ATTACHMENT 2
Executive Summary Form

SAND2017-6501R

Aero-MINE (Motionless, INtegrated, Energy) for Distributed, Scalable Wind Power

1. Project description:

The proposed Aero-MINE technology will extract energy from wind without any exterior moving parts. Aero-MINEs can be integrated into buildings or function stand-alone, and are scalable. This gives them advantages similar to solar panels, but with the added benefit of operation in cloudy or dark conditions. Furthermore, compared to solar panels, Aero-MINEs can be manufactured at lower cost and with less environmental impact. Power generation is isolated internally by the pneumatic transmission of air and the outlet air-jet nozzles amplify the effectiveness. Multiple units can be connected to one centrally located electric generator. Aero-MINEs are ideal for the built-environment, with numerous possible configurations ranging from architectural integration to modular bolt-on products.

Traditional wind turbines suffer from many fundamental challenges. The fast-moving blades produce significant aero-acoustic noise, visual disturbances, light-induced flickering and impose wildlife mortality risks. The conversion of massive mechanical torque to electricity is a challenge for gears, generators and power conversion electronics. In addition, the installation, operation and maintenance of wind turbines is required at significant height. Furthermore, wind farms are often in remote locations far from dense regions of electricity customers. These technical and logistical challenges add significantly to the cost of the electricity produced by utility-scale wind farms. In contrast, distributed wind energy eliminates many of the logistical challenges. However, solutions such as micro-turbines produce relatively small amounts of energy due to the reduction in swept area and still suffer from the motion-related disadvantages of utility-scale turbines. Aero-MINEs combine the best features of distributed generation, while eliminating the disadvantages.

2. Project goals and objectives:

This project has four overarching project goals and objectives. Goals *(i)* and *(ii)* span technical readiness levels (TRLs) 2-6, and goals *(iii)* and *(iv)* involvedissemination and technology transfer:

(i) Design, Proof-of-Concept and Technology Demonstration of 1st-Gen Aero-MINE Airfoil-pair
- computational design and optimization of an airfoil-pair to maximize efficiency
- wind tunnel testing (laboratory-scale) for proof-of-concept and computational validation
- field test (pilot-scale) of a single airfoil-pair to demonstrate fundamental technology

(ii) Optimization, Technology Development and Technology Demonstration of the 2nd-Gen Aero-MINE Array through Integration and Validation
- computational design and optimization of an integrated array of multiple airfoil-pairs
- wind tunnel testing to validate multiple-pair amplification effect
- performance and cost benefit analysis of with wind tracking alignment
- field test integrated array to demonstrate technology for commercialization

(iii) Knowledge Dissemination and Educational Outreach
- publish and present findings at technical conferences in each year of the project
- donate the 1st generation Aero-MINE to a high school in Oakland, CA serving disadvantaged children, underrepresented in science, technology, engineering and math
- prepare curriculum and volunteer to demonstrate the technology at the school

(iv) Commercialization and Technology Transfer
- patent additional technological advancements
- transfer technology to a company to prepare for commercialization

3. Explanation of how project goals and objectives will be achieved, quantified, and measured:

The team builds on several long-existing wind energy collaborations, including *(i)* between Drs. Westergaard and Houchens when they were at Vestas and Rice University, respectively, and

ATTACHMENT 2
Executive Summary Form

Vestas funded several wind turbine optimization projects, *(ii)* between Drs. Blaylock, Cooperman, and van Dam, the latter being the PhD advisor of the two former who conducted complimentary computational studies and wind tunnel tests on microjets for active load control on wind turbine blades (a concept very similar to the Aero-MINE technology), and *(iii)* within Sandia where Dr. Blaylock has long utilized the computational resources needed to complete the proposed work, including the codes NALU, the Sierra Suite, and Dakota which were developed at Sandia.

The project will advance Aero-MINEs from a TRL of 2 to 6 within the proposed 3 years. The 1st-generation Aero-MINE Airfoil pair will be designed as follows. First, reduced-order, 2D modeling will allow fast iteration to narrow the parameter space of functional designs. Then, rigorous 3D computational fluid dynamics (CFD) simulations with NALU and Sierra software will be combined with the optimization package Dakota to maximize the performance. Additive manufacturing (3D printing) will be used to create a prototype for wind tunnel experiments, which will serve as cross-validation of CFD simulations. Finally, field testing will provide the technology demonstration. A 2nd-generation Aero-MINE Array will undergo a similar design cycle to optimize the multiple-pair amplification effect and yield a commercial-ready design.

4. Project task description:

Full task descriptions are provided in Attachments 4 and 6. Briefly these are:

Task 1. Administrative Project Management

The project will be administered at Sandia-CA with PI Houchens dedicated to project management to ensure *(i)* strong lines of communication across participants, *(ii)* achievement of milestones, *(iii)* access to computational and manufacturing resources, and *(iv)* dissemination of findings to a broad base including stakeholders and technical audiences.

Tasks 2-6. Design, Optimization and Testing of 1st-Generation Aero-MINE Airfoil Pair

In the first 18 months the 1st-gen Aero-MINE will be designed with CFD, prototyped and tested in both laboratory (wind tunnel) and field conditions. This will provide proof-of-concept and critical understanding of the arrangement of the airfoils and air-jet nozzles.

Tasks 7-10. Design, Optimization and Testing of 2nd-Generation Aero-MINE Array

The 2nd-gen Aero-MINE will be designed with CFD and a scaled model will be rapid prototyped and tested in wind tunnel and field experiments to show power amplification.

Tasks 11-13. Evaluation of Benefits, Knowledge Dissemination and Educational Outreach

At least 3 publications will result including: *(i)* a purely computational efficiency maximization of the 1st-gen Aero-MINE using CFD simulations and optimization, *(ii)* a comparison of experiments with simulations, and *(iii)* a study of the array amplification effect of the 2nd-gen Aero-MINE array. Additionally, the 1st-gen Aero-MINE will be donated to a charter high school serving disadvantaged children to aid in their design education curriculum.

Task 14. Commercialization and Production Readiness Plan

Patents will be pursued and a business model will be developed. This will set the groundwork for commercialization. Technology and lessons-learned will be transferred to a company in preparation for fundraising, design-for-manufacturability and market studies.

