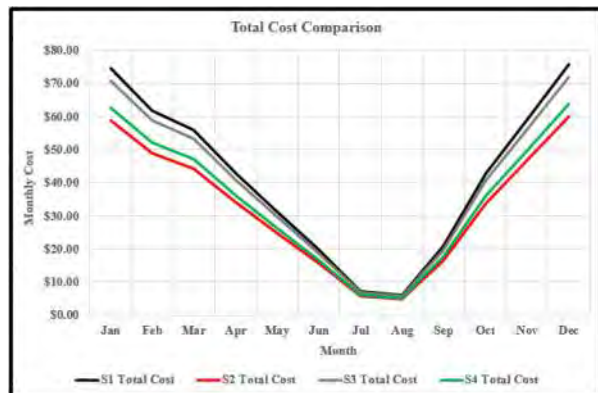
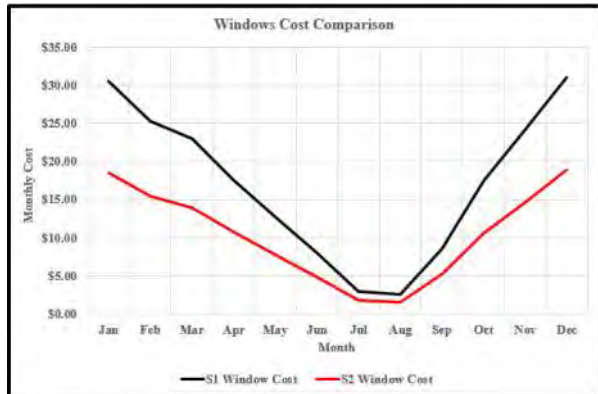
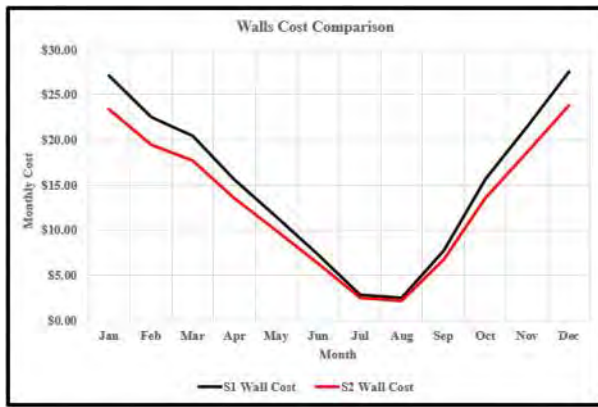


Figure 10: Single family house CFD mesh

The CFD model of the single-family house (11.4M grid points) has the following characteristics:

- Variable insulation layers in vertical walls (2 inner/2 outer) and in ceiling (2 inner).
- Variable 'gap' layer between window panes that can be specified as either gases (air or Argon) or solid (aerogel).
- Ability to isolate and swap different window/door configurations into the main grid.

The weather data from the city of Moscow, Idaho has been used to model the outside temperature over the course of a year while the inside house temperature was kept at 70° F.



Simulations Number	Aerogel in Window	Aerogel in Walls (1/2")
S1	No	No
S2	Yes	Yes
S3	No	Yes
S4	Yes	No

Figure 11: Total energy cost

Figure 11 shows the total monthly energy cost of walls, windows, and both windows and walls for various insulation combinations. Compared to no aerogel insulation, using aerogel saves energy for both walls and windows but much more significant for the latter. As a result, the total cost shows that the energy cost savings from the largest to the smallest are aerogel for both walls and windows, window insulated but not walls, wall insulated but not windows, and

neither wall or window is insulated. It is noted that the savings for all insulation combinations reach the maximum during the winter and minimum during the summer, i.e., the larger temperature difference between inside and outside temperatures, the larger the energy savings are.

VI. CONCLUSIONS

The feasibility of using aerogel blankets for walls and windows as a super insulator has been verified using small scale laboratory testing, and high-fidelity computer simulations. The following conclusions have been drawn from the project tasks conducted:

- CFD model was validated to be a promising tool to predict transient room temperature decay.
- CFD can be used to accurately predict the temperature, heat flux, and energy (cost) through windows, walls, floors, doors, ceilings, and their combination under various insulation conditions difficult to create using experiments.
- CFD simulations were used to show that the overall yearly savings using 1 layer of window aerogel insulation is 39% (Figure 10).
- The overall yearly savings using 1 layer and 4 layers of wall aerogel insulation coupled with window aerogel insulation is 13.3% and 38.3%, respectively for the single-family house, compared to traditional insulation.
- Overall, the savings with 1 and 4 layers of aerogel are 21% and 30% when taking heat flux through the insulated floor and ceiling into account.
- Savings percentages are typically affected (and limited) by original house insulation; and also, the window's quality and configurations.

VII. References

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APPENDIX E
Final Report: All-Iron Battery

Avista Final Report: All-Iron Battery for Renewable Energy Storage
Allen Lab at the University of Idaho Department of Chemistry

Introduction:

The Allen Lab set out to scale-up and refine the all-iron battery. The all-iron battery uses inexpensive and safe chemistry to store electrical energy. The all-iron battery uses an iron electrode and an iron salt cathode. An outline of the iron chemistry is shown in **Figure 1**. We have scaled the battery to a 1 L size. We have demonstrated that our energy storage capacity is close to the theoretical limit. We have also shown that the power delivered by the cell can be increased to a practical level using carbon additives.

Part 1 of this report describes the scale-up of the iron battery. This includes a description of the best features of the various iterations. We extrapolate the best features of our cells to a size suitable for grid energy storage. We estimate the cost of a shipping container size battery as well as its possible energy and power capacity. We conclude that such a cell could store approximately one megawatt-hour and deliver 1 MW of peak power for a total cost of \$0.09 per watt-hour stored.

Part 2 of this report describes our efforts to develop a low-cost battery tester. The cost of battery test equipment was an impediment to our progress. We had access to one high-performance potentiostat, which could be used for battery cycling. Commercial battery test instruments that can test multiple batteries simultaneously are very expensive. We endeavored to create an open-source battery tester that could cycle a battery repeatedly while measuring voltage, and current applied to (or delivered by) the battery.

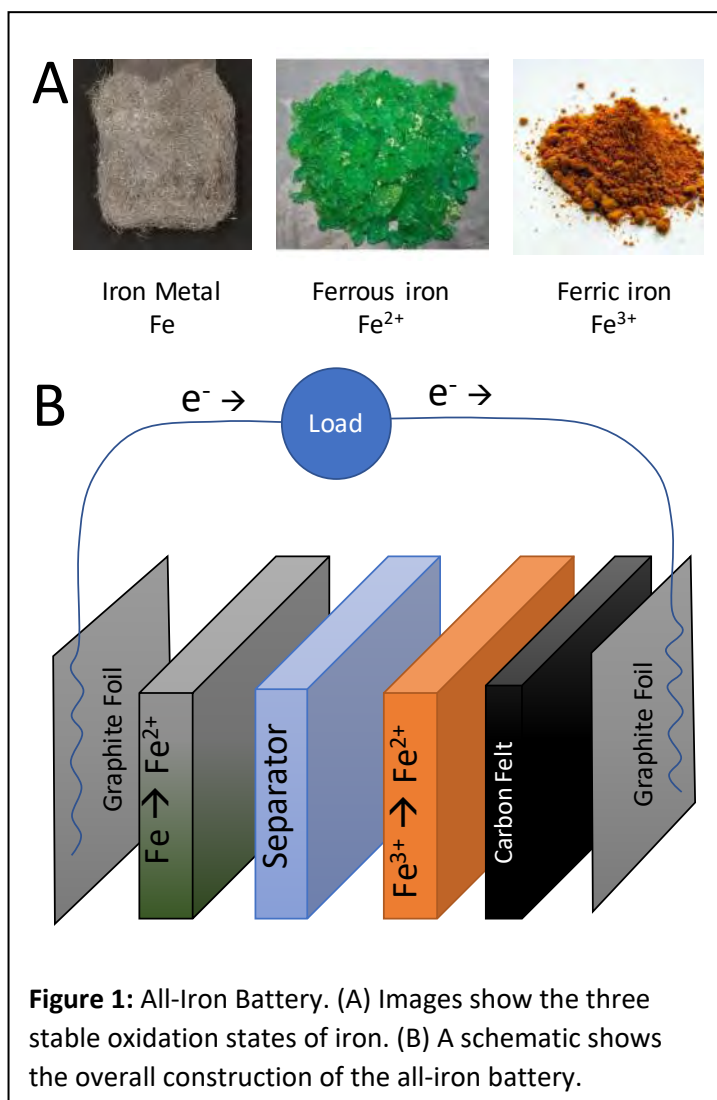
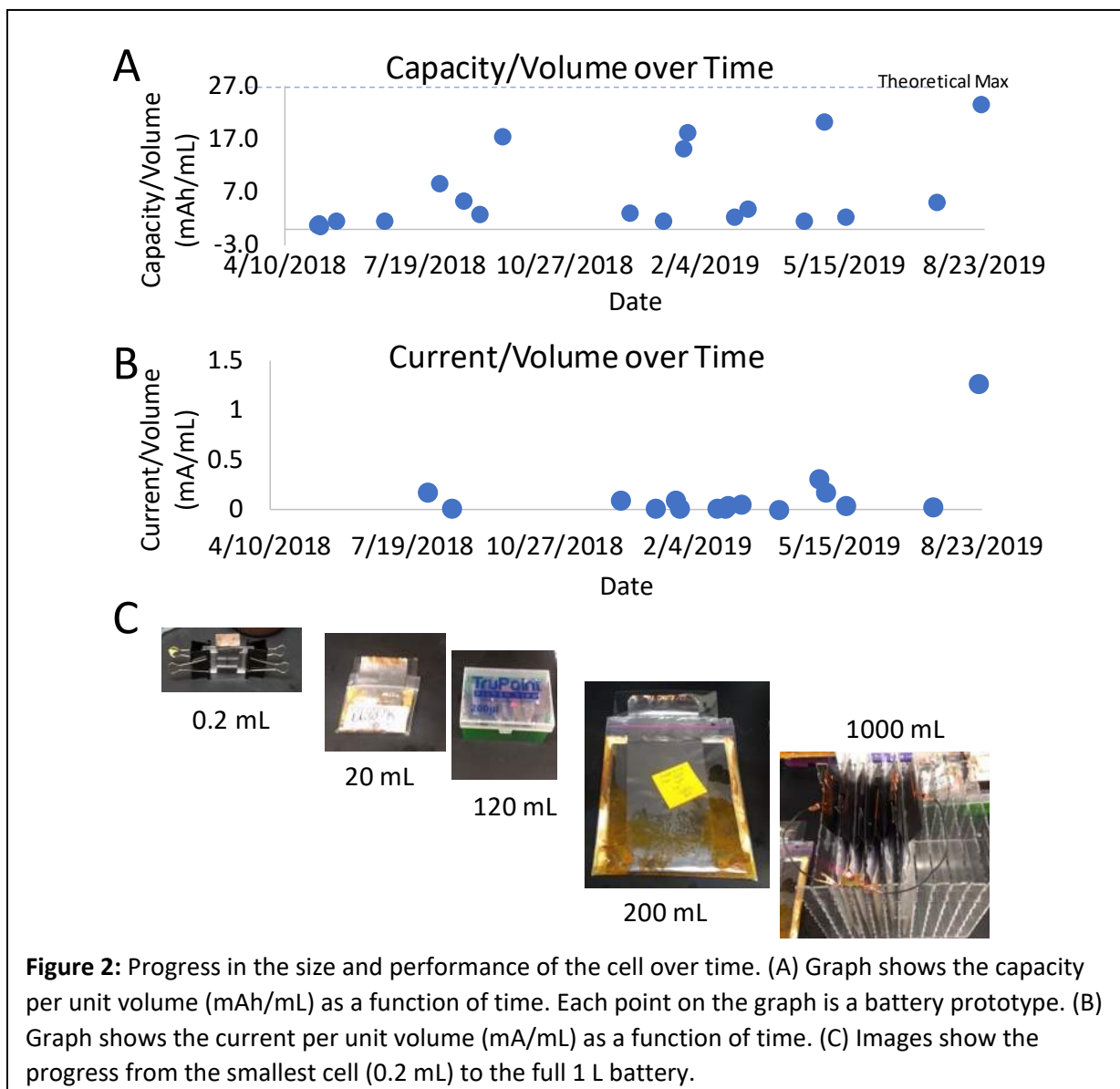


Figure 1: All-Iron Battery. (A) Images show the three stable oxidation states of iron. (B) A schematic shows the overall construction of the all-iron battery.

Part 1: Scale-up and performance of the Iron Battery

Scale-up of the cell:



We increased the size of our battery from 0.2 mL in 2018 to 1 L in 2019. The progress is shown in **Figure 2**. Our smallest cells were built using acrylic plastic. We used these cells to test changes to the chemistry and the membrane quickly. Larger cells (20 mL) were used to test the total capacity per unit volume and the total current per unit volume. These cells were assembled by folding a membrane into an envelope and filling the envelope with iron. The space outside of the envelope was filled with iron salt. A stack of these cells wired in series was made to 120 mL. When we established that these cells performed as expected, we moved to a 200 mL cell and a 1 L battery.

As our chemistry was refined, we had a general trend toward higher capacity per unit volume. The maximal capacity per unit volume is defined by the number of iron atoms in the battery. If every atom of iron is used, we get a total capacity directly proportional to the concentration of iron in the cell. Experimentally, we were only able to prepare the cathode material at a concentration of 11% iron by mass. This translates to a theoretical maximum of 27 mAh per milliliter. **Figure 2** shows that we were able to approach this theoretical maximum with our experimental cells.

Figure 2B shows that our initial current was very low. Because the cell provides approximately

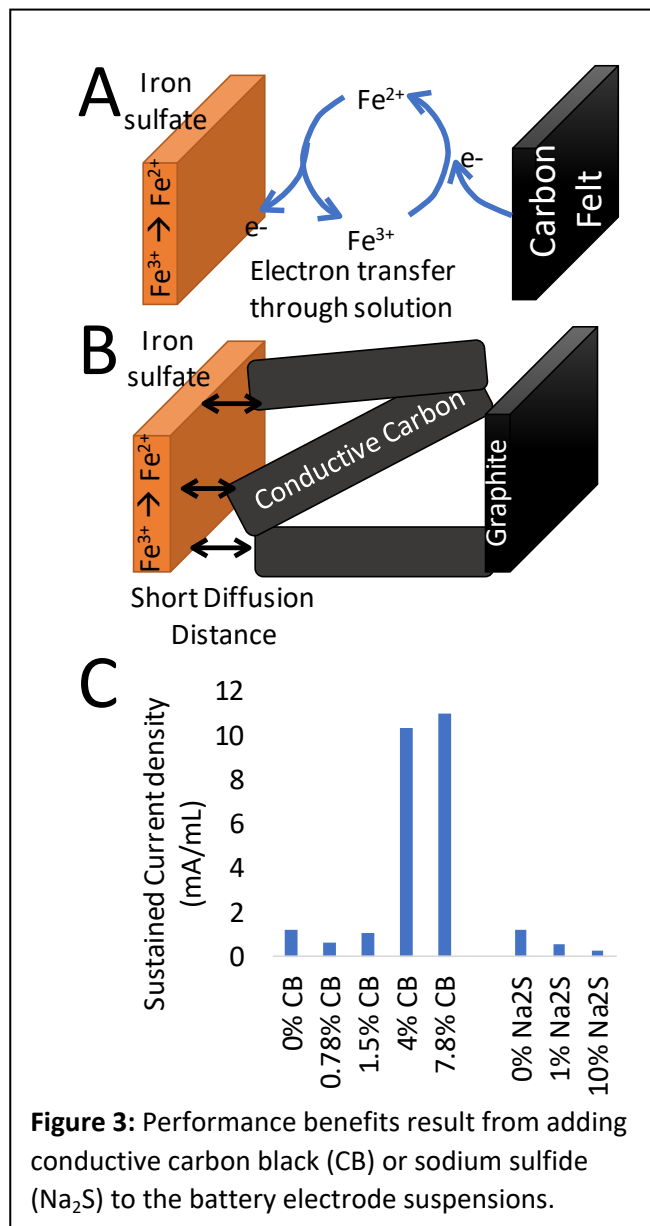
0.8 V, a 1.25 mA current translates to 1 mW. In practice, the power would be lower than this upper limit. Our early prototypes gave impractically low current per unit volume. Over the course of the project, we were able to increase the current (and thus the power) to a usable value. **Figure 2B** shows that the sustained current delivered by the cells at the end of the project period was approximately 1.5 mA per milliliter or approximately 1 W per liter.

Overcoming Internal Resistance:

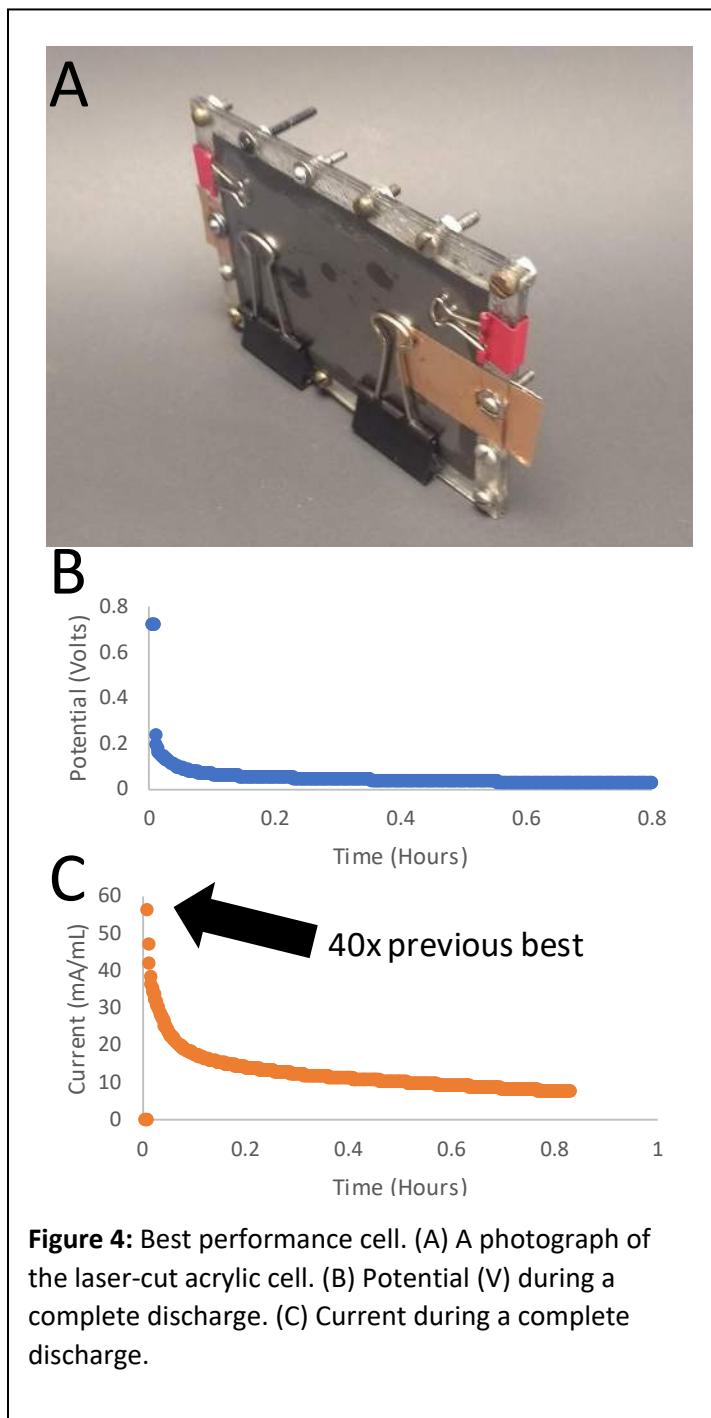
Over the course of our scale-up, we discovered that the power output from our battery chemistry was very limited. Our first 1 L battery produced only 40 mA continuous current. In order to address this, we endeavored to find an additive that could transfer electrons more easily between the load and the chemical compounds. We hypothesized that the long distance between the conductive carbon and the insulating crystals of iron sulfate was causing high resistance in the battery (**Figure 1A**). We introduced a range of concentrations of conductive carbon to reduce the diffusion distance between the carbon electrical connection and the iron phosphate (**Figure 3B**). **Figure 3C** shows the results of these experiments. The current produced by the battery was increased by more than a factor of ten.

We also tested several alternative membranes and sodium sulfide as an additive. Sodium sulfide is electrochemically active (it can be oxidized to polysulfide or reduced to sulfur). We hypothesized that it could be added to the anode to act as a “shuttle” for electrons from the iron to the iron sulfate. The results were not encouraging. Added sodium sulfide decreased the current. It did reduce the viscosity of the solution, however, and could be an interesting additive in combination with conductive carbon to make battery assembly easier. We also tested the possibility that the separator membrane was introducing additional resistance, but this was not found to be the case. Rather, the physical construction of the battery and thickness of the anode and cathode materials were found to produce a larger resistance than the difference between low-cost and high-performance battery membranes.

We tested GUITAR-coated carbon felt as well as GUITAR coated halloysite as additives. GUITAR, graphite from the University of Idaho thermolyzed asphalt reaction, is a proprietary conductive carbon developed in the Cheng lab. The material does not wet easily with water without surface treatments. We oxidized the surface with hydrogen peroxide so that water was not excluded from the material. With



peroxide-treated GUITAR on carbon felt, we observed very impressive storage capacity. The GUITAR felt cathode stored 28.8 mAh/ml, slightly higher than the theoretical maximum of our iron (III) sulfate cathode. We took this to indicate that the surface-treated GUITAR itself was an active cathode independent of the iron (III) sulfate. Unfortunately, this proved to be impossible to obtain reliably and the cost for production of kilogram scale GUITAR is still too high for practical purposes.



Stability:

The iron battery is very stable. Many battery chemistries slowly degrade over time. The more cycles of charging and discharging to which they are subjected, the lower their total capacity. The iron battery chemistry survives thousands of repeated cycles without significant loss of performance. We used a microcell (0.2 ml) to test the number of cycles the battery could survive. We charged and discharged four thousand times without significant losses.

Best Performance:

The performance of our improved chemistry in the 1 L cell was not as high as the performance within the 0.2 mL cell. We hypothesized that this was due to the physical construction of the cell. The pouch design (Figure 2C, 200 mL cell) has relatively thick pockets of anode and cathode material. The 0.2 mL cell has a very thin anode and cathode compartments (1 mm thick). Thinner geometry may decrease resistance. We scaled the 0.2 mL cell to 3 mL to test the hypothesis that this would increase the current. Indeed, our new 3 mL thin cell produced extremely high performance in terms of current and capacity. Figure 4 shows the results. The 3 mL cell produced 40 times as high a maximal current per unit volume as the previous best. Therefore, we conclude that the thinner cell with 4-5% conductive carbon is optimal.

Cost:

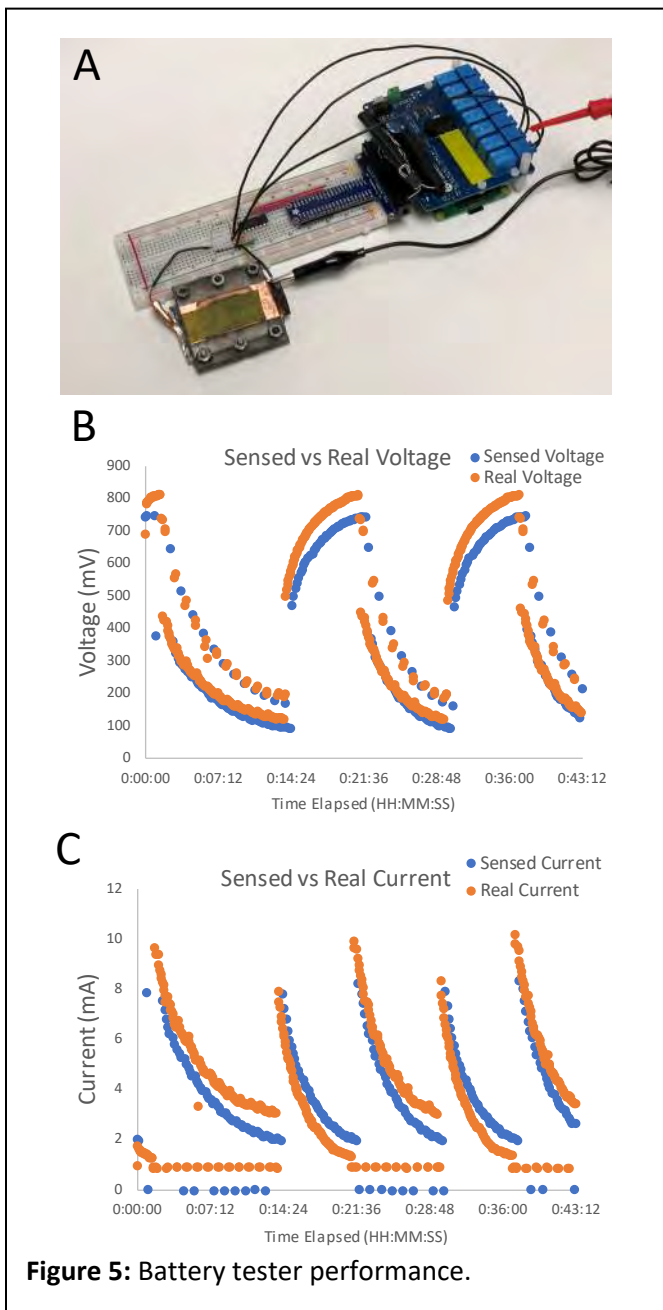
We found wholesale sources for the components of the battery to estimate

the cost per unit energy. We took the sustained current and electrical storage capacity per unit volume

from our best cell and used this to extrapolate the capacity of a shipping container-size battery (66 m³). This yielded a projection for price and capacity. The most expensive components are the graphite sheet and Nafion-coated paper. Even without further development, the price for the components is lower than current storage solutions on the market (which are usually between \$0.3 - \$1.0 per watt-hour).

Cost Estimate: 1.7 MW-h Container

4.2 Metric Tons Iron	\$20
7 Metric Tons Carbon Black	\$7,000
38,000 Liters of Iron (III) Chloride	\$8,000
38,000 Liters of Iron (II) Chloride	\$18,000
38,000 m ² Nafion Paper	\$150,000
38,000 m ² Graphite Sheet	\$150,000
Totals:	\$330,000
Cost per Energy:	\$0.09/W-h



Part 1 Conclusions and Future Work:

The thin cell with carbon additives has commercially useful storage and power capacity. The next step is to scale this more effective design to a larger size (1 L). This should then be tested to determine if the same performance and reliability are obtained. We will also test less expensive alternatives to our current graphite foil and a “bipolar” design in which the cells are constructed in layers separated by a graphite foil. This would reduce the demand for graphite by a factor of two at the possible cost of more difficult manufacturing. Finally, we will continue to test less expensive alternatives to Nafion-coated paper separators. We have tested polyacrylic acid as one alternative, and we have investigated Amberlite and Purolite ion exchange resins as possible alternatives. We can test these more quantitatively by developing Electrochemical Impedance Spectroscopy methods.

Part 2: Open-Source Battery Tester

As we tested many cells over the course of our study, we found that a major bottleneck was the availability of an instrument to charge and discharge our battery. We endeavored to build an open-source instrument to perform these tasks (see **Figure 5**). We used a Pine Instruments

Potentiostat to do most charge-discharge experiments. This is a \$3,000 instrument that is more capable than necessary for simple charge-discharge experiments. We needed the ability to automatically connect a power supply to the battery for charging, then connect a load to the battery for discharging. In its simplest form, this can be connected to a data logger (e.g., Vernier voltmeter and ammeter) for data collection. In further iterations, we propose to integrate data logging. This solves our internal problem (availability of the instrument) and may contribute to the open-source hardware community; the most comparable open-source battery tester requires components that cost \$5,000, which is still more affordable than an Arbin battery test instrument (\$30k or more).

Performance:

Our open-source battery tester currently is only accurate to ~10% of the real value for electrical current and voltage (see the discrepancy between real and sensed current and voltage in **Figure 5B-C**). The relay modules and control software are functional with a precision of less than one second. It will be important to reduce the error in the sensed voltage and current with better analog-to-digital converters and a calibration protocol (still in development).

Cost:

The components for the system can be purchased for just over \$200 (see table below). The system marks an order of magnitude improvement compared to even the low-cost open-source alternatives. This means that we can build several battery testers and run multiple experiments in parallel.

Cost Estimate: Open Source Battery Tester

<i>Raspberry Pi Model 3 B+</i>	\$39.95
<i>Wall Adapter Power Supply</i>	\$7.95
<i>SanDisk Ultra 32GB microSDHC</i>	\$6.69
<i>RELAYplate (8 relays for connecting power/load)</i>	\$41.95
<i>Alligator Clip Test Lead Multicolor</i>	\$11.90
<i>Wire Jumper Kit 350pc</i>	\$12.95
<i>E12 Resistor Assortment</i>	\$9.95
<i>MCP3304-BI/P</i>	\$4.44
<i>830 Point Solderless Breadboard</i>	\$8.79
<i>KORAD KD3005P - Precision Power Supply</i>	\$106.99
Total:	\$211.61

Part 2 Conclusions and Future Work:

Our battery testing system is still quite preliminary. We hope to integrate newer, cheaper parts into our next design. Our current analog-to-digital converters are only 12-bit systems. By increasing to a 16-bit integrated circuit, we can sense much smaller currents with equivalent high-quality shunt resistors. Additionally, a higher quality ADC will allow us to make more precise voltage measurements. We plan to use a common D-cell battery and calibrated resistor to calibrate the measurements from the ADCs. We will then confirm the quality of our calibration using our Pine Instruments potentiostat. This will allow future users to perform a similar calibration. We will use the calibrated instrument for cycling our iron battery, and we hope to publish the designs separately as well.

Overall Conclusions:

While our best 1 L battery did not produce sufficient current to be of commercial value, our further results indicate that this can be overcome with the addition of conductive carbon black. Our next steps are to construct a full 1 L battery in the high-performance, thin cell design. We hope then to publish an updated paper in HardwareX describing the higher performance battery and its construction. We will test this larger, higher performance battery using our automated tester. This automated tester will charge and discharge the battery hundreds or thousands of times while collecting current and voltage data. Based on previous results, we anticipate that the battery will be robust to thousands of charge-discharge cycles. The construction and operation of this automatic battery tester are sufficiently novel to warrant submission for publication as well.



APPENDIX F

Final Report: Energy Trading Phase I

Avista Transactive Power: Phase I: Final Project Report

Center for Secure and Dependable Systems, University of Idaho¹

Abstract

We analyzed, designed, and developed a prototype software system with the objectives of supporting the creation and management of a market that enables prosumers and consumers to trade power between themselves or with the utility, with utility oversight. This prototype software system supports the creation and management of power transaction agreements between prosumers and consumers and also supports the determination of transaction execution feasibility by fully integrating Power Flow analysis within the prototype.

Keywords: Transactive energy trading platform

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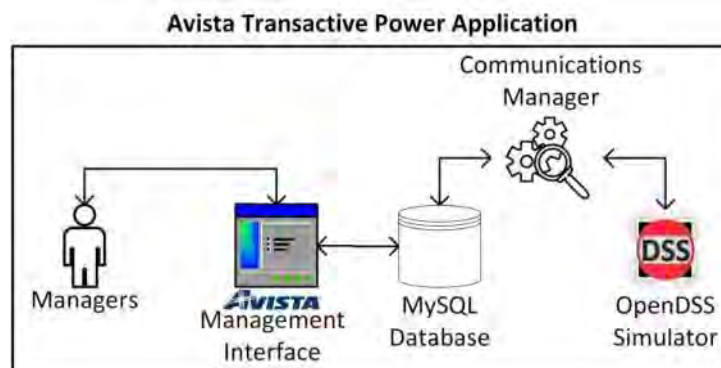


Figure 1: High-level architecture of the Avista Transactive Power Application

1. System Architecture

ATPA's system architecture consists of four modules. They are: 1) Distribution System Model & OpenDSS Simulation, 2) Web-based management interface; 3) MySQL Database; and 4) Communication Manager.

The Management interface is the module that is intended to be used by managers as an interface to the ATPA. The management interface module, in turn, interfaces with the MySQL database to populate transaction and entity profiles data. MySQL database obtains the entity profiles data from OpenDSS simulation by interfacing with the communications manager. The system was evaluated using an example distribution model that is a modification of the IEEE 13-bus system. The communication manager is invoked by the management interface and interacts with the Database and OpenDSS modules. Figure 1 presents the ATPA's system architecture.

In the following sections we describe each of the four system modules. The distribution system model and its OpenDSS simulation are laid out in Section 2. Section 3 discusses the management interface. MySQL database information is presented in Section 4. Section 5 lays out the communication manager's workflow.