5. Agreement management description:

The project will be managed by PI Dr. Brent Houchens of Sandia National Laboratory in Livermore, California. Major computational modeling, optimization efforts and field testing will be guided by Dr. Myra Blaylock of Sandia. Dr. Carsten Westegaard of Texas Tech University will oversee reduced-order, 2D computational modelling for fast iteration on potential concepts and also provide technology transfer and commercialization strategies. Wind tunnel testing will take place at UC-Davis, overseen by Professor Case van Dam and Dr. Cooperman. Dissemination through publications and presentations will involve all project participants and PI Houchens will coordinate and participate in educational outreach efforts.

ATTACHMENT 3
Fact Sheet Template

EPC-16-310
Aero-MINE (Motionless, INtegrated, Energy) for Distributed, Scalable Wind Power

Development of a motionless, distributed, scalable system for wind energy extraction in both building-integrated and stand-alone configurations, at the point of customer use.

The Issue

Operational and logistic barriers of utility-scale wind turbines limit their competitiveness with fossil fuels for electricity production. These large turbines require installation and maintenance at very significant height, and are often located far from electricity customers. In contrast, distributed micro-wind turbines are located at the point of use, but have small swept areas and can produce only small amounts of energy. Furthermore, they have added risk to humans due to proximity. Both utility-scale and micro turbines create significant aero-acoustic noise, pose wildlife mortality risks, and create visual impairments including flicker and scenery obstruction.

Project Description

The Aero-MINE (Motionless, INtegrated, Energy) solution combines the advantages of distributed electricity production while significantly increasing the maximum possible energy extraction in a safe, quiet, motionless design. First, a single Aero-MINE airfoil-pair will be designed and optimized using computational fluid dynamics (CFD) simulations. The optimized design will be constructed using large-scale rapid prototyping capabilities at Sandia and tested in both wind tunnel and field tests. Then, an array of three Aero-MINE airfoil-pairs will then be designed and optimized using CFD to account for interaction and demonstrate the multi-pair amplification effect and scalability. An array of airfoil-pairs, as shown in Figure 1, has the benefit of significantly increasing the swept-area of wind from which energy can be extracted.

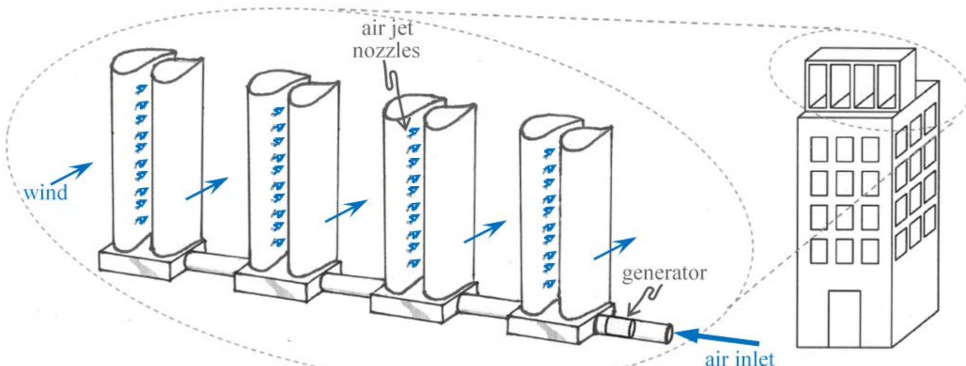

Figure 1. Aero-MINEs integrated into a building rooftop, with a close-up of the four airfoil-pairs with air-jet nozzles on the surfaces between each pair. Reduced pressure between the airfoil-pairs causes suction on the hollow system. Air is sucked in through the duct, passes over and drives a fan-generator, then exits the hollow airfoils through the air-jet nozzles.

Anticipated Benefits for California

General Benefits:

Extracting wind energy for electricity production is critical to achieving the State of California goals for emissions reduction. As customer-scale storage and grid-tied electrical systems become more widely available, distributed wind energy has the potential to supply, alone or in concert with distributed solar, a large fraction of business and residential power needs, both day and night. Aero-MINEs overcome existing limitations of distributed micro-wind energy in that they can safely and quietly extract more wind energy by having a larger equivalent swept area. In rooftop and building-integrated settings, Aero-MINEs provide a viable complimentary power source for climate control of commercial and public buildings, manufacturing facilities, and data-centers and server-centers. They are scalable, safe, and passive, making them attractive for apartments and communities.

Specific Benefits:

- Lower costs:
  Aero-MINEs allow for distributed electricity production with similar benefits to solar panels, at lower cost per kilowatt-hour due to simpler manufacturing using less toxic materials and processes.
- Greater reliability:
  Aero-MINEs have few moving parts and thus are highly reliable. The only required moving part is a single fan-generator housed inside the duct work, which can further be located in an internal, climate-controlled environment away from inclement conditions.
- Increased safety:
  Aero-MINEs have no external moving parts and transfer energy pneumatically by moving air through ducts. Thus they are very safe and do not require isolation from humans, unlike micro-wind turbines or solar panels. The fan-generator is internal to the duct, and can be further isolated within the building. Aero-MINEs pose no threat to birds.
- Economic development:
  As this proposed work will move the technology from TRL2 to TRL6, it is anticipated that Aero-MINEs will be commercialization-ready upon completion of the project.
- Environmental benefits:
  A viable, distributed wind energy solution will be designed, developed, optimized and piloted. Cost-effective Aero-MINE arrays can soon after provide renewable wind energy for commercial rooftop applications for major power consumers such as warehouses and data-centers, contributing up to half of the "50% Renewables Portfolio Standard by 2030" goal on these buildings, the other half coming from self-generation solar PV.
- Public health:
  Aero-MINEs produce power from wind, offsetting the need to burn fossil fuels and thereby reducing pollution and emissions that have negative health impacts. Up to 4 $MMtCO_2$-equivalent emissions may be cut per year just by supplementing existing self-generation solar PV systems on commercial buildings in CA.
- Consumer appeal:
  Aero-MINEs offer the potential for shared-community power production. They are attractive, non-polluting and safe, making them very appealing to electricity consumers.
- Energy security:
  Aero-MINEs offer distributed wind energy conversion and accommodate both off-grid storage and grid-tied systems, providing renewable energy independent from foreign imports or polluting means.