2. Distribution System Model

Modeling small generation facilities, home and buildings management systems, storage technologies and the local network is the first step in an electrical framework. We propose to model the electrical behavior of small generation, such as home solar panels or wind turbines, and the issues of electrical compatibility to the distribution network. Simulation of this model will provide an appropriate technical electrical understanding of the seller's electrical side of the energy trading system. Issues of safety for people and equipment, capacity to supply what has been agreed upon, availability of energy from the means at hand (solar energy deals for nighttime delivery may not work well), and interface to the distribution network must be investigated and appropriate methods to ensure technical capability established.

Modeling of the grid provides understanding of how to deliver the purchased energy through the distribution system. When the energy arrives, the same instrumentation and metering issues apply. The customer must have capacity and appropriate protection. From the customer's point of view, this process is similar to the service that the public utility already provides. For example, reactive power is necessary to stabilize the voltage. If the public utility produces this, then a fee may be in order. The same is true for grid management services. In this research we propose to develop a model of a typical electric grid in coordination with the utility's engineers. Appropriate supervision based upon grid conditions must be communicated to the producer.

In developing a transaction verification system, an accurate model to test and experiment on was needed. It was decided that the IEEE 13 bus system would be implemented as the base model for testing and verifying sets of transactions.

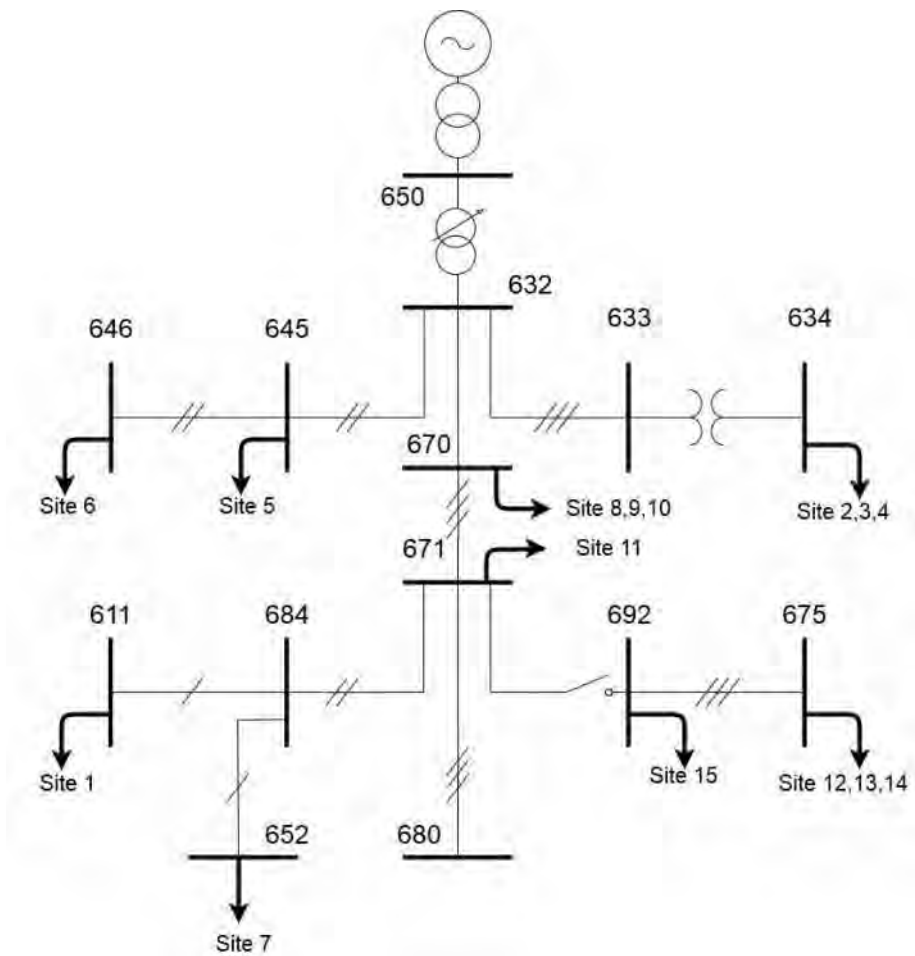


Figure 2: Modified IEEE 13 Bus System

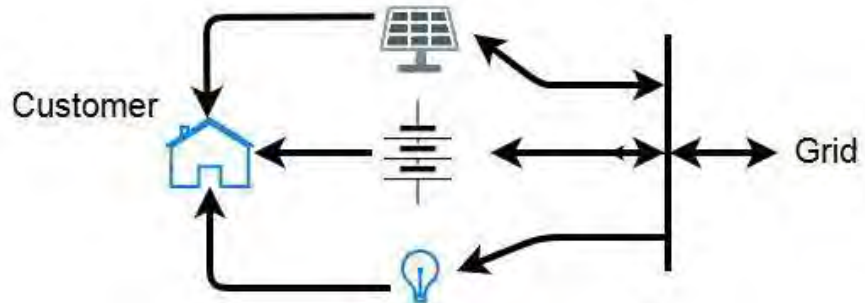


Figure 3: Definition of Prosumer Connections

Load #	P (kW)	Q (kVA)	Bus #	Phase
1	170	80	611	1
2	160	110	634a	1
3	120	90	634b	1
4	120	90	634c	1
5	170	125	645	1
6	230	132	646	2
7	128	86	652	1
8	17	10	670a	1
9	66	38	670b	1
10	117	68	670c	1
11	1155	660	671	3
12	485	190	675a	1
13	68	60	675b	1
14	290	212	675c	1
15	170	151	692	2

Table 1: Load Description Modified IEEE 13

PV #	P (kW)	Bus #	Phase
1	170	611	1
2	160	634a	1
3	120	634b	1
4	120	634c	1
5	170	645	1
6	230	646	1
7	128	652	1
8	17	670a	1
9	66	670b	1
10	117	670c	1
11	500	671	3
12	485	675a	1
13	68	675b	1
14	290	675c	1
15	170	692	1

Table 2: PV Site Parameters

Battery #	P (kW)	kWh	Bus #	Phase
1	100	100	611	1
2	100	100	634a	1
3	100	100	634b	1
4	100	100	634c	2
5	100	100	645	1
6	100	100	646	1
7	100	100	652	3
8	100	100	670a	1
9	100	100	670b	1
10	100	100	670c	1
11	100	100	671	1
12	100	100	675a	1
13	100	100	675b	1
14	100	100	675c	1
15	100	100	692	1

Table 3: Battery Site Parameters

The modified IEEE 13 bus system was created as specified in the previous section, with the additional PV and storage capabilities. Furthermore, to simplify the system and allow for analytics on purely the prosumer information, the voltage regulator and capacitor were removed from the test case. Figure 4 shows the system as the dedicated test case exported from OpenDSS.

At each customer location there is a meter recording voltage, current, angle, and power. When a case is run, it calculates the power flow and exports the metered data for analytics. When a transaction is sent to the web application a load profile is modified for the respective PV panel or battery (Sell). Additionally, when a purchase order is sent to the web application the prosumers load profile is modified to reflect it within the simulation.

With metered data collected at each customers location, the application may monitor the outputs for bounds of operation. The main focus is over voltage of 1.05 Per Unit. If the voltage reaches 1.05 Per Unit the transaction will be cancelled and the application will re-initiate a simulation to verify this.

2.2. Photovoltaic Load Profiles

Load profiles used for industrial and residential loads have been implemented as recurring dynamic and static loads throughout a 24-hr load profile. To accurately model a distribution system with photovoltaics, data was gathered from the National Solar Radiation Database and used as the load profiles' baseline for the photovoltaics [1]. We used data collected at the Spokane Airport during June 2010. A weeks' worth of data was used for the test model to simulate real

PV profiles that the customers may experience, such as clouds, and rain. Figure

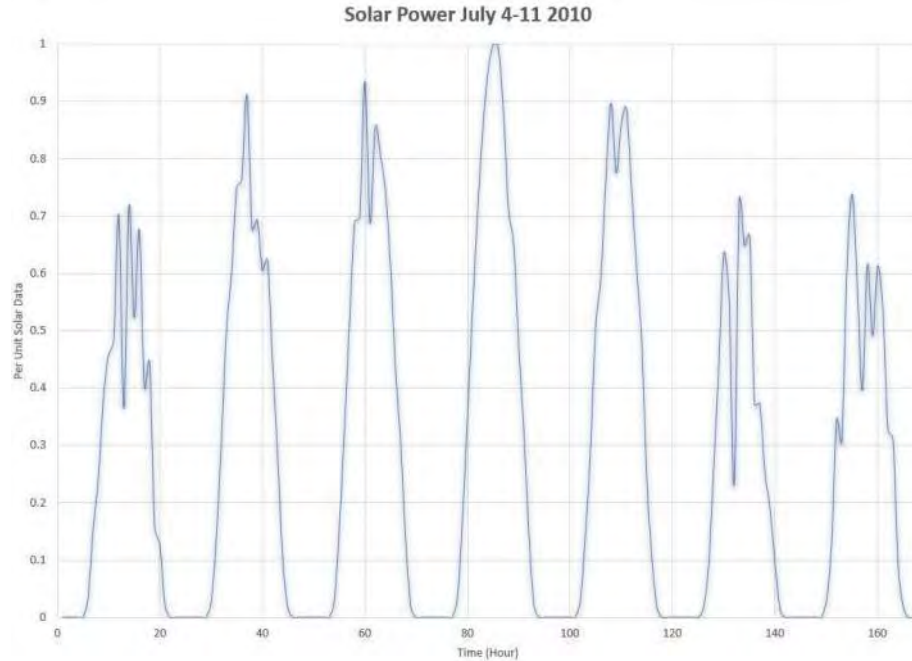


Figure 5: One Week of PV Data

5 depicts a graph of our PV profile. OpenDSS uses Per Unit value instead of irradiance as an input for PV. As such, we normalized with the maximum irradiance value (of the year) to create a Per Unit based input vector for OpenDSS. The residential load profile consists of 6 loads. Figure 6 presents a graph of our residential load profile.

We use this test case to verify that our distribution system will not be overloaded due to a specific transaction. We collect data points such as voltages, currents, and angles as metered on the buses and lines. These data points will be used by the ATPA's communication manager to accept or deny a transaction.

Once the electrical energy is produced, it must be metered and documented as it enters the electrical distribution network. Appropriate metering such as smart meters must be installed, if not already in place, to document the quantity and timing of energy flow. Such things as demand and power factor, as well as energy delivery, must be measured and recorded. Interface to the distribution grid in accordance with rules established by appropriate authority must be enforced. In the long term, designing and programming the means to allow or inhibit energy transfer based on compliance must be assessed and enforced at the metering interface.

3. Management Interface

Figure 7 shows the login screen for the management interface. Using this

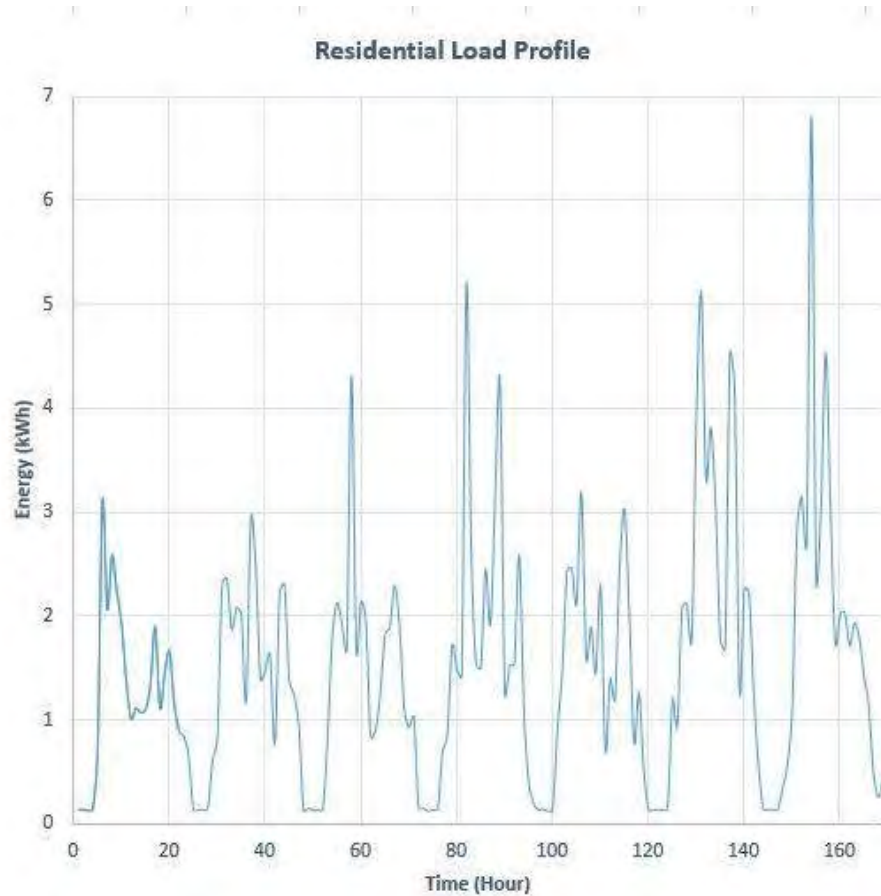


Figure 6: Residential Load Profile One Week

interface, managers can potentially create accounts, reset passwords, and log into the management interface. ATPA’s management interface’s main menu can be accessed by clicking on the three horizontal bars in the top left corner of the homepage. Figure 8 depicts the management interface’s main menu, which is divided into three sections: Customer, Management, and Administration. The main menu also has a search functionality, which searches through the menu items for a keyword and displays relevant matches. Customer Portal can be accessed by clicking on the circle in the top right corner of the homepage. Figures 10 and 9 present the customer portal and the customer menu, respectively. Managers can change their account password and log out of the application using the customer menu/portal.