Project Specifics

Contractor:	Sandia National Laboratories, Livermore, California Project Manager – Brent C. Houchens, Principle Mechanical Engineer brent.houchens@sandia.gov, (925) 294-6703
Partners:	University of California, Davis and Texas Tech University
Amount:	$ 1,249,722
Co-funding:	$ 865,825
Term:	3 years, November 15, 2017 – November 14, 2020

ATTACHMENT 7
General Budget Worksheet Instructions

1. A separate set of complete budget forms, including the full set of worksheets, is required for the Contractor/Recipient and for each subcontract containing: 1) $100,000 or more of Energy Commission funds; or 2) 25% or more of the total Energy Commission funds requested.
2. For each worksheet, only identify the expenses to be incurred by the organization to which the budget forms pertain.
3. Only complete information for non-shaded cells; all other information will be automatically filled or calculated.
4. When more rows are required, copy an existing row and "insert the copied cells" between existing rows to keep template formulas accurate.
5. Budgeted Energy Commission funds and match share must be in whole dollars. Rates (labor, fringe, indirect or profit) and unit costs for materials/equipment must be in dollars and cents (two decimal places only).
6. Do not create new formulas in the tables as they may cause rounding discrepancies.
7. Each worksheet has specific instructions located below the form.
8. All rates (labor, fringe, indirect, and profit) included in these forms are caps, or the maximum amount allowed to be billed. The Energy Commission will only reimburse for actual expenses incurred, not to exceed the rates specified in these forms.
9. All costs (including indirect costs) must adhere to the Agreement Terms and Conditions, Generally Accepted Accounting Principles (GAAP) and the Office of Management and Budget (OMB) Circular or Federal Acquisition Regulations applicable to your organization.
10. Never delete Rows, Columns or Worksheets. Leave unused cells blank.

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Category Budget

(see instructions)

Name of Organization Small Micro Disabled Veteran Contractor/Recip Subcontrac	Sandia National Laboratories

Cost Category	Energy Commission Reimbursable Share	Match Share	Total
Direct Labor	$ 466,240	$ -	$ 466,240
Fringe Benefits	$ 194,889	$ -	$ 194,889
Total Labor	**$ 661,129**	**$ -**	**$ 661,129**
Travel	$ 32,406	$ -	$ 32,406
Equipment	$ -	$ -	$ -
Materials/Miscellaneous	$ 37,335	$ 735,000	$ 772,335
Subcontractors	$ 200,253	$ 130,825	$ 331,078
Total Other Direct Costs	**$ 269,994**	**$ 865,825**	**$ 1,135,819**
Indirect Costs	$ 318,599	$ -	$ 318,599
Profit (not allowed for grant recipients)	$ -	$ -	$ -
Total Indirect and Profit	**$ 318,599**	**$ -**	**$ 318,599**
Grand Totals	***$ 1,249,722***	***$ 865,825***	***$ 2,115,547***
Amount of funds to be Spent in California**			
Percentage of Funds to be spent in California			

Category Budget Instructions

1. Insert name of the organization (either Contractor/Recipient or Subcontractor). All subcontracts containing: a) $100,000 or more of Energy Commission funds; or b) 25% or more of the total Energy Commission funds awarded must complete a full set of budget forms.

2. Check appropriate box to identify whether the budget forms are for the Contractor/Recipient or a Subcontractor.
3. Check appropriate box(es) to identify whether entity is a small business, micro business, and/or Disabled Veteran Business Enterprise.
4. No other input is necessary on this page as other cells self-populate.
(**) "Spent in California" means that: (1) Funds in the "Direct Labor category and all categories calculated based on direct labor (e.g., fringe benefits, indirect costs and profit) are paid to individuals that pay California state income taxes on wages received for work performed under the agreement. Payments made to out-of-state workers do not count as “funds spent in California.” However, funds spent by out-of-state workers in California (e.g., hotel and food) can count as “funds spent in California.”; AND (2) Business transactions (e.g., material and equipment purchases, leases, and rentals) are entered into with a business located in California. (3) Total should include any applicable subcontractors.

Direct Labor (Unloaded)

(see instructions)

Sandia National Laboratories

Hourly Rates

Employee Name	Job Classification / Title	Maximum Labor Rate ($ per hour)	# of Hours	Energy Commission Funds	Match Share	Total
	Engineering and Operations / Product Design Engineer	$ 94.97	21	$ 1,994	$ -	**$ 1,994**
	Research & Development	$ 49.50	961	$ 47,571	$ -	**$ 47,571**
	Research & Development	$ 54.71	5,174	$ 283,082	$ -	**$ 283,082**
	Research & Development/ R&D S&E, Mechanical Engineering	$ 90.25	910	$ 82,124	$ -	**$ 82,124**
	Research & Development/ R&D S&E, Mechanical Engineering	$ 99.75	516	$ 51,470	$ -	**$ 51,470**
				$ -	$ -	**$ -**
Hourly Direct Labor Totals				**$ 466,240**	**$ -**	**$ 466,240**

Monthly Salary Rates

Employee Name	Job Classification / Title	Maximum Labor Rate ($ per month)	# of Months	Energy Commission Funds	Match Share	Total
		$ -		$ -	$ -	**$ -**
		$ -		$ -	$ -	**$ -**
		$ -		$ -	$ -	**$ -**
		$ -		$ -	$ -	**$ -**
		$ -		$ -	$ -	**$ -**
		$ -		$ -	$ -	**$ -**
Monthly Direct Labor Totals				**$ -**	**$ -**	**$ -**

	Energy Commission Funds	Match Share	Total
Direct Labor Grand Totals	**$ 466,240**	**$ -**	**$ 466,240**

Direct Labor (Unloaded) Instructions

1. Insert employee name(s) that will be charged as direct labor as either a reimbursed cost or match share. (optional, but recommended)
2. Insert employee(s) job classification/title. (required)
3. Insert the maximum hourly monthly labor rate (unloaded) by employee job classification/title to be billed during the approved term of the agreement. This is the highest salary or wage rate that is actually paid to the employee before the application of fringe benefits, indirect costs or profit.
4. Complete the appropriate table based on your organization's standard accounting practices. If an employee is paid based on an hourly rate, use the hourly table. If an employee is paid based on a monthly salary, use the monthly table.
5. The rates in these forms are rate caps, or the maximum amount allowed to be billed for the entire term of the agreement. The Energy Commission will only reimburse for <u>actual</u> direct labor expenses incurred, not to exceed the rates specified in these forms. Rates must include dollars and cents (two decimal places only).
6. Insert the approximate number of hours or months to be worked by employee or job classification/title including for all "to be determined" (TBD) employees. The Energy Commission will only reimburse for actual time worked. The Contractor/Recipient or Subcontractor must maintain auditable documentation of actual time worked hourly, daily, weekly or monthly using standard accounting practices.
7. Insert the dollar amount by employee or job classification/title to be reimbursed with Energy Commission funds. ***Whole dollars only.***
8. Insert the dollar amount by employee/classification to be charged as match share. ***Whole dollars only.***
9. Confirm totals across and down are accurate.
10. Totals on each line must be less than or equal to Maximum Labor Rate multiplied by the Number of Hours.