3.1. Management Menu: Transaction Management

Figure 11 presents the management menu. Using the menu option “Main

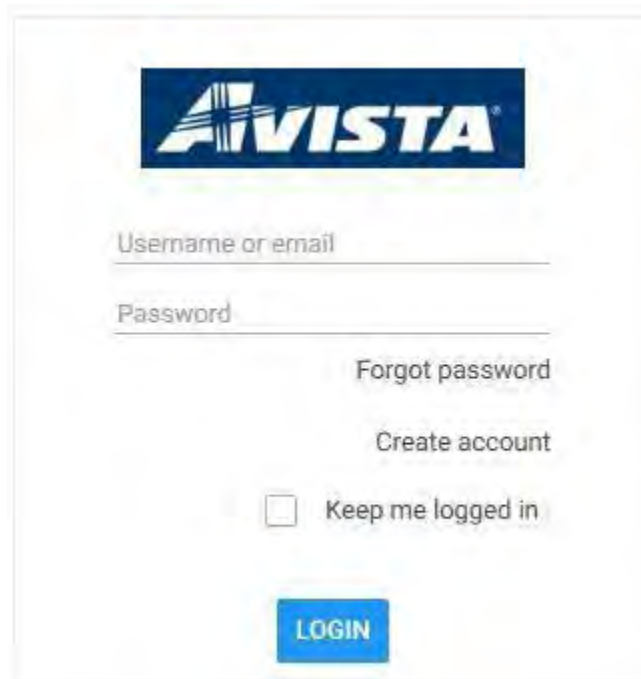


Figure 7: Log in interface for the ATPA management interface

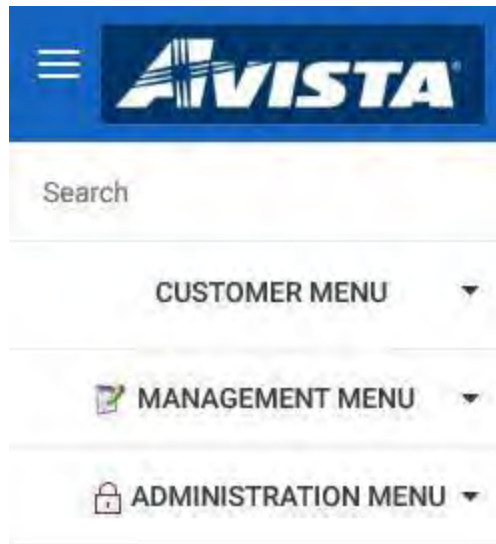


Figure 8: Main menu of the ATPA management interface

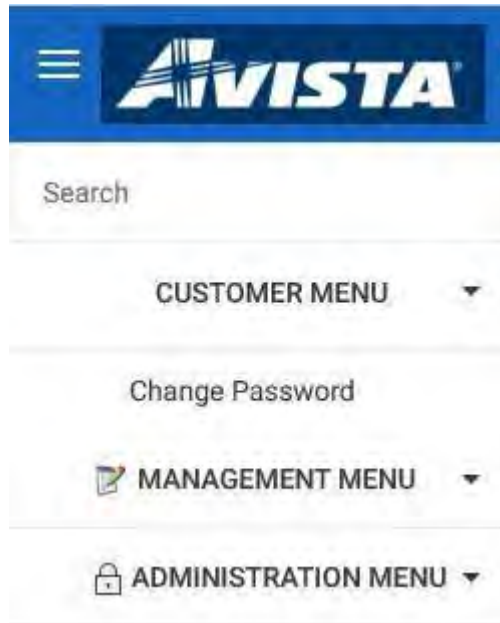


Figure 9: Customer menu of the ATPA management interface

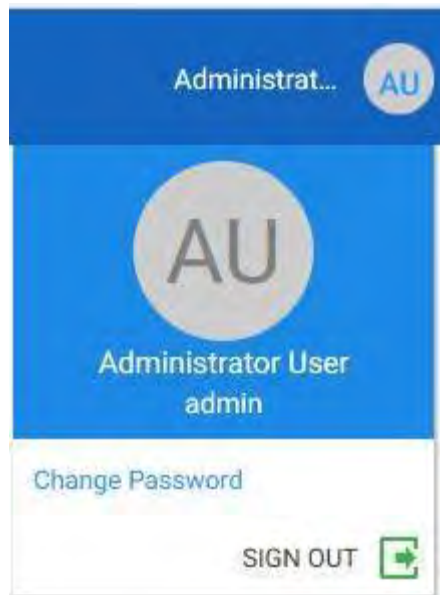


Figure 10: Customer portal of the ATPA management interface

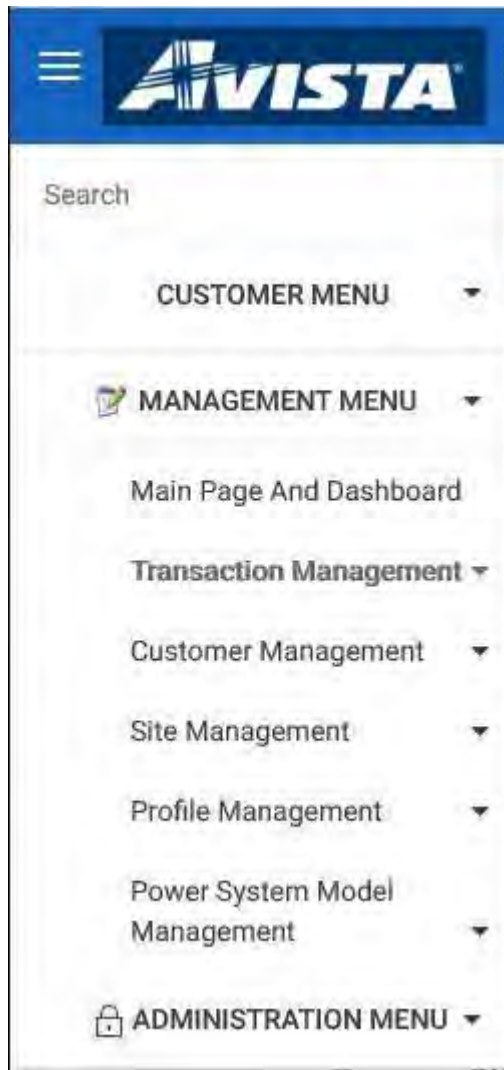


Figure 11: Management menu of the ATPA management interface

Page and Dashboard”, an administrator can potentially configure how the management interface’s main page and dashboard look like. Within the “Transaction Management” menu option, there is one sub-menu option named “Transaction

Agreement Manager”. Figure 27 depicts a snippet of the “Transaction Agreement Manager” screen. All the power transaction agreements available in the database are displayed in the “Transaction Agreement Manager” screen. Transaction agreements can be filtered based on date and time ranges by clicking on the blue pocket button in the upper left side of the “Transaction Agreement Manager” screen. Transaction agreements can also be filtered by transaction column fields,

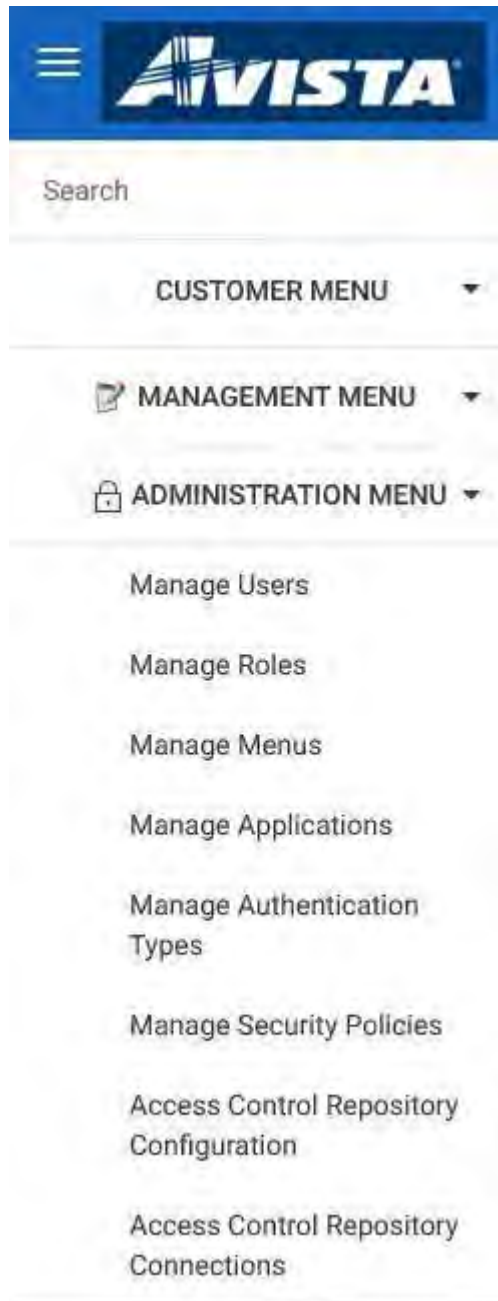


Figure 12: Admin menu of the ATPA management interface

using the search bar that's available beside the blue filter button. Figure 13 de-

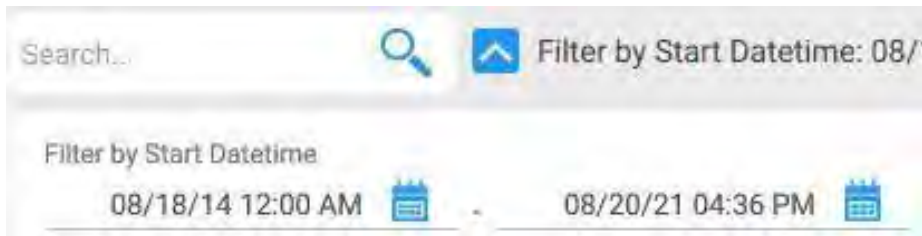


Figure 13: Transactions search and filtering menu in the transaction agreement manager screen

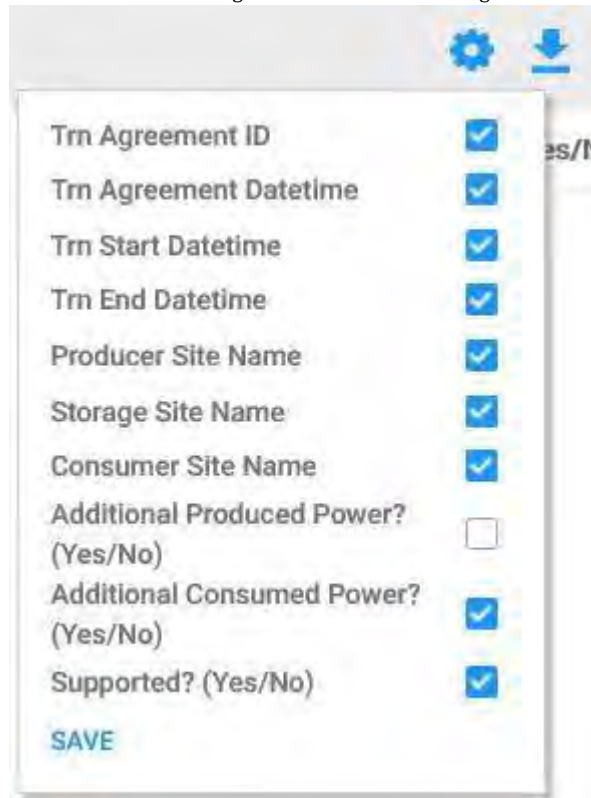


Figure 14: Transaction columns field filtering menu in the transaction agreement manager screen

picts the filter and search options.

Each transaction has multiple column fields, which are: transaction agreement ID, agreement datetime¹, start datetime, end datetime, producer site

¹ Datetime is also known as Timestamp.

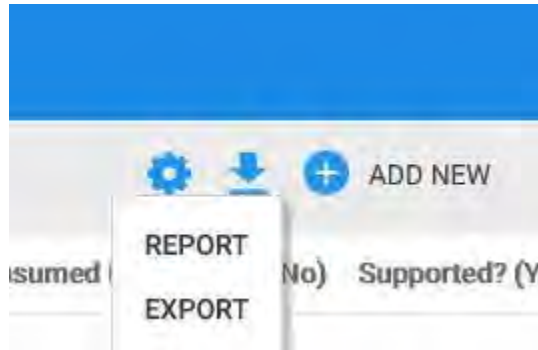


Figure 15: Transactions export menu in the transaction agreement manager screen

Trn Agreement ID	Trn Agreement Datetime	Trn Start Datetime	Trn End Datetime	Producer	Site Name
101/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV611	
201/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV634	
301/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV645	
401/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV646	
501/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV652	
601/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV670	
701/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV671	
801/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV675	
901/01/18	12:00 P	07/08/19 12:00 A	07/08/19 01:00 A	PV682	
1001/01/18	12:00 P	07/08/19 01:00 A	07/08/19 02:00 A	PV611	

Figure 16: Report generation in the transactions export menu

name, storage site name, customer site name, additional power consumption check, additional power production check, and support check. Additional power consumption will be checked if a consumer is requesting more power than the maximum specified for their profile. Similarly, additional power production will be checked if a producer is willing to provide power on the grid for more than one transaction. Support box will be checked for a transaction if transaction is accepted by the agreement algorithm.

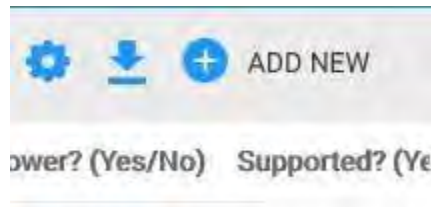


Figure 17: Add new transactions button in the transaction agreement manager screen

On the upper right side of the “Transaction Agreement Manager” screen, there is a blue gear icon. This is the transaction view configuration menu. Using the view configuration menu, the transaction’s column fields can be hidden or shown as desired. Figure 14 represents the view configuration menu. Beside the blue gear icon, there is a download icon. This is the export menu. Using the export menu, the management interface’s managers can download a transaction report or export the transactions. Figures 15 and 16 respectively present the export menu and the report generated by the “Report” menu option. There is also an “ADD NEW” menu, which can be used to add new power transactions into the database. Figure 17 depicts the “ADD NEW” button.

3.2. Management Menu: Customer Management

Under “Management Menu”, there is the “Customer Management” sub-menu, which contains the “Customer Manager” screen. Figure 29 represents the “Customer Manager” screen. Each customer has multiple column fields. Which are: an ID, a name, a description, an address and US State, and a geo-location. All of the customer column field values can be edited by the ATPA management interface’s admin user. The filtering, searching, view configuration, export menu, and menu to add new customers are all designed similar to the ones found in the “Transaction Agreement Manager” screen.

3.3. Management Menu: Site Management

Under “Management Menu”, there is the “Site Management” sub-menu, which contains the “Producer Site Manager” screen. Figure 30 represents the “Producer Site Manager” screen. Each producer site has multiple column fields. Which are: an ID, a name, a site image, a site geolocation, site creation timestamp, and Cap kW. Cap kW is a cap on maximum power that the producer site can sell. All the producer site column field values can be edited by the ATPA management interface’s admin user. A producer site has several field values that are not yet displayed on the “Producer Site Manager” screen. Some of which are: Phase, Bus Label, and relationship with a particular customer. The filtering, searching, view configuration, export menu, and menu to add new producer sites are all designed similar to the ones found in the “Transaction Agreement Manager” screen.

Under “Management Menu”, there is the “Site Management” sub-menu, which contains the “Consumer Site Manager” screen. Figure 31 represents the “Consumer