Fringe Benefits
(see instructions)

Sandia National Laboratories

Fringe Benefit Base Description (Employee or Job Classification/Title)	Max. Fringe Benefit Rate (%)	Direct Labor Costs ($)	Energy Commission Funds	Match Share	Total
Engineering and Operations / Product Design Engineer		$ 834	$ 834	$ -	**$ 834**
Research & Development		$ 19,884	$ 19,884	$ -	**$ 19,884**
Research & Development		$ 118,328	$ 118,328	$ -	**$ 118,328**
Research & Development/ R&D S&E, Mechanical Engineering		$ 34,328	$ 34,328	$ -	**$ 34,328**
Research & Development/ R&D S&E, Mechanical Engineering		$ 21,514	$ 21,514	$ -	**$ 21,514**
			$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
		$ -	$ -	$ -	**$ -**
Fringe Benefit Totals		**$ 194,889**	**$ 194,889**	**$ -**	**$ 194,889**

Fringe Benefits Instructions

1. Insert the fringe benefit (FB) base description. The base is typically the direct labor costs that are multiplied by the fringe benefit rate to arrive at the fringe benefit cost (FB base multiplied by the FB rate = FB cost).
2. Organizations that charge the same fringe benefit rate for all classifications should insert "All Classifications" under the base description and complete the top line only. If more than one fringe benefit rate is utilized, use additional lines and adequately describe (by employee or classification) the base for each fringe benefit rate charged.
3. Insert the maximum fringe benefit rate to be charged during the approved term of the agreement. Round percentages **<u>up</u>** to the nearest hundreth (two decimal places). For example, manually enter 20.26% instead of 20.2511%
4. The fringe benefit rates in these forms are rate caps, or the maximum amount allowed to be billed. The Energy Commission will only reimburse for <u>actual</u> fringe benefit expenses incurred, not to exceed the rates specified in these forms.
5. Insert the direct labor costs allocable to each fringe benefit rate. These costs must be consistent with the costs identified on the Direct Labor worksheet. The total for the Direct Labor Costs column on this worksheet must match the Grand Total for all Direct Labor (Energy Commission Funds and Match Share) on the Direct Labor worksheet.
6. Insert the dollar amount of fringe benefit costs to be reimbursed with Energy Commission funds. ***Whole dollars only.***
7. Insert the dollar amount of fringe benefit costs to be charged as match share. ***Whole dollars only.***
8. Totals on each line must be less than or equal to Maximum Fringe Benefit Rate multiplied by Direct Labor Costs.
9. The Energy Commission expects to only reimburse fringe benefit costs which are allocable to the Fringe Benefit base costs reimbursed by the Energy Commission. For example, if the Energy Commission reimburses 45% of the direct labor, the Energy Commission expects to only reimburse up to 45% of the fringe benefit costs.
10. Confirm all totals across and down are accurate.

Travel

(see instructions)

Sandia National Laboratories

Task No.	Traveler's Name and/or Classification	Departure and Destination	Trip Purpose	Energy Commission Funds	Match Share	Total
	Research & Development / R&D S&E, Mechnical		Organizational Meeting - Once per year for 3 years	$ 5,401	$ -	**$ 5,401**
	Research & Development / R&D S&E, Mechnical		Organizational Meeting - Once per year for 3 years	$ 5,401	$ -	**$ 5,401**
	Research & Development		Organizational Meeting - Once per year for 3 years	$ 5,401	$ -	**$ 5,401**
	Research & Development / R&D S&E, Mechnical		Conference - Once per year for 3 years	$ 8,102	$ -	**$ 8,102**
	Research & Development		Conference - Once per year for 3 years	$ 8,102	$ -	**$ 8,102**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
			Total:	**$ 32,406**	**$ -**	**$ 32,406**

Travel Instructions

1. All travel costs are reimbursed at state rates except in agreements between the Energy Commission and a UC campus or the Federal Government. Current state travel rates can be found at http://www.energy.ca.gov/contracts/TRAVEL_PER_DIEM.PDF. Please see terms and conditions for more information.
2. Identify all travel costs to be incurred by the organization to which these budget forms pertain (e.g. subcontractor travel will be shown on the subcontractor travel sheet, not on the Contractor/Recipient travel sheet). All travel identified as "To Be Determined (TBD)" is not pre-approved and requires prior written approval from the Commission Agreement Manager and Commission Agreement Officer in accordance with the terms and conditions.
3. All travel listed on agreement budget forms must obtain pre-approval from the Commission Agreement Manager and Commission Agreement Officer in accordance with the terms and conditions. All subcontractors under $100,000 or 25% of the Commission Funds, who do not have their own travel sheets, must get all travel pre-approved in writing as needed.
4. Insert the applicable Task No. from the Scope of Work that the trip supports.
5. Insert the traveler's name and/or classification.
6. Insert the departure and destination locations. For example, "From Sacramento to Los Angeles and Return." It is strongly recommended that all out of state or out of country travel be paid with match funding.
7. Insert a brief purpose of the trip.
8. Insert the dollar amount of each trip to be reimbursed with Energy Commission funds. ***Whole dollars only.***
9. Insert the dollar amount of each trip to be charged as match share. ***Whole dollars only.***
10. Confirm all totals across and down are accurate.

Equipment
(see instructions)

Sandia National Laboratories

Task No.	Description	Purpose	# Units	Unit Cost	Energy Commission Funds	Match Share	Total
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				Total:	**$ -**	**$ -**	**$ -**

Equipment Instructions

1. Equipment is defined as items having a ***per unit*** cost of at least $5,000 and a useful life of at least 1 year. Equipment means any products, objects, machinery, apparatus, implements or tools purchased, used or constructed within the Project, including those products, objects, machinery, apparatus, implements or tools from which over thirty percent (30%) of the equipment is composed of Materials purchased for the Project. Items not meeting this definition should be included on the Materials & Miscellaneous worksheet.
2. Insert the applicable Task No. from the Scope of Work that the equipment supports. Multiple tasks may be identified.
3. Insert a description of the equipment. The description should be sufficient to allow the Energy Commission to easily tie the equipment to backup documentation provided with the invoice and the Scope of Work.
4. Insert a concise purpose of the equipment (i.e., why is the equipment needed for the project?).
5. Insert the number of units to be purchased.
6. Insert the ***per unit*** cost of the equipment.
7. Insert the dollar amount to be reimbursed with Energy Commission funds. ***Whole dollars only.***
8. Insert the dollar amount to be charged as match share. ***Whole dollars only.***
9. Totals on each line ***must equal*** # of Units multiplied by the Per Unit Cost.
10. Confirm all totals across and down are accurate.

Materials & Miscellaneous

(see instructions)

Sandia National Laboratories

Task No.	Description	Purpose	# Units	Unit Cost	Energy Commission Funds	Match Share	Total
	Service Center Charge	3D Printing		$ 1,756	$ 1,756	$ 120,000	$ 121,756
	Installation Cost	Installation of Printed Material		$ 35,579	$ 35,579	$ -	$ 35,579
	Codes and Computational Resources	Usage of codes and computational resources		$ 615,000	$ -	$ 615,000	$ 615,000
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
				$ -	$ -	$ -	$ -
					Total:		
					$ 37,335	$ 735,000	$ 772,335

Materials & Miscellaneous Instructions

1. Materials are items under the agreement that do not meet the definition of Equipment. Miscellaneous are items of cost that do not fit in other cost categories contained in this workbook.
2. Insert the applicable Task No. from the Scope of Work that the material/miscellaneous expense supports.
3. Insert a description of the material/miscellaneous item. The description should be sufficient to allow the Energy Commission to easily tie the material/miscellaneous expense to backup documentation provided with the invoice and the Scope of Work.
4. Where appropriate and logical, materials and miscellenous items can be grouped together. Grouped items must be clearly and thoroughly described. Grouped items can use "varies" for the # of units and unit cost. (Examples may include various pipes and pipe fittings or various nuts and bolts, etc...)
5. Insert a concise purpose of the material/miscelleneous expense (i.e., why is the material/miscellaneous expense needed for the project?).
6. Insert the number of units to be purchased.
7. Insert the ***per unit*** cost of the material/miscelleneous item.
8. Insert the dollar amount to be reimbursed with Energy Commission funds. ***Whole dollars only.***
9. Insert the dollar amount to be charged as match share. ***Whole dollars only.***
10. Totals on each line ***must equal*** # of Units multiplied by the Per Unit Cost.
11. Confirm all totals across and down are accurate.

Subcontracts

(see instructions)

Sandia National Laboratories

Task No.	Subcontractor Name	Purpose	CA Business Certifications DVBE/ SB/MB/None	Energy Commission Funds	Match Share	Total
	UC Davis	UC Davis Wind Tunnel Testing		$ 92,253	$ -	**$ 92,253**
	Texas Tech University	Westergaard Solutions		$ 108,000	$ 130,825	**$ 238,825**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
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				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
				$ -	$ -	**$ -**
			Total:	**$ 200,253**	**$ 130,825**	**$ 331,078**

Subcontracts Instructions

1. Each subcontract containing: 1) $100,000 or more of Energy Commission funds; or 2) 25% or more of the total Energy Commission funds requested requires completion of separate set of complete budget forms detailing the expected expenditures of the subcontractor.
2. Include all subcontractors that have a direct contractual relationship with the organization to which these budget forms pertain including those that must also complete their own set of budget forms.
3. Insert the applicable Task No. from the Scope of Work that the subcontract supports. Insert multiple task numbers if applicable.
4. Insert the name of the subcontractor, if known. If not known, insert "TBD."
5. Insert a concise purpose of the subcontract (i.e., why is the subcontract needed for the project?).
6. Insert the dollar amount to be reimbursed with Energy Commission funds. ***Whole dollars only.***
7. Insert the dollar amount to be charged as match share. ***Whole dollars only.***
8. Totals on each line ***must equal*** total amount of subcontract.
9. Confirm all totals across and down are accurate.
10. Insert whether the subcontractor is a certified Disabled Veteran Business Enterprise (DVBE), Small Business (SB) or Micro Business (MB). Appropriate answers are "DVBE", "SB", "MB", "None", or "TBD". Certification status can be verified at the following website: http://www.bidsync.com/DPXBisCASB

Indirect Costs and Profit

(see instructions)

Sandia National Laboratories

Indirect Cost(s)

Name of Indirect Cost	Maximum Rate	Indirect Cost Base Description	Indirect Cost Base Amount	Energy Commission Funds	Match Share	Total
SNL Overhead		Labor	$ 267,269	$ 267,269	$ -	**$ 267,269**
SNL Overhead		Subcontracts	$ 22,211	$ 22,211	$ -	**$ 22,211**
SNL Overhead		Travel	$ 3,594	$ 3,594	$ -	**$ 3,594**
SNL Overhead		Service Center	$ 25,525	$ 25,525	$ -	**$ 25,525**
			$ -	$ -	$ -	**$ -**
			Total:	**$ 318,599**	**$ -**	**$ 318,599**

Profit

(Profit is not allowed for Grant Recipients)

Profit Rate	Profit Base Description	Profit Base Amount	Energy Commission Funds	Match Share	Total
		$ -	$ -	$ -	**$ -**
		Total:	**$ -**	**$ -**	**$ -**

Indirect Costs Instructions

1. All indirect costs charged must be reasonable, allocable to the project, and fully supported by backup documentation. The Energy Commission reserves the right to request supporting documentation of all indirect costs reimbursed or charged as match share.
2. Indirect costs must adhere to the Agreement Terms and Conditions, Generally Accepted Accounting Principles (GAAP) and the OMB Circular or Federal Acquisition Regulations applicable to your organization.
3. Insert the name of the indirect cost.
4. Insert the maximum indirect cost rate to be charged during the approved term of the agreement.
5. The indirect cost rates on this form are caps, or the maximum amount allowed to be billed. The Contractor/Recipient/Subcontractor can only bill for actual indirect costs incurred, not to exceed the rates specified in these forms.
6. Describe the indirect cost base (categories or items of costs within the budget) on which the indirect cost rate is applied.
7. Insert the dollar amount of the indirect cost base. This is the sum of the budgeted costs described in the indirect cost base description.
8. Insert the dollar amount to be reimbursed with Energy Commission funds. ***Whole dollars only.***
9. Insert the dollar amount to be charged as match share. ***Whole dollars only.***
10. The Energy Commission expects to only reimburse indirect costs which are allocable to the indirect base costs reimbursed by the Energy Commission. For example, if the Energy Commission reimburses 45% of the costs included in the indirect cost base, the Energy Commission expects to only reimburse up to 45% of the indirect costs. Match share expenditures are allowed to cover higher percentages of indirect costs.
11. Totals on each line must be less than or equal to Maximum Indirect Cost Rate multiplied by the Indirect Cost Base Amount.
12. Confirm all totals across and down are accurate.