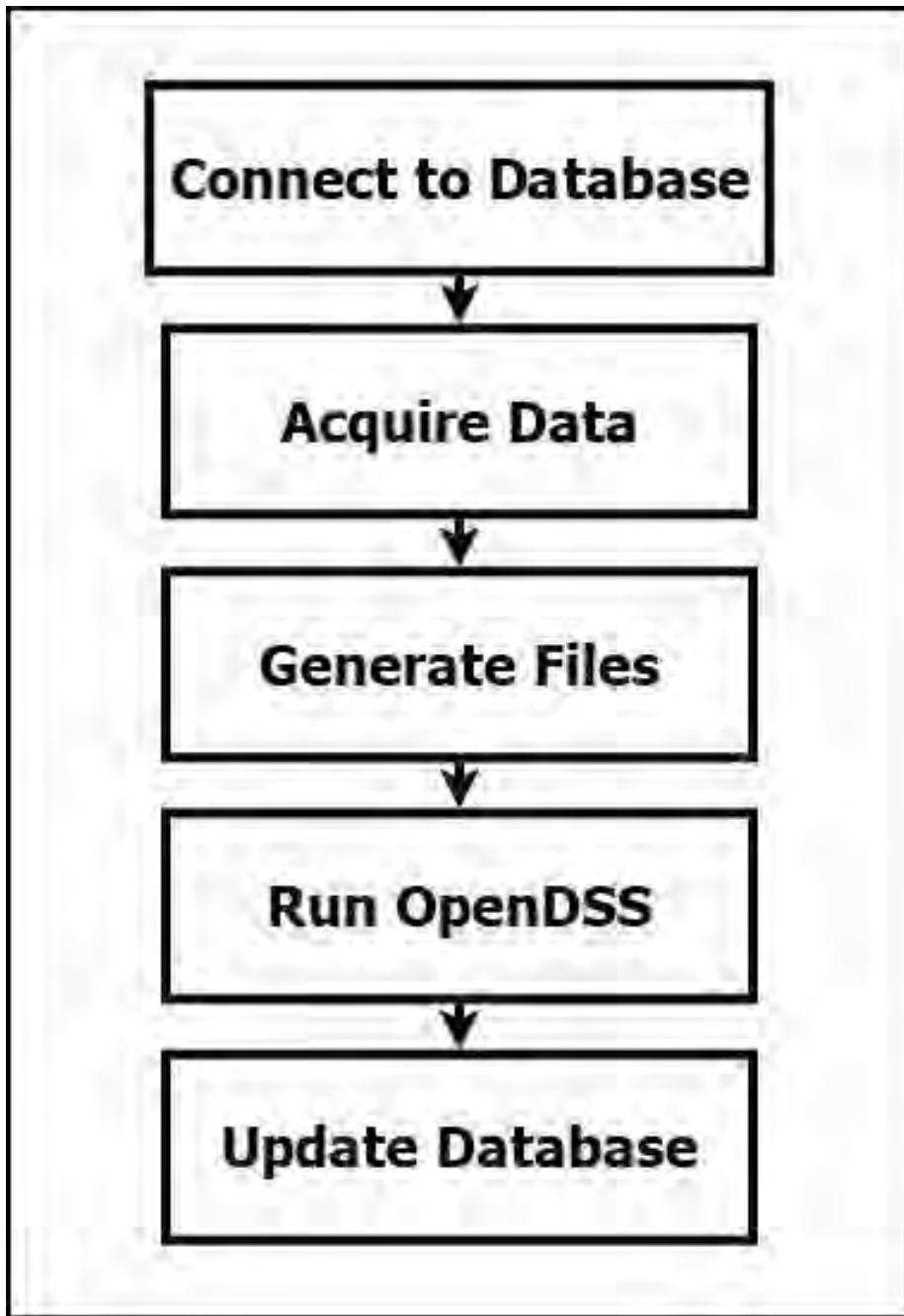


Figure 18: An overview of the Communication Manger's workflow

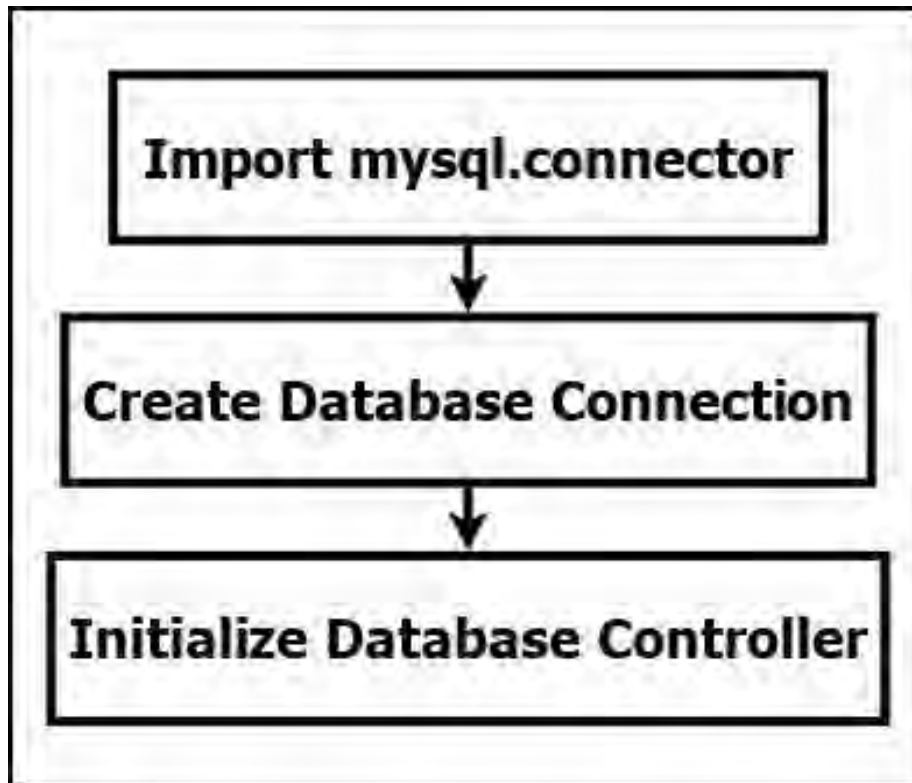


Figure 19: Workflow of the Communication Manger's 'Connect to Database' module

Site Manager" screen. Each consumer site has multiple column fields. Which are: an ID, a name, and a site image. All the consumer site column field values can be edited by the ATPA management interface's admin user. A consumer site has several field values that are not yet displayed on the "Consumer Site Manager" screen. Some of which are: Phase, Bus Label, power rating in kW, approval info, and relationship with a particular producer. Figure 32 depicts the dialogue box with additional configuration options for a consumer site. The filtering, searching, view configuration, export menu, and menu to add new producer sites are all designed similar to the ones found in the "Transaction Agreement Manager" screen.

3.4. Management Menu: Profile Management

Under "Management Menu", there is the "Profile Management" sub-menu, which contains the "Producer Site Profile Manager" screen. Figure 33 represents the "Producer Site Profile Manager" screen. Each producer profile has two column fields, which designate ID and name of the producer profiles. The "Customer Site Profile Manager" screen can also be found within the

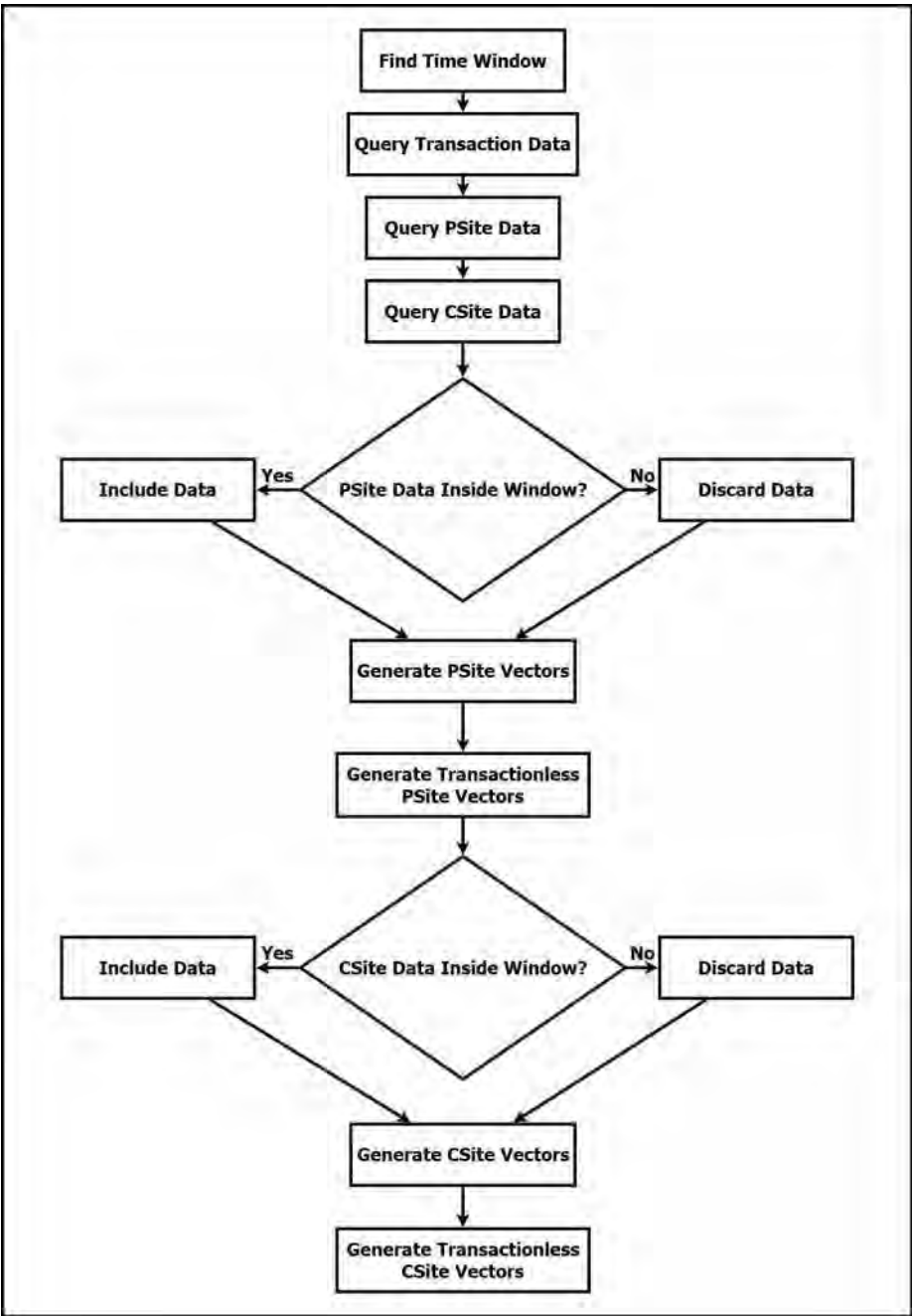


Figure 20: Workflow of the Communication Manger's 'Acquire data' module

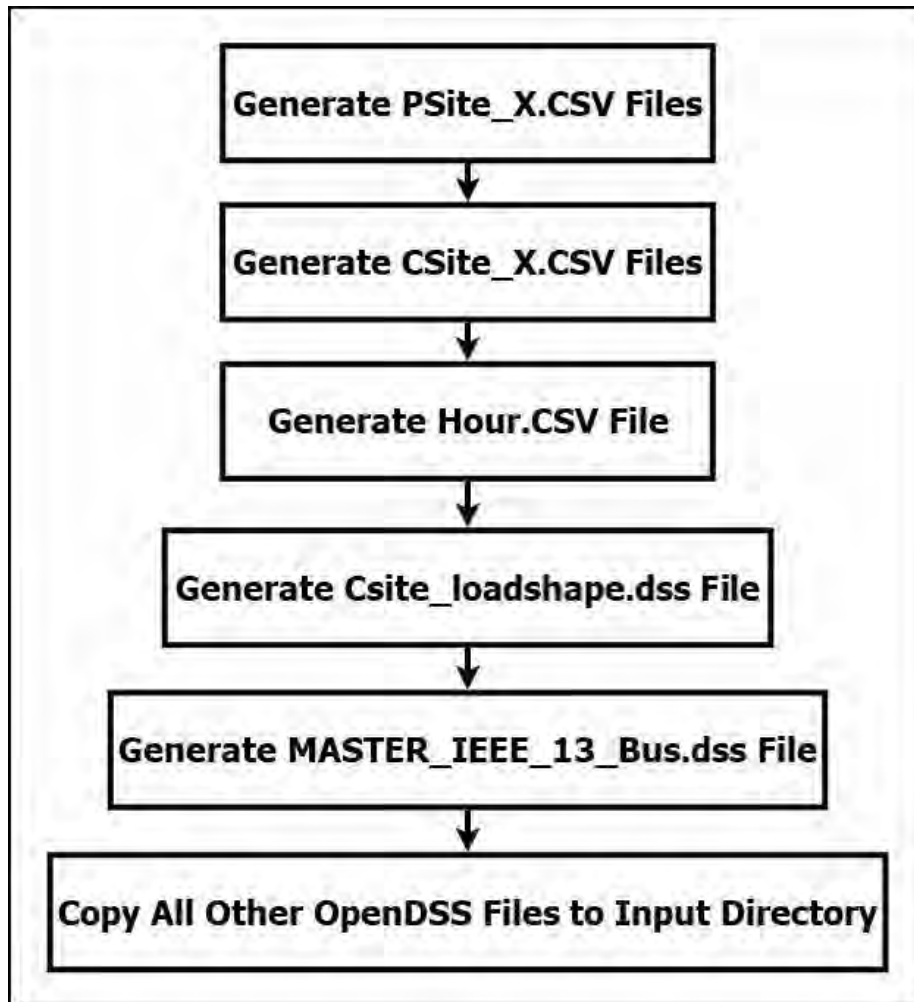


Figure 21: Workflow of the Communication Manger's 'Generate Files' module

"Profile Management" sub-menu of the "Management Menu". Figure 34 represents the "Customer Site Profile Manager" screen. Each customer profile has two column fields, which designate ID and name of the customer profiles. All of the column field values can be edited by the ATPA management interface's admin user, for both producer and consumer profiles. The filtering, searching, view configuration, export menu, and menu to add new producer/consumer profiles are all designed similar to the ones found in the "Transaction Agreement Manager" screen.

3.5. Management Menu: Bus Management

Under "Management Menu", there is the "Power System Model Management"

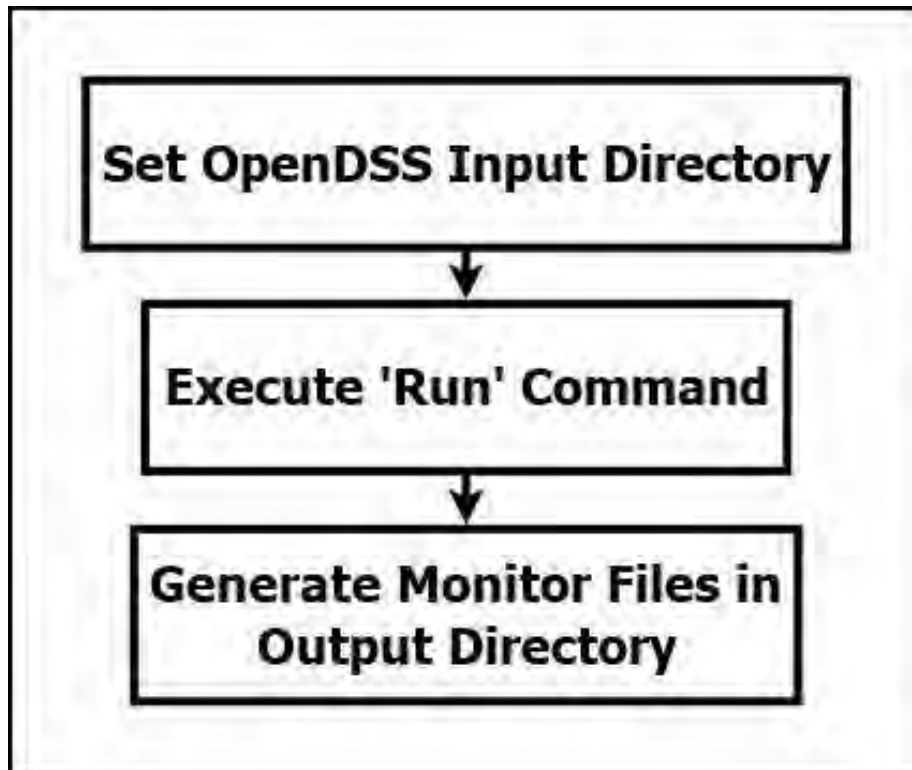


Figure 22: Workflow of the Communication Manger's 'Run OpenDSS' module

sub-menu, which contains the “PSM Bus Manager” screen. Figure 35 represents the “PSM Bus Manager” screen. PSM stands for Power System Model. In this screen, all the buses available in ATPA’s database are listed. Each bus has multiple column fields. Which are: label, geolocation, number of phases, and list of phases. The bus labels correspond to the bus object codes used by OpenDSS. OpenDSS bus object codes can be found in their reference guide [2]. The buses already available in the database can be edited and new buses can be created.

3.6. Management Menu: Line Management

Under “Management Menu”, there is the “Power System Model Management” sub-menu, which contains the “PSM Line Manager” screen. Figure 36 represents the “PSM Line Manager” screen. PSM stands for Power System Model. In this screen, all the lines available in ATPA’s database are listed. Each line has multiple column fields. Which are: label, name, number of phases, list of phases, and length in meters. Line label and name correspond to the buses the line is attached to. The lines already available in the database can be edited and new lines can be created.

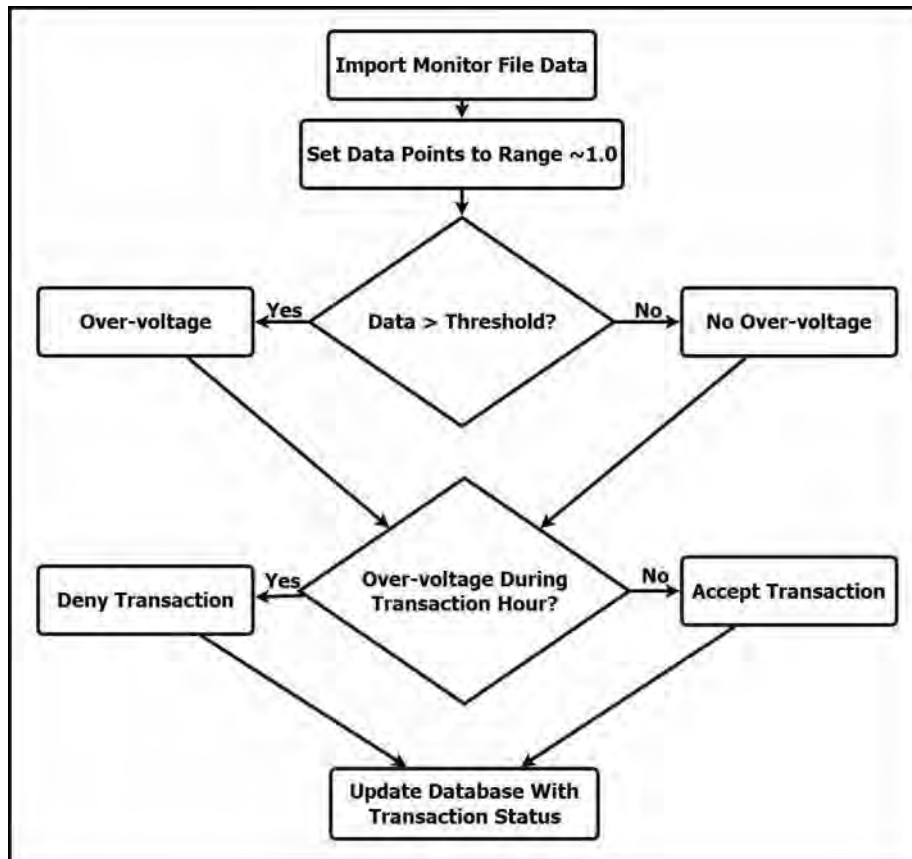


Figure 23: Workflow of the Communication Manger's 'Update Database' module

3.7. Management Menu: Line Type Management

Under "Management Menu", there is the "Power System Model Management" sub-menu, which contains the "PSM Line Type Manager" screen. Figure 37 represents the "PSM Line Type Manager" screen. PSM stands for Power System Model. In this screen, all the lines available in ATPA's database are listed. Each line has multiple column fields. Which are: ID, name, and number of phases. The line type IDs correspond to the line type ID object codes used by OpenDSS. OpenDSS lint type ID object codes can be found in their reference guide [2]. The line types already available in the database can be edited and new line types can be created.