Profit Instructions

1. **For Grant Agreements Only:** Recipients CANNOT be reimbursed for more than their actual allowable expenses (i.e., cannot include profit, fees, or markups) under the agreement. Subcontractors (all tiers) are allowed to include up to a maximum total of 10% profit, fees or mark-ups on their own actual allowable expenses less any expenses further subcontracted to other entities (i.e., profit, fees and markups are not allowed on subcontractor expenses). For example, if a subcontractor has $100,000 in actual allowable costs but has further subcontracted $20,000 to another entity, then the subcontractor can only include up to 10% profit on $80,000 ($100,000 minus $20,000). See terms and conditions for more information on allowable costs.
2. **For Contract Agreements Only:** Contractors and subcontractors can include up to a maximum total of 10% profit, fees or markups on their own actual allowable expenses less any expenses further subcontracted to other entities (i.e., profit, fees and markups are not allowed on subcontractor expenses). For example, if a contractor has $100,000 in actual allowable costs but has further subcontracted $20,000 to another entity, then the contractor can only include up to 10% profit on $80,000 ($100,000 minus $20,000). See terms and conditions for more information on allowable costs.
3. **For All Agreement Types:** Forgone profit, fees, or markups are NOT eligible match share expenditures. Forgone profit, fees and markups are defined as profit, fees or markups that are not claimed or actually paid to a contractor, recipient or subcontractor. For example, if a contractor pays its own funds to a subcontractor (funds the contractor will not seek reimbursement from the Energy Commission) and the payment includes profit, fees or markups, the amount paid to the subcontractor including the profit, fees or markups can count as a match share expenditure since it was actually paid. However, if a contractor or subcontractor would normally include profit, fees or markups in its invoices and indicates it will forgo charging these costs, the forgone profit, fees, or markups cannot count as a match fund expenditure since it was not paid. This restriction does not apply to equipment or material discounts appropriately documented and provided to the project.
4. Insert the maximum profit rate to be charged during the approved term of the agreement. The profit rate in these forms are caps, or the maximum amount allowed to be billed.
5. Describe the profit base (categories or items of costs within the budget) on which the profit rate is applied.
6. Insert the dollar amount of the profit base. This is the sum of the budgeted costs described in the Profit Base Description.
7. Insert the dollar amount to be reimbursed with Energy Commission funds. ***Whole dollars only.***
8. Insert the dollar amount to be charged as match share. ***Whole dollars only.***
9. The Energy Commission expects to only reimburse profit which is allocable to the profit base reimbursed by the Energy Commission. For example, if the Energy Commission reimburses 45% of the profit base costs, the Energy Commission expects to only reimburse up to 45% of the profit. Match share expenditures are allowed to cover higher percentages of profit.
10. Totals on each line must be less than or equal to: Max. Profit Rate X Profit Base Amount.
11. Confirm all totals across and down are accurate.

1. Technical Merit and Need

Utility scale wind energy is successfully deployed in our nation in spite of numerous technical challenges and barriers associated with the many moving parts in the energy conversion. The main reason for its success is low material consumption per swept energy extracting area due to its sheer size. Small distributed wind or building integrated wind do not benefit from this, and the barriers with the moving parts are much more difficult to overcome cost effectively. Two reasons solar panels are more suitable for the distributed energy applications is that they are mechanically passive and that the power aggregation is modular. This new wind technology can extract wind energy without externally moving parts, while being modular through pneumatic connectivity to one generator unit. The impact on energy efficiency and green buildings will be significant over existing technologies. Based on National Renewable Energy Laboratory (NREL) report on distributed wind opportunities[1], the addressable resource potential for distributed wind exceeds the total electricity demand, out of which 42GW capacity is expected to be commercially viable by 2020. As of 2014, only 4.3MW capacity was installed at average levelized cost of energy (LCOE) of 110 $/MWh[2]. The proposed technology has the potential to address this market opportunity, justifying further maturing of the concept. The goal is to demonstrate that this concept has the potential to exceeds the current LCOE.

It is envisioned that early adaptors of the technology are to be found in the commercial building space because large commitments to building integrated renewable energy already have begun. Companies like Target, Walmart, Google, Tesla etc. are implementing solar on their warehouse rooftops in an effort to meet their own renewable energy goals. This means an existing market is present. The size of the market is very big and growing. The top 10 companies, alone, represent a market opportunity of $2B.

A second market is the residential market. This is also a large opportunity, but requires dis-proportional large investments in supply chain and distribution in order to impact.

a. Goals, Objectives, Technological Advancement, and Innovation

One of the challenges implementing wind energy on or near buildings is that the motion of wind turbines is intrusive and potentially dangerous. This also makes them vulnerable to the wind environment on buildings, which is highly turbulent and thereby taxing on the mechanical structure, impairing their integrity and performance.

This new technology provides completely mechanically passive wind energy extraction with an energy harvesting potential which is often higher than solar energy, as the same energy can be provided from the rim of the building rather than the entire roof. The new technology has no externally moving parts and do therefore not impose visual distractions, vibration/noise impairment, wild life risk or even military radar impact, completely on par with solar panels.

The technology is modular and offer both standardized installations, for example on warehouses, but also in architectural integration. As solar energy has already proven a market

[1] Assessing the Future of Distributed Wind: Opportunities for Behind-the-Meter Projects Eric Lantz, Benjamin Sigrin, Michael Gleason, Robert Preus, and Ian Baring-Gould National Renewable Energy Laboratory, Technical report: NREL/TP-6A20-67337 November 2016

[2] Renewable Energy – Overview, California Energy Commission – Tracking Progress
A report made by CEC staff, Last Updated December 22, 2016

for building integrated renewables, this technology can compete with solar energy, and/or be complementary. In particular, the complementary aspect is of interest to increase renewable energy building integration, because wind energy often is complementary relative to the diurnal cycle of solar energy.

The basic design and functionality has been developed and demonstrated by the inventor at Texas Tech University reaching reasonable efficiency as a concept. The goal of this project is to improve the details of the technology and demonstrate the commercial viability of the technology. We will use Sandia supercomputing facilities to develop aerodynamic details which will be validated in UC Davis wind tunnel, where after large scale 3D printing technology at Sandia will be used to manufacturer a scaled prototype to be tested in an in-situ environment. These efforts will be sufficient enable commercialization.

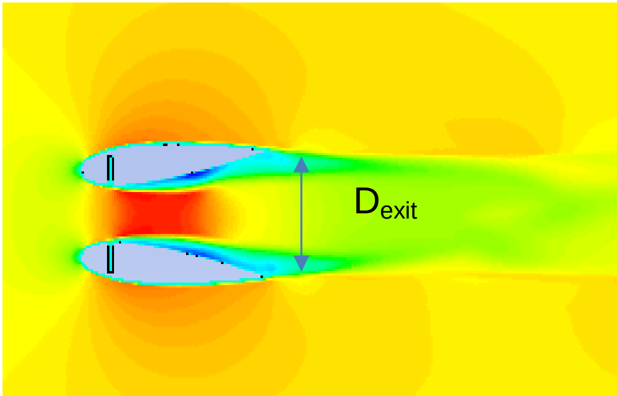
b. Advancement / Breakthroughs to Barriers to California Statutory Energy Goals

The proposed Aero-MINE technology has the potential to significantly impact the 50% Renewables Portfolio Standard (RPS) by 2030. This is particularly true on large commercial buildings where the roof perimeter can be utilized, leaving the remainder for solar photovoltaics (PV). Combined, the systems can operate day and night on the same electrical infrastructure. Once proven in this setting, other applications such as apartment complexes and schools can be considered. It is expected that the cost per kWh of produced electricity will be less expensive than distributed solar. Additional, the Aero-MINEs should have incredibly long service lives and involve low toxicity manufacturing.

c. Status of Relevant Technology and Scientific Knowledge and Advancement, Supplement and Replacement due to the Proposed Project

The fundamental principle is to bleed air through the surface of an airfoil shape and extract energy from a fan at the inlet (in water, water is bled through the skin). While the use of a Venturi effect may not be a new idea, previous concepts do not deploy strong aerodynamics principles and certainly not with a novel self-amplifying effect through air-jet technology, such as proposed here.

The simplest implementation of the innovation is two opposing airfoils, see Figure 1, where a low pressure is generated in between them. The low pressure allows fluid to penetrate orifices in the airfoil surface from the inner airfoil plenum. The inner plenum is connected to ambient pressure. If the flow to the plenum is regulated with energy extraction, for example by a regular electric fan in the flow path, energy can be extracted from this fan. The pressure drops over the fan multiplied by the volume flow is the energy extracted. When the pressure drop across the fan is the same as the pressure drop generated by the airfoil, there is no volume flow and thus no energy extraction. As this is eased, the volume flow increases, until this flow through the surface of the airfoil is disruptive for the flow between the airfoils, reducing the pressure potential and thus the energy extraction potential. In between is an optimum, such as the simulation result shown in Figure 1.



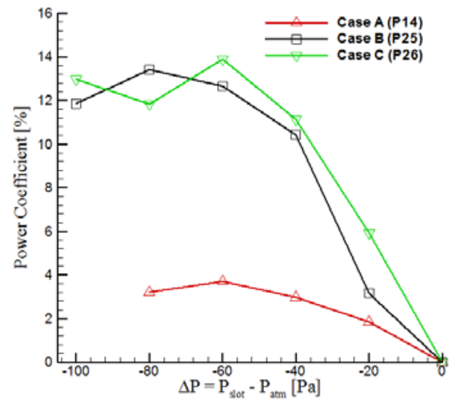


Figure 1 Left: One implementation, two opposite airfoils and inlet from plenum to the flow. Color contours show velocity. Right: Power coefficient of the device based on frontal (swept) area. None of these results include self-amplification effects of air-jets or high performance airfoils.

The essence of the innovation, is that the flow through the orifices should be arranged as air-jet vortex generators, item labeled 604 in Figure 2. Unlike the mechanism described above and shown in Figure 1, an increased flow through air-jets will enhance the airfoil performance rather than destroying it. The team have practical experience with air jets from past work on ordinary wind turbines, see Figure 3. The higher the volume flow, the higher the airfoil performance, the lower the pressure, and, thereby higher the energy extraction potential. The mechanism has by this arrangement become self-amplifying. Obviously, the self-amplifying mechanism will eventually stop working as well due to viscous flow effects. However, the team expect to bring the efficiency of the device close to Betz limit (a power coefficient of 59%) relative to the largest dimension of the device, D_{exit} indicated in Figure 1.

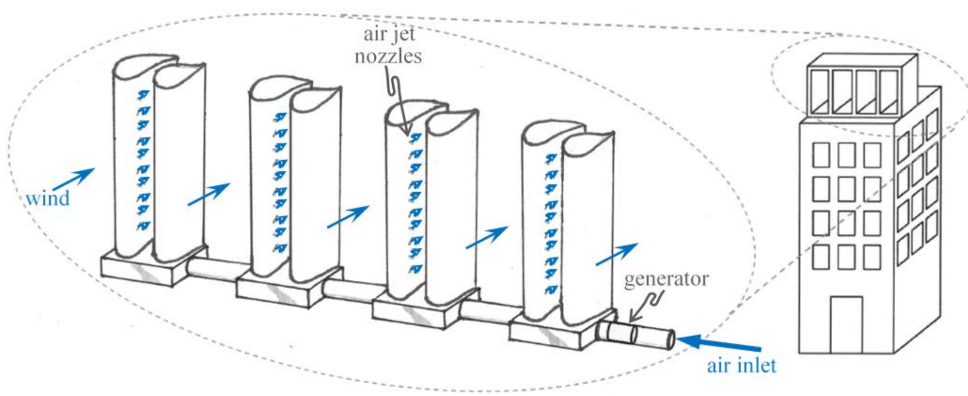


Figure 2 Aero-MINEs integrated into a building rooftop, with a close-up of the four airfoil-pairs with air-jet nozzles on the surfaces between each pair. Reduced pressure between the airfoil-pairs causes suction on the hollow system. Air is sucked in through the duct, passes over and drives a fan-generator, then exits the hollow airfoils through the air-jet nozzles..