3.8. Administration Menu

The management interface allows managers to perform administrative actions. These actions can be found under the "Administration Menu". Figure 12 depicts a snapshot of the "Administration Menu". Managers can administer

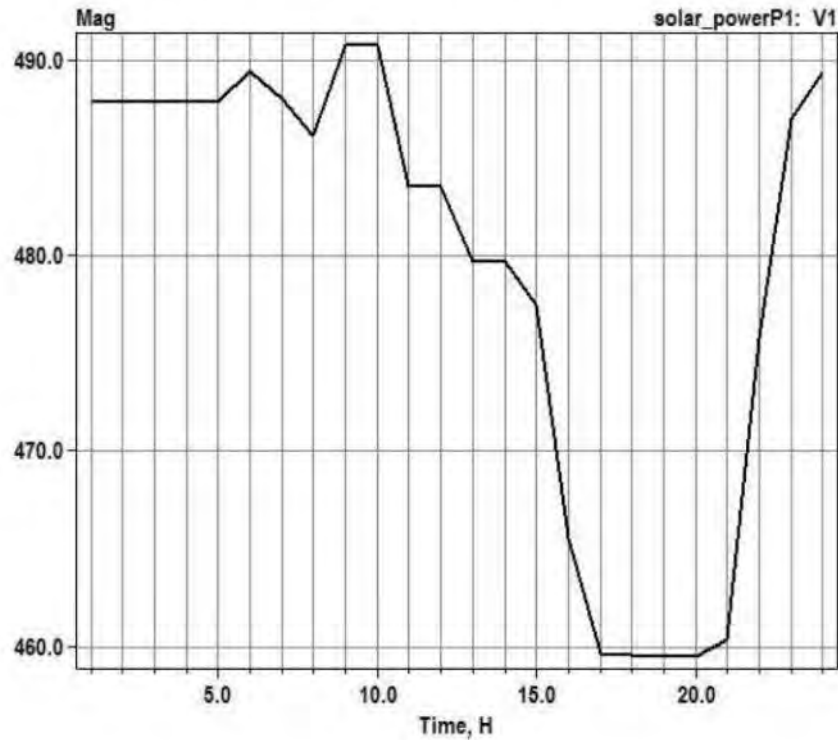


Figure 24: Customer 1 Voltage Waveform

users, their roles, interface's menus, authentication types, application windows, and security policies for the interface. Managers can also control database's connections and deployment configuration.

4. MySQL Database

The relationships between the database's entities are presented in Figure 26. The database consists of profiles for consumer, producer, and storage sites for a duration of one year and at a frequency of one hour. The data within these profiles is obtained from their respective site entities. The site entities, in turn, obtain data from actor entities. Actors can be either a producer or a consumer or both. The site entities also obtain bus and line information from the bus entity. The bus entity interacts with the line entity to obtain line information. The transaction agreement algorithm maintains a data entity that obtains data from all three entity sites.

hour	t(sec)	V1	VAngle1	V2	VAngle2	I1	IAngle1	I2	IAngle2
1	0	2435.3	119.409	0	0	38.5747	94.2083	38.5747	-85.7917
2	0	2435.3	119.409	0	0	38.5748	94.2081	38.5748	-85.7919
3	0	2435.3	119.409	0	0	38.5748	94.2081	38.5748	-85.7919
4	0	2435.3	119.409	0	0	38.5748	94.2081	38.5748	-85.7919
5	0	2435.3	119.409	0	0	38.5748	94.2081	38.5748	-85.7919
6	0	2454.51	119.888	0	0	0	0	0	0
7	0	2435.09	119.624	0	0	0	0	0	0
8	0	2418.82	119.6	0	0	0	0	0	0
9	0	2402.89	120.45	0	0	0	0	0	0
10	0	2425.03	121.689	0	0	0	0	0	0
11	0	2394.56	121.919	0	0	0	0	0	0
12	0	2383.36	120.77	0	0	0	0	0	0
13	0	2397.65	122.5	0	0	39.1804	97.2948	39.1804	-82.7052
14	0	2367.78	120.319	0	0	39.6764	95.1159	39.6764	-84.8841
15	0	2380.05	122.059	0	0	39.4706	96.8579	39.4706	-83.1421
16	0	2375.74	121.9	0	0	39.5398	96.6893	39.5398	-83.3107
17	0	2367.55	120.166	0	0	39.6806	94.9654	39.6806	-85.0346
18	0	2359	119.704	0	0	39.8218	94.5022	39.8218	-85.4978
19	0	2350.85	119.278	0	0	39.9596	94.0764	39.9596	-85.9236
20	0	2347.91	119.131	0	0	40.0103	93.9297	40.0103	-86.0703
21	0	2359.06	119.327	0	0	39.8228	94.1254	39.8228	-85.8746
22	0	2361.71	119.396	0	0	39.7772	94.1952	39.7772	-85.8048
23	0	2452.13	121.425	0	0	38.3084	96.2015	38.3084	-83.7985
24	0	2446.34	119.977	0	0	0	0	0	0

Figure 25: Customer 1 Voltage Waveform

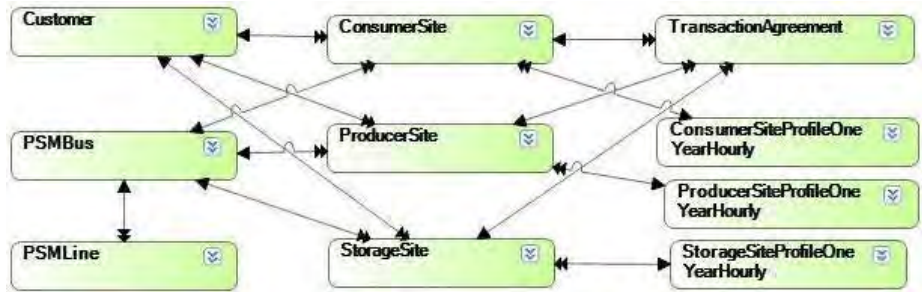


Figure 26: An entity-relationship diagram for the ATPA's database

5. Communication Manager's Workflow

ATPA's Communication Manager is a set of scripts written in Python language. An overview of the communication manager's workflow can be found in Figure 18. The communication manager processes data acquired from the database and generates files that are fed into OpenDSS and files resulting from OpenDSS process are used to update the database. The communication manager consists of the five modules: 1) Connect to Database; 2) Acquire Data;

Tin Agreement ID	Tin Agreement Datetime	Tin Start Datetime	Tin End Datetime	Producer Site Name	Storage Site Name	Consumer Site Name	Additional Consumed Power? (Yes/No)	Supported? (Y/N)
J	01/01/19 12:00 PM	07/08/19 12:00 AM	07/08/19 01:00 AM	PV611	NullStorage	Load634a	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
B	01/01/19 12:00 PM	07/08/19 12:00 AM	07/08/19 01:00 AM	PV634	NullStorage	Load634b	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
X	01/01/19 12:00 PM	07/08/19 12:00 AM	07/08/19 01:00 AM	PV645	NullStorage	Load634c	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
X	01/01/19 12:00 PM	07/08/19 12:00 AM	07/08/19 01:00 AM	PV646	NullStorage	Load645	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Figure 27: Transaction Agreement Manager screen of the ATPA management interface

Tin Agreement ID	Tin Agreement Datetime	Tin Start Datetime	Tin End Datetime	Producer Site Name	Consumer Site Name	Supported? (Y/N/No)
21	01/01/19 12:00 PM	07/08/19 02:00 AM	07/08/19 03:00 AM	PV6342	Load634c	<input type="checkbox"/>
22	01/01/19 12:00 PM	07/08/19 02:00 AM	07/08/19 03:00 AM	PV6343	Load645	<input checked="" type="checkbox"/>
23	01/01/19 12:00 PM	07/08/19 02:00 AM	07/08/19 03:00 AM	PV645	Load646	<input checked="" type="checkbox"/>
24	01/01/19 12:00 PM	07/08/19 02:00 AM	07/08/19 03:00 AM	PV646	Load652	<input checked="" type="checkbox"/>
25	01/01/19 12:00 PM	07/08/19 02:00 AM	07/08/19 03:00 AM	PV652	Load670a	<input type="checkbox"/>
26	01/01/19 12:00 PM	07/08/19 02:00 AM	07/08/19 03:00 AM	PV6701	Load670a	<input type="checkbox"/>

Figure 28: Transaction Agreement Manager screen of the ATPA management interface

Customer ID	Customer Name	Customer Description	Customer Address	US State	Geocodestate
1000	Undefined Customer	Undefined customer description	New address	Washington	610000, 0.000000
1001	Customer ONE	Customer description here	Address here	Washington	47.826779, -117.426049
1002	Customer TWO	Customer description here	Address here	Washington	47.826779, -117.426049
1003	Customer THREE	Customer description here	Address here	Washington	47.826779, -117.426049

Figure 29: Customer manager screen

3) Generate Files; 4) Run OpenDSS; and 5) Update Database. Following is a brief description of each of these modules' workflows. The workflows of the five modules are depicted in Figures 19, 20, 21, 22, and 23.

The database connection module imports any given database's connector, which is mysql.connector in our case. The connector is used to create database connection and to initialize the database controller. To acquire data from the database, the data acquisition module first looks for a given time window. With the time window, the module queries data from transactions, producer sites, and

Producer Site ID	Producer Site Name	Site Image	Site Geolocation	Created Date/Time	Cap KW
1	PV631		47.638779, -117.426048	01/01/19 12:00 PM	100.000
2	PV634		47.638779, -117.426048	01/01/19 12:00 PM	100.000
3	PV645		47.638779, -117.426048	01/01/19 12:00 PM	100.000
4	PV646		47.638779, -117.426048	01/01/19 12:00 PM	100.000
5	PV652		47.638779, -117.426048	01/01/19 12:00 PM	100.000
6	PV670		47.638779, -117.426048	01/01/19 12:00 PM	100.000
7	PV671		47.638779, -117.426048	01/01/19 12:00 PM	100.000
8	PV672		47.638779, -117.426048	01/01/19 12:00 PM	100.000
9	PV682		47.638779, -117.426048	01/01/19 12:00 PM	100.000

Figure 30: Producer site manager screen

Consumer Site ID	Consumer Site Name	Site Image
1	Load 631	
2	Load 634	
3	Load 634B	
4	Load 634C	

Figure 31: Consumer site manager screen

UPDATE CONSUMER SITE MANAGER

TABS: BASIC INFO | CUSTOMER INFO | APPROVAL INFO | POWER CHARACTERISTICS

Consumer Site ID: 1

Consumer Site Name: Load 631

Site Image:

Site Geolocation: 47.658779, -117.426048

Site Description: Consumer site description

Buttons: UPDATE | CANCEL

Figure 32: Additional configuration options in the consumer site manager screen

consumer sites. If both the producer site and consumer site data fall within the time window, their respective vectors are generated. Otherwise, the data is

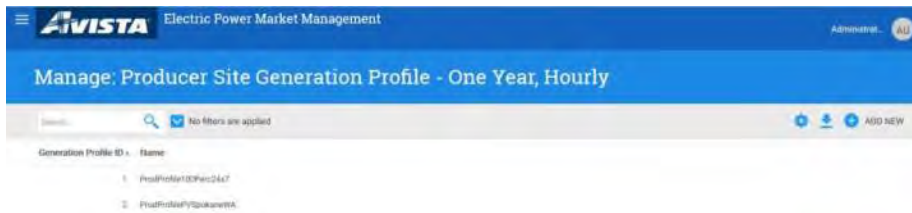


Figure 33: Producer Site Profile Manager

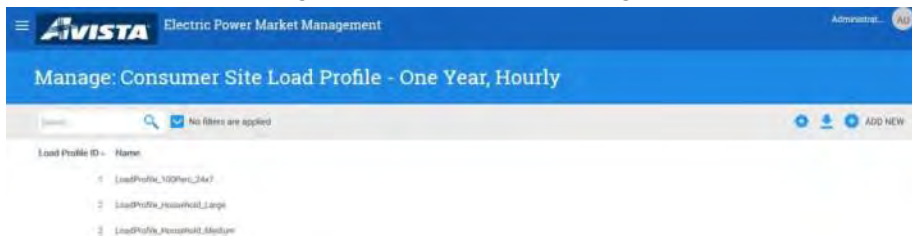


Figure 34: Consumer Site Profile Manager

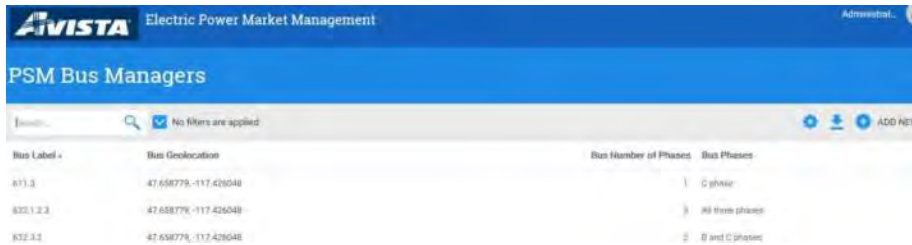


Figure 35: Bus Manager



Figure 36: Line Manager

discarded.

Meanwhile, the file generator module generates producer site and consumer site data at an hourly rate. Loadshape and the master data for the simulation's power system model is also generated. All the relevant OpenDSS files are copied to the communication manager's input directory. The communication

Type ID	Type Name	Number of Phases
101	Std O-One	1
102	Std O-Two	2
103	Std O-Three	3

Figure 37: Line Manager

manager invokes OpenDSS, which then generates monitor files. The monitor files are placed in the output directory. A transaction decision algorithm takes the monitor files, checks for over-voltage and produces updated transaction status. Transaction status will be 'denied' if there occurs an over-voltage in the transaction hour. Otherwise, the transaction status will be 'accept'. The updated transaction status is written into the database.

6. Simulations

Once the Communications Manager has called OpenDSS, the modified IEEE 13 bus system model containing all the transaction agreement information will run and output .csv files for every customer containing voltages, currents, and power. An example of such a .csv file is depicted in Figure 25. As before the main criteria is based upon over voltages with a limiting factor of 1.05. In simulation, it was found while using realistic load profiles for residential, sun, and storage the IEEE 13 bus system model would only reach 1.03 per unit voltage, and this was used as a threshold to test the application of approving or denying transactions.

Each simulation will be run on at a time step of 1 hour with the full data set of 24 hours. As shown in Figure 24 of customer 1 located at bus 611 we may see the customers voltage does not reach the voltage threshold and will be accepted for each transaction. In the figure it can be seen that their voltage reaches 1.018 per unit and doesn't drop below 0.95 per unit.

This process of running OpenDSS has been implemented to run every 5 minutes to simulate running the application as transactions are enabled. Once OpenDSS has fully run, the .csv files are read into the web application and the transaction agreement algorithm decides to keep or reject the transaction. Figure 28 depicts the "Transaction Agreement Manager" screen where some transactions are rejected by the transaction agreement algorithm.

7. Related Work

Transactive Energy (TE) systems is in research and development phase since 2006 [3]. TE systems with Distribution Locational Marginal Price (DLMP) model is being researched and developed since 2016 [4]. In our extensive literature searches of the current state-of-the-art, we were unable to discover reports

prototype systems such as the one described in this report. We report here on related research work.

Ghamkhari presents a theoretical power market to demonstrate DLMP model for real time TE systems [5]. Ghamkhari's model also uses a supply and demand formula to derive a real time value of the DLMP model [5]. Ghamkhari's work is based on mathematical analysis using real world test case derivations [5]. Sajjadi et al. present a stockholder-based scheme for implementing DLMP model in TE systems [4]. The scheme includes all participants in the TE system as potential stockholders and net benefits for all stockholders is analyzed [4]. Sajjadi et al. validate their scheme via a mathematical analysis applied on the IEEE 9-bus test system [4]. In contrast to both Ghamkhari's and Sajjadi et al.'s works, our work presents a prototype software platform for implementing DLMP model for real time TE systems. Our work also presents a decision algorithm for validating transactions to be traded on the platform.

The Pacific Northwest National Lab (PNNL) has developed the Pacific Northwest Smart Grid Demonstration (PNWSGD) project [6]. The PNWSGD project proved the feasibility of DLMP model for TE systems using real world test cases [6]. These test cases consisted of 55 instantiations across 11 utilities. Our work builds on the proof of concept provided by the PNWSGD project and in addition, presents a decision algorithm for validating transactions. Under project named gridSMART, the American Electric Power Ohio campus (AEP Ohio) implemented a real time and real world DLMP model-based TE system for 110,000 producer-consumer users in the state of Ohio [7]. gridSMART enabled users to monitor price fluctuations in their neighborhood [7]. However, the gridSMART project did not present a platform for selling and buying power. In contrast to gridSMART, our work presents a platform that enables producerconsumer users to sell and buy power.

In Europe, the Flexible Power Alliance Network has developed the EF-Pi software platform, which enables users to choose their source of electricity production [8]. Although EF-Pi provides options to qualify as a transactive energy system, it is not a trading platform.

8. Conclusion and Future Work

We described the architecture, design, and evaluation of a prototype system for enabling the creation and management of a transactive power market while ensuring the integrity of the electric power distribution grid.

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APPENDIX G
Final Report: IR Camera Phase I



**INTEGRATED
DESIGN LAB**
University of Idaho

USING IR CAMERAS IN BUILDING CONTROLS
PROJECT REPORT PREPARED FOR AVISTA UTILITIES

September 30, 2019

Prepared for:

Avista Utilities

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Report Number: 1808_01

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ACRONYMS AND ABBREVIATIONS

AHU	Air Handling Unit
ASHRAE	American Society of Heating Refrigeration and Air conditioning Engineers
EMS	Energy Management Control System
EPW	Energy Plus Weather file
HVAC	Heating, Ventilation and Air Conditioning
IDL	Integrated Design Lab
MRT	Mean Radiant Temperature
PMV	Predicted Mean Vote
PNNL	Pacific Northwest National Laboratory
PPD	Percentage of Population Dissatisfied
TMY	Typical Meteorological Year
UI	University of Idaho

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2. EXECUTIVE SUMMARY

The University of Idaho – Integrated Design Lab (UI-IDL) combined an infrared camera with a thermostat to deliver more efficient heating and cooling signals. The team set up a camera in an experimental chamber and verified the accuracy of the camera’s temperature readings. The team then used an algorithm to process the camera’s measurements into a comfort index. In addition to assessing comfort, the team processed the camera inputs through a separate machine learning process to detect occupancy. The comfort and occupancy data is translated into a standard control signal for a thermostat. The team used Energy models to estimate the potential savings of such a controller and documented the results.

3. RESEARCH MOTIVATION

Last year, the Integrated Design Lab collected data at several office buildings in the northwest. Data collected from these sites was used to quantify the occupant comfort levels. The research team found that all offices surveyed dipped below the ASHRAE comfort guidelines and were calculated to be uncomfortably cold. Typical thermostat settings were found to be 70°F for heating and 74°F for cooling with setbacks that varied by location. In every case that was monitored, instruments installed next to the thermostats recorded higher air temperatures than instruments installed closer to the working areas of the office employees.

Controlling a building based on both surface and air temperatures could reduce energy consumption and promote healthier buildings. Most buildings manage their heating or cooling based solely on zone air temperature. Even when the thermostats are kept within a narrow band of 4°F, occupant complaints persist [1]. A large factor of human comfort is being missed in conventional thermostats: the inclusion of the mean radiant temperature. Many previous studies have established that the temperatures of the surfaces surrounding us have a far greater impact on our comfort than the air temperature [2]. While operative temperature is widely used for predicting human comfort, rarely is it directly used in building controls.

Building operations could benefit greatly from operative temperature control. Operative temperature control would allow for wider air temperature setpoints, thus saving energy each year. A study by the Pacific Northwest National Lab estimated the following general energy savings: a 2°F adjustment on both heating and cooling setpoints led to a fairly uniform HVAC energy savings of 12-20% [3]. Nationwide, such savings would be equivalent to 370-615 trillion Btu saved annually [4]. This research focus is decidedly narrower in scope: focusing purely on small commercial office buildings in the Pacific Northwest, where HVAC energy is typically 35% of the annual load [4]. Research has shown that a thermostat reset could result in total annual energy savings of 4-7% of annual energy consumption per

building [5]. The adoption of wider setpoints based on operative temperatures by controls engineers and consultants could quickly scale up and result in widespread savings. In addition to energy savings, the operative temperature control could dramatically enhance occupant comfort, thus making it an attractive service to offer to clients.

The simple shift in control from air temperature to operative temperature may have a dramatic impact on energy consumption. Controlling for operative temperatures can be done with relatively simple and inexpensive instruments: thermocouples. Expanding just the air cooling setpoint by 5°F can save up to 27% of the total HVAC energy [5]. However, expanded setpoints are only viable if occupant comfort is maintained. While establishing high cooling setpoints can save a lot of energy, if the occupant is uncomfortable, they will either adjust the thermostat on their own or place considerable pressure on the building operator to do so (thus nullifying any potential savings). Occupant satisfaction (or the lack thereof) is the driving force behind thermostat adjustments. Up to \$330 per employee per year in lost productivity at work can be attributed to an office environment outside the bounds of ASHRAE 55's comfort setpoints [6]. Therefore, any thermostat control scheme, operative or otherwise, should focus on comfort so that the setpoints are not immediately changed after they are implemented. An operative thermostat control scheme focused on comfort has a far greater likelihood of remaining in place. Most energy modeling misses this crucial interaction and instead assumes standard setpoints and setbacks. That is why the first phase of this research was identifying typical setpoints at real buildings instead of relying on ideal assumptions.

A control system that incorporates the operative temperature of a zone would allow for a wider range of supply air temperatures and better meet the needs of occupants. The wider range of air temperatures would reduce energy consumption and help to capitalize on operational features such as natural ventilation, night-flush and optimized set-points. The outline of the work is to develop a proof of

concept for a thermostat that incorporates surface temperature measurements to deliver a better comfort profile. This could save energy by reducing overcooling during the summer.

4. PROJECT METHODS

4.1 Importing Data from the IR Camera

The first step of the project was to verify that an inexpensive camera could pick up accurate surface temperatures. The research team purchased a Flir C2 camera, which retails for \$499 (the camera specifications are available in the Appendix). The team set up the camera on a tripod in the experimental chambers at IDL. The chamber is an empty office room with two windows and a ductless mini-split heat pump. The room was heated and cooled at various points to test the camera at a range of temperatures. The team measured surface temperatures in three ways: by using thermocouples attached to the wall with insulation tape, specialized thermocouples (TMCx-HE) with thermal paste, an IR beam gun, an expensive thermal camera, and the inexpensive Flir C2 camera.

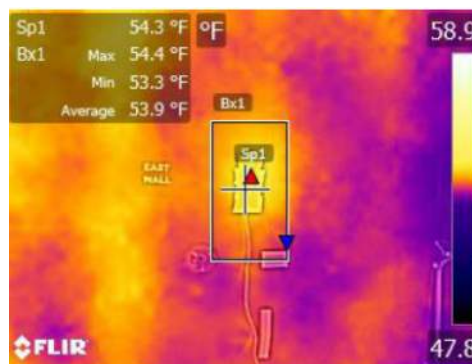


Figure 1: Thermocouple sensor as viewed through the Flir C2 IR camera

After conducting experiments at a range of conditions, the team was able to verify that the Flir C2 could predict the surface temperature within 1°F of accuracy compared to the other methods. This provided enough accuracy for the team to use the camera to estimate the mean radiant temperature of the space. The camera requires inputs of reflected (air temperature), emissivity values (0.9 is the default that worked best) and the camera's distance from the object (set between 0 and 3 meters).

Once the camera settings were verified, the team used that data to calculate the average of the surrounding surface temperatures in the room or the Mean Radiant Temperature (MRT). The mean radiant temperature is based on view factors between a point in space and the surfaces that surround it. P.O. Fanger [7] developed a set of formulas that can be used to predict the view factors of a seated occupant and their surrounding surface temperatures. The team began with this approach. Fanger uses a set of multiple integrals to calculate the radiation impact of each surface. The research team wished to avoid using multivariable calculus, and so curve approximations were developed in Excel. The best method was found to be recommended by the RHEVA guidebook [8]. These equations were programmed into an Excel worksheet and are listed below:

$$F_{p-N} = F_{\max} (1 - e^{-(a/c)/T}) \cdot (1 - e^{-(h/c)/Y})$$

$$T = A + B(a/c)$$

$$Y = C + D(b/c) + E(a/c)$$

	F_{\max}	A	B	C	D	E
Seated Person, Figure 2.2a Vertical Surfaces: Wall, Window	0.118	1.216	0.169	0.717	0.087	0.052
Seated Person, Figure 2.2a Horizontal Surfaces: Wall, Window	0.116	1.396	0.13	0.951	0.08	0.055

Table 1 : Equations for calculations of the angle factors

[8]

The mean radiant temperature is calculated using the below equation in excel,

$$T_{mrt} = \sqrt[4]{\sum(F_{p-N} * T_N^4)}$$

Where T_{mrt} is mean radiant temperature

F_{p-N} is the view factor from person to surface

T_N is the temperature of the surface being measured by the infrared camera

The team now had the ability to take a photo of the wall, export that temperature data into Excel, and estimate the mean radiant temperature for an occupant. The mean radiant temperature was imported into a separate spreadsheet that calculates thermal comfort predictions. Thermal comfort metrics include the following: humidity, dry-bulb temperature, mean radiant temperature, air velocity, clothing level, and activity level. The team measured humidity and dry-bulb temperature with HOBO data loggers. Assumptions were made for air velocity (20 fpm) and occupant clothing and activity levels (seated, typing, wearing jeans and a long-sleeve shirt).

The comfort metrics can be calculated in two ways: either as a Predictive Mean Vote (PMV) or as a Percentage of Population Dissatisfied (PPD). The PMV ranges in its values from -3 to +3, where negative values are associated with being too cold, and positive values corresponding to being too warm. Thermal comfort is defined as having a PMV between -0.5 and +0.5. This value is directly related to the percent that are predicted to be uncomfortable in that situation. For example, a PMV of 1 equals a PPD of 25%. The minimum PPD is 5%.

4.2 Occupancy Detection Methods

One of the advantages of using an IR camera to measure surface temperatures is that it can also be used to count the occupants in a room. This provides crucial information to the HVAC system on the ventilation requirements in a space, which are now required in many systems under Washington's new energy code (WEC C403.1.6.1). The team used machine learning to detect occupants with the low resolution camera. There are numerous open source codes available to detect humans in RGB images.

The IDL researchers used the same codes by changing the infrared image inputs to an RGB format. The application program interface used is the TensorFlow object detection.

TensorFlow is an open source platform from machine learning. The TensorFlow project has many useful framework extensions, one such is Object detection API. As the name suggests, the extension enables TensorFlow users to create powerful object detection models using TensorFlow's directed compute graph infrastructure. The TensorFlow Object Detection API is an open source framework built on top of TensorFlow that makes it easy to construct, train and deploy object detection models. This API can be used to detect, with bounding boxes, objects in images or video using either some of the pre-trained models made available. The object detection code was downloaded and used from Github, a host to open source projects owned by Microsoft. TensorFlow was developed by Google's AI team and codes are available on Github to download. It can be implemented and modified according to user's application needs. The repository is maintained by individual researchers on Github.

4.3 Generating a Control Signal

The purpose of using the camera is to send better heating and cooling signals to the HVAC system for an office. The established protocol for sending control signals is the Building Automated Control Network Protocol, or BACnet. The research team bought a wireless thermostat as well as a digital router that can process BACnet signals. With this, the team was able to establish both wired and wireless communication with a thermostat. Typically a thermostat tries to maintain a certain air temperature keeping the room within a certain deadband between heating and cooling setpoints. For this project, the setpoints were manipulated in order to maintain certain comfort levels. For example, if the PMV comfort calculated for the room drops below -0.5, then the setpoints are increased above the current air temperature to force the heating system on. Similarly, if the calculated PMV rises above +0.5, the thermostat is to call for

cooling. During unoccupied times, the setpoints are expanded dramatically and the PMV is allowed to float anywhere between ± 3 .

5. RESULTS

5.1 Energy Modeling Methods

The research team used a small office prototype model to estimate energy savings. The energy model uses the DOE software program, EnergyPlus. The geometry and loads are derived from the Pacific Northwest National Lab's database of standard building types. These prototype models are used by organizations to test the impacts of new energy codes.

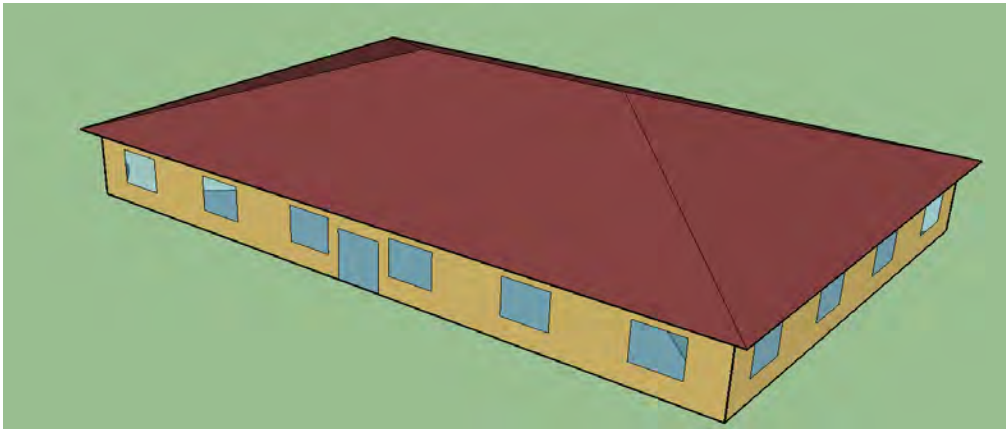


Figure 2: PNNL Small office prototype energy model

The model can be paired with different weather files to estimate utility costs in different locations. The American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE) partitions the US into eight climate zones that account for minimum/maximum temperatures and humidity. All of Avista's service territory falls into either climate zone 5B, or 6. A sketch overlaying climate information onto the general Avista territory is shown in Figure 3

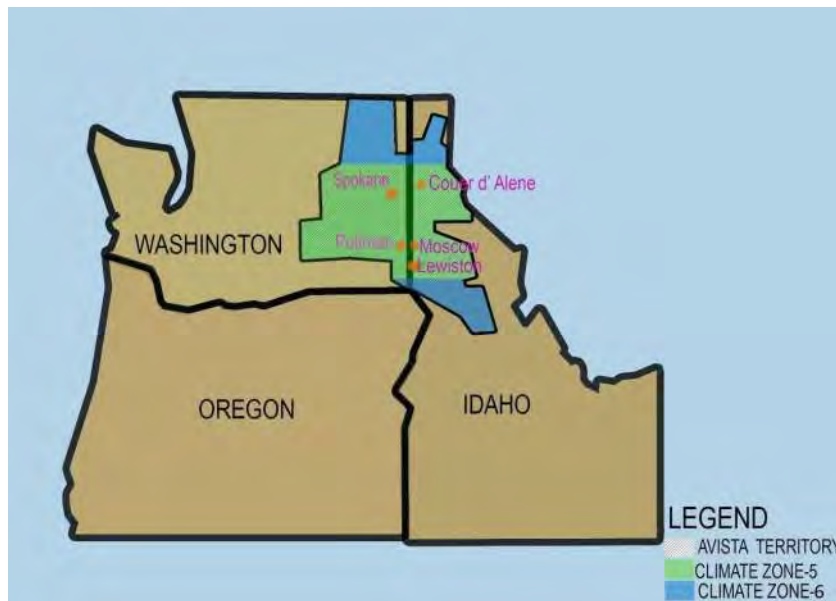


Figure 3 A general outline of Avista's service territory and the climate zones present in that area.

The weather files used in this project included locations in Lewiston, Spokane, and Kalispell. Lewiston and Spokane, which are both within ASHRAE climate zone 5. The Kalispell weather file is in climate zone 6 and was used to approximate the weather Avista's rural customers experience in northern Idaho and Washington.

Initially, the prototype model was simulated with a standard thermostat that uses air temperature setpoints and setbacks. The team then adjusted the code within the model to have the thermostat trigger heating and cooling based on PMV instead of air temperatures. During business hours, the PMV was maintained between ± 0.5 , while at night, the PMV was allowed to float between ± 3 . Savings were identified for each climate. For each of the weather files tested, the heating load increased, while the cooling load decreased. In each situation, the decrease in cooling load was greater than the increase in heating, leading to a net energy savings in every location. The savings were smallest for the colder climate zone 6, with the Kalispell model predicting 3% HVAC savings annually in a typical year. In Spokane, the small office model predicted 5% annual HVAC energy savings from using a thermostat based on PMV,

while in Lewiston, the building saved 7% of its annual HVAC energy. The small office in Spokane reduced its cooling energy by over 1,500 kWh, while keeping the occupants more comfortable.