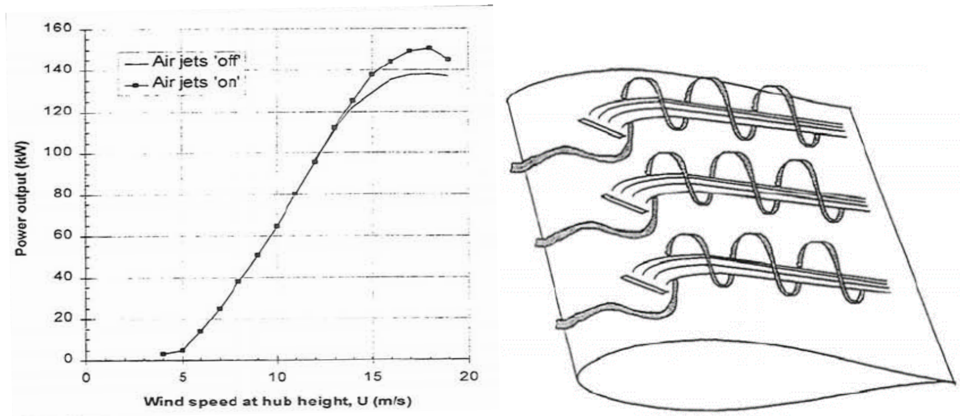


Figure 3 Air-jet technology implemented on an ordinary 150kW wind turbine to control power. Left: results, right: concept. Work performed by Oliver, Wootton, Westergaard, Prats, Voutsinas (1996)

The challenge is to design air-jets for high volume flow in combination with the airfoil design. Secondly, fundamental configurations allowing for cross flow originating from change in wind direction. The first is best explored in with computational methods, while the second is better addressable in wind tunnel and during real in-situ testing.

As the aerodynamics is optimized for one unit, multiple units can be combined in one ducting system, to which a power generation fan can be connected. This will almost literally be a reversed variable speed HVAC fan system. Also, an assessment of the cost benefit of being able to orient the units directly into the wind needs being assessed. No large obstacles are expected in any of these methods.

d. Justification for EPIC Funding

The proposed work is not currently supported by competitive or regulated markets because of the challenges of distributed wind generation discussed above, coupled with the need for TRL2 and 3 research investment to optimize the system. Aero-MINEs however offer novel advantages of longevity, safety and plausible building integration due to their motionless and scalable design. They provide a perfect complement to distributed solar PV, which already has a strong foothold in commercial building integration, without competing for resources. Aero-MINEs can provide complimentary power throughout the nighttime hours and in cloudy conditions. When combined with solar PV, Aero-MINE technology will allow achievement of the 50% Renewables Portfolio Standard (RPS) by 2030 on commercial buildings.

e. Technical Feasibility and Achievability within the Proposed Schedule

This project is designed to have several stages of technology advancement. Because the concept is already proven with a non-optimized blade and configuration, there is assurance that the 1st-generation will function and should have significantly enhanced performance compared to the patented concept. The 1st-generation study is highly valuable on its own merit and will generate considerable enhanced understanding. The 2nd-generation array is critical to understanding the multiplier-effect of an array of airfoil-pairs with air-jets. The 2nd-generation work can begin even if the 1st-generation is not ideally optimized, and thus achievability is high.

f. Measurement and Verification Plan

The measurement and verification plan relies on a series of complimentary computations, wind tunnel tests and field demonstrations, providing a high degree of confidence in the results. In particular, the field tests will be used to directly generate power and charge a battery bank. By measuring the wind speed and the voltage and current associated with charging the battery bank, the energy extracted from the wind will be determined directly. This field demonstration will serve as final validation of the more controlled conditions in the CFD and wind tunnel experiments, where pressure drop will be calculated and measured, respectively. The field demonstrations of the 1st and 2nd-generation Aero-MINEs can be directly extrapolated to potential distributed energy production for electricity customers.

g. Compliance with the California Environmental Quality Act (CEQA)

The computational and wind tunnel tests utilize existing capabilities at Sandia and UC-Davis and thus have little environmental impact. The field tests will use skid-mounted Aero-MINEs and will be temporary installations, removed after the project. Furthermore, because the Aero-MINEs are motionless, there is no danger to wildlife.

h. Benefit to Disadvantaged Communities

The primary benefit to disadvantaged communities within the project period is the donation of the 1st-generation Aero-MINE airfoil-pair as a renewable energy education lab to Latittude High School, a new *Education for Change* school. This school will serve low-income, first-generation college bound students in census tract 6001.4061.00 in Oakland, CA, which has a CalEnviro-Screen 3.0 percentile range of 86-90% and a Pollution Burden Percentile of nearly 86%[3]. The Aero-MINE and associated curriculum will promote renewable energy education in this disadvantaged community.

i. Project adherence to Requirements denoted in Section II.B.2.a

This project advances the Aero-MINE technology from a technical readiness level (TRL) of 2 completely through TRL6. It does involve two field demonstrations, though the fundamental understanding comes from lower TRL aspects such as modeling and wind tunnel studies.

All field and experimental work will be carried out within California's electricity Investor-owned Utilities (IOU) service territory.

The goal of the optimization of the Aero-MINES is to maximize distributed wind resources in California and create the highest possible capacity factor. Aero-MINEs will add reliability to the electrical systems in that they are distributed and robust. They will be inexpensive to manufacture and maintain.

[3] http://www.calepa.ca.gov/EnvJustice/GHGInvest/

2. Technical Approach

a. Technique, Approach, and Methods to be Used

The design methodology is iterative, cycling between low resolution 2D computational fluid dynamics (CFD) studies, high resolution 3D CFD studies, and optimization algorithms. Once an optimized solution is found, rapid prototyping will be used to create the Aero-MINEs. These will then be tested in wind tunnels to verify the accuracy of the CFD.

The 1st-generation design will be accelerated by use of 2D simulations which already have a foundation at Texas Tech University.

b. Task Execution and Coordination with Participants and Team

Two administrative tasks (1 and 14), three dissemination and outreach tasks (11-13) and nine technical tasks (2 through 10) are overviewed below. Specific subtasks are in Attachment 6.

Task 1. General Project Tasks

The project manager, Dr. Houchens, will be responsible for organizing team meetings, filing status reports, submitting conference papers and ensuring overall satisfactory progress to achieving the technical tasks 2 – 10. Flexibility is built into the tasks involving the 2nd-generation Aero-MINE array (asks 7-10) to take full advantage of the understanding gained during studies ont the 1st-generation system. The project manager will also oversee dissemination and outreach tasks 11-13, and assist with foundational work for commercialization (Task 14).

<u>Tasks for Design, Optimization and Testing of 1st-Generation Aero-MINE Airfoil Pair</u>

Task 2. 2D Aero-MINE Airfoil-pair Simulations

Texas Tech University (TTU) will based on initial achievements design an airfoil system with a large chamber and angle between the airfoils to achieve the largest possible exit dimension (D_{exit}) using 2D CFD simulations. The simulations will not include the air jet amplifying technology, only the self-destructive technique previously