6. DISCUSSION AND FUTURE WORK

The research work this year proved that it is possible to use an inexpensive thermal camera to predict comfort and occupancy in an office and run a thermostat based on those comfort predictions. The energy models showed net energy savings for Avista customers in both ASHRAE climate zones 5 and 6. The camera was able to accurately record surface temperatures, those surface temperatures were converted into a comfort signal. The team also trained the camera to recognize occupants in low-resolution IR images using machine learning. By processing that information through an Excel spreadsheet, that information can be sent as a BACnet signal to a standard thermostat.

Over the next year, the research team will work to streamline and automate this process. The goal is to commercialize this device so that Avista customers may benefit from its development. The IDL also hopes to incorporate glare detection into the algorithm so that this device may serve multiple functions and eliminate superfluous sensors and wiring and in buildings. So far the team has only sent and received thermostat signals from a computer. In the next year, the team aims to connect a heating and cooling device to the thermostat to complete the control feedback loop. This will allow for further testing and refinement as well as providing physical data on energy savings.

7. BUDGET SUMMARY

These hours reflect only Avista’s contribution to this project and are not reflective of total project investment by the research team, industry sponsors, or other university staff.

Personnel	Hours estimate	Description
Ken Baker	60	Provide overall management of the project
Damon Woods, P.E.	240	Provide technical support and energy modeling
Jubin Mathai	560	Execute daily tasks of this project

FY18/FY19

Expense

PI/Faculty Salaries (Cooper and TBD ME)	\$ 13,243
PI/Faculty Benefits (Cooper and TBC Woods)	3,509
Graduate Student Salaries	8,960
Student Benefits	340
Graduate Student Tuition Remission (partial)	5,387
Travel	2,250
Equipment	500
F&A / Overhead (Excludes Tuition)	<u>13,200</u>
Total	\$ 47,935

Indirect Costs

For this contract, UI-IDL was considered an on-campus unit of the University of Idaho with a federally negotiated rate of 50.3%.

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Table 2: Camera Specifications

Specification	FLIR C2
USB	2.0
Operating temperature range	-10°C to +50°C
Color palettes	Iron, Rainbow, Rainbow HC, Gray
Digital camera	3.07MP
Image Frequency	9 Hz
NETD, Thermal sensitivity	100mk, <0.10°C
Field of view	41°C x 31°C
IR resolution	320*240
Focus	Focus free
Frame rate	9hz
Minimum focus distance	Thermal: 0.15m (0.49ft)
Minimum focus distance with MSX	1.0m (3.3ft)



APPENDIX H

Two-Page Report: Energy Trading Phase II

Designing and Evaluating an Energy Trading System for Prosumers – Phase II

Project Duration: 12 months

Project Cost: Total funding \$96,164

OBJECTIVE

The objective of this project is to analyze and develop a prototype system that would enable Avista prosumers and consumers to trade power on-demand with utility oversight, or with the utility while also ensuring the utility's network resilient operation. In phase I of this project, we completed the analysis and implementation of the first prototype of this application. In Phase II, we propose to design, implement, and integrate a transaction prioritization and pricing algorithm into this prototype. Such algorithm would have the goal of maximizing the economic benefit, welfare, and availability of the electric power grid in the presence of prosumers, while adequately incentivizing prosumer-offered services where and when needed. Such system will enable Avista to create a new market for prosumer-consumer power trading and to plan, manage, and control such market and the flow of power through its network.

BUSINESS VALUE

Avista will benefit from such prototype in the following ways:

- Provide a platform for testing new technologies and algorithms that would enable larger-scale implementations of such customer-driven trading markets.
- Enable the collection of data on sharing behaviors and trading patterns.
- Enable data analytics that may lead to increased efficiency in the distribution system.
- Enable the implementation of real-time profitable and constraint-based electric power pricing strategies.

INDUSTRY NEED

The adoption of consumer-level electric energy production and storage and of smart consumer appliances is accelerating. Examples of technologies leading this rapid adoption are

photovoltaics, small wind, electric vehicles, and smart water heaters and freezers, among other technologies. Within such a new prosumer-enabled smart grid, enabling the managed, but timely and selective trading and transmission of power between prosumers (producer-consumer) and with the utility may enable a more efficient use of the power grid as well as provide utility savings on generation and transmission. For example, a temporary increase in demand from a smart-grid-enabled customer could be served from a grid-near prosumer with stored capacity or solar generation.

BACKGROUND

The following is an example of how the proposed prosumer-consumer power trading may operate. One of Avista's customers installs solar panels or has a storage system such as an electric vehicle and generates or stores electricity. To sell some of this prosumer's excess electricity, this prosumer uses the Avista-managed website and enters the amount of energy that they want to sell, the target price, its nature, and other constraints such as timing. Another Avista customer needs some additional electricity at a scheduled time. Such customer uses the same website and indicates an interest in buying energy under certain conditions, pricing, and time period. The proposed system then creates a match between the prosumer energy offers, requests, restrictions, timing, and pricing. The system then informs the customers and enables and records the business transaction.

SCOPE

Task 1: Meet with Avista® to gather system requirements.

Discussions have been productive in determining the desired modeling system and how to incorporate external transmission Locational Marginal Prices (LMP) into the distribution system.

Task 2: Review of the literature on prioritization and pricing strategies at the distribution level.

Research has been conducted in reviewing past and current literature on LMP and distribution Locational Marginal Price (DLMP). Past project and transactive markets have also been studied on how to incorporate a prosumer-based market into the power system for transaction support.

Task 3: Evaluate options for revenue or objective prioritization and pricing functions

Studies have been reviewed for customer costs on the power system. Base prices and cost of energy production have been evaluated for a per customer basis on the power system.

Task 4: Enhance the simulated model of the power distribution network developed in phase I

The model developed within Phase I of the project has been successfully enhanced from the IEEE 13 bus system to the IEEE 34 Bus system (OpenDSS). This IEEE 34 Bus system has been modified to incorporate customers with renewable resources.

Task 5: Implement the prioritization algorithm in a modern programming language

The prioritization algorithm will be developed in a modern programming language such as MATLAB or Python. Implementation is progressing on schedule. Options to transfer the algorithm to Python are being evaluated.

Task 6: Integrate the transaction control system prototype with the updated distribution model.

Transaction control from the database will expand on the system implemented in the Phase I portion of the project. This integration is being implemented currently and requires full system development from the database.

Task 7: Analyze the power grid condition and economic benefits for different scenarios

Different scenarios will be designed to study the impact of different prices and operating points of the model power system. Task 7 will begin once Task 5 has completed.

Task 8: Design and perform tests for: Functionality, Usability, and Security.

The team has the individual parts (SQL query, OpenDSS, and Python) in the testing phases. Once all the components are autonomously interacting with each other, tests will be

developed to observe the systems performance.

Task 9: Produce user and administrator usage guides

This task will be completed once Task 8 has been completed.

DELIVERABLES

The deliverables of the project include:

- Written final report.
- Interim reports and online conferences with Avista, including one mid-term report.
- Proof-of-concept software and user and administrative documentation.
- Proof-of-concept evaluation within a small-scale simulated distribution system.
- Outlines of proposals for follow-on funding to further develop and refine the prototype.

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SCHEDULE

TASK	TIME ALLOCATED	START DATE	FINISH DATE
Task 1	4.5 months	08/18/19	01/01/20
Task 2	5.5 months	08/18/19	01/31/20
Task 3	5.5 months	08/18/19	01/31/20
Task 4	5.5 months	08/18/19	01/31/20
Task 5	4 months	12/01/19	03/01/20
Task 6	3 months	03/01/20	06/01/20
Task 7	5 months	03/01/20	08/01/20
Task 8	3 months	06/01/20	08/31/20
Task 9	1 month	08/01/20	08/31/20



APPENDIX I

Two-Page Report: Gamification of Energy Use



Gamification of Energy Use Feedback

Project Duration: 12 months

Project Cost: Total Funding \$108,736

OBJECTIVE

In human systems, feedback is essential to understanding the relationship between effort, error, and optimal (or at least successful) performance. If human users can be made explicitly aware of the essential elements of their performance, they can modify that performance. The intent in this project is to use the gaming metaphor to make attention to feedback appealing and frequent. The most effective feedback systems then offer behavioral options, i.e., actions a user can take to change his or her future outcomes. A slate of options that affect usage, but also bring users to educational modules and helpful products will be recommended.

BUSINESS VALUE

Gamification can stimulate greater attentiveness to energy use; attention can lead to reductions in usage. A gamification system will give the utility the ability to incentivize conservation, and can also reward citizen continuing education about energy systems and products.

INDUSTRY NEED

To meet increasing demands and increasing costs, the industry would benefit from customers' conservation behaviors. We believe that the utility would benefit from better monitoring of their energy usage by customers. As meter systems become "smarter", information available to customers can be more granular, more up-to-date, and thus potentially actionable. Presumably, those customer actions will lead to optimization of their usage. Optimization can be in the service

of their own savings but could also serve their other pro-social interests (donations of savings to worthy causes, environmental protection, etc.).

BACKGROUND

This is a new project. However, energy use reduction is, essentially, a human performance problem. There are extensive literatures on feedback systems in general, and gamification efforts in particular. Moreover, gamification has been attempted in utility settings, albeit with disappointing outcomes. We believe the causes of those disappointments can be identified, and that a system can be developed that takes into account preferences for games types, sustained play, action choices, and incentive preferences.

SCOPE

To be consistent with our ongoing set of bi-weekly short reports, we have consolidated some of the tasks reported there into superordinate tasks headings.

Task 1: --- A general review of incentive systems and gamification. We will review past and current attempts to use feedback-based systems by utilities. These attempts have been well-crafted but could not be sustained. We want to learn from those attempts without repeating the mistakes.

Task 2: -- We will review the literature on successful incentive strategies. Then, **survey** customers to create a user profile system that will be the basis of customer gamification choices.

Task 3: -- We will identify the utility data collection capabilities that would allow feedback to customers. E.g., what information can be made available (taking into account security concerns)? Then, we will provide evidence of concept, as follows.

Game prototypes will be developed taking into account gamification capabilities in mobile and home devices. These will be linked to incentives to monitor usage (informed by incentive profiles). Potential customer actions will be added in the course of development.

Task 4: We will user-test the system and make appropriate modifications. Small samples of potential users will be identified at appropriate venues.

DELIVERABLES

- 1) A report will be prepared that updates Avista about what systems and devices are "out there" (with analyses of reasons for success or failure).
- 2) We will have a detailed inventory of incentive strategies, and an overview of customer profile information linked to those strategies.
- 3) We will have survey data on # 2, drawn from actual and potential utility customers in Avista's service area.
- 4) We will create, and test, a prototypical multiplatform application that will gamify energy usage monitoring. By playing simple entry-level games designed to entertain and challenge, customers will find they have also entered the "big game" (i.e., power usage). Once there, they can be directed to power savings advice, educational modules, and product recommendations (and perhaps discounts). They can earn points, badges, and other rewards as they compete against others or try to beat their own "personal bests." The combination of usage awareness and behavioral options within the "big game" can foster behaviors that lead to more efficient usage.

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SCHEDULE

TASK	TIME ALLOCATED	START DATE	FINISH DATE
1. Research on incentive systems and gamification; report prepared	11 months (the bulk gathered by the 5 th month)	9/19	7/20
2. Survey developed, deployed; data analyzed	4 months to develop/deploy; 2 months of analysis	9/19	3/20
3. Mockups/prototypes developed and tested	11 months	9/19	7/20
4. User testing	4 months	4/20	8/20



APPENDIX J

Two-Page Report: IR Camera Phase II



Using IR Cameras in Building Controls – Phase II

Project Duration: 12 months

Project Cost: Total Funding \$52,500

OBJECTIVE

In 2019, the Integrated Design Lab (IDL) demonstrated the technical feasibility of using a low-cost infrared (IR) camera to provide better temperature management of rooms. The objective of the second phase is to bring the concept of IR thermostats closer to commercialization. The research team is working to miniaturize, automate, and add glare detection and occupant counts to the IR thermostat. The research includes setting up a test chamber to compare the new product to a traditional thermostat, while developing a business case.

BUSINESS VALUE

The IR thermostat functions as an all-in-one sensor that is capable of measuring temperatures and counting occupants. This device can replace individual sensors, thus limiting wiring costs and installation times. The team is also working to add glare detection algorithms so that this device can dim lights and adjust motorized blinds. The lab aims to commercialize the concept of combining three sensors into one device to provide improved comfort and energy savings.

INDUSTRY NEED

Most buildings manage their heating or cooling based solely on zone air temperature, when in reality human comfort is dominated by surrounding surface temperatures. A control system that incorporates the surface temperatures of a zone would allow for a wider range of supply air temperatures to better meet the comfort needs of occupants. The wider range of air temperatures has the potential to reduce energy consumption and can help to capitalize on operational features such as natural ventilation, night-flush and optimized set-points. Current occupancy signals rely on CO₂ sensors, which are

expensive and require frequent recalibration. The IR thermostat will be able to count the occupants in a room and provide accurate levels of ventilation without the need for CO₂ sensors.

BACKGROUND

The IDL measured the thermal comfort parameters of several offices within Avista's climate zones. The findings indicated that current thermostat controls fail to provide adequate comfort in offices and waste cooling energy while doing so. Last year, the IDL explored the possibility of using a thermal camera to incorporate surface temperatures into thermostat controls. This process was carried out with a large camera mounted on a tripod and manual calculations. The research showed that using the IR camera to estimate comfort and detect occupancy is feasible.

SCOPE

The primary focus of this phase of research is to automate and commercialize the IR thermostat concept. To advance this concept, the IDL will utilize a thimble-sized IR camera on an automatic pan/tilt platform and some micro processing boards. The research team will set up communication between the IR thermostat and a piece of HVAC equipment to serve as a test-bed for analysis. This will close the communication loop between the camera and a heating or cooling device to condition a space and provide a direct comparison to the functioning of a traditional thermostat. The team will convert the manual inputs of surface temperatures and conditions into the standard comfort formula to deliver better heating and cooling signals through standard Building Automation Control network (BACnet) protocols. IDL has used open-source machine learning codes to identify occupant outlines from pixelated IR images. The team will modify

and enhance this approach to use the camera to count the number of occupants in a space and to detect direct sunlight (glare) coming through any windows to adjust blinds and optimize cooling controls. The research team is working with the University of Idaho's College of Business and Office of Technology Transfer on commercialization options.

Task 1: Project Planning and Reporting

Conduct team meetings and ongoing project updates, reports and deliverables as required by Avista staff, project management contractors, and the PUC. This task continues throughout the project.

Task 2: Set up HVAC Equipment

The team will link the IR thermostat to an HVAC terminal unit that is able to respond to BACnet control signals to condition the experimental chambers.

Task 3: Automate IR Signal Processing

The camera will be set up to scan the room and take pictures at automatic intervals and process this into a control signal on a regular schedule.

Task 4: Develop Glare Detection Algorithm

In parallel with Tasks 2 and 3, IDL will use the operational data collection to correlate the IR camera files to readings of glare within the space.

Task 5: Run Comparison with Traditional Thermostat

The research team will compare the signal response between the IR thermostat and a traditional thermostat to gauge potential energy savings.

Task 6: Document Results

The final task will be to prepare for commercialization of this product and seek outside investment. The team will provide a final report and presentation to Avista as well as pursue publication in an academic journal such as Energy and Buildings.

- Project team has installed the device on a pan/tilt mechanism and has scheduled the photography and signal processing for autonomous deployment.
- Project team has translated glare readings to BACnet signal objects for blind controls.
- Project team has compared performance of using an IR thermostat versus a traditional thermostat to manage the temperature of an experimental chamber and can quantify the difference in energy used.
- Project team is able to articulate the process, move towards commercialization, and produce a final report of findings for Avista. The team has completed a current literature review of the relevant technology in this sector.

PROJECT TEAM

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SCHEDULE

TASK	TIME ALLOCATED (Months)	START DATE	FINISH DATE
Project planning	12	09/01/19	08/30/20
Set up HVAC equipment	2	09/01/18	01/01/20
Automate IR signal processing	4	01/01/20	05/01/20
Develop glare detection algorithm	6	10/01/19	04/01/20
Run comparison with traditional thermostat	2	05/01/20	07/01/20
Document results	2	07/01/20	08/30/20

DELIVERABLES

- Project team has set up a piece of HVAC equipment with a call and response to the IR thermostat that can either heat or cool the experimental chamber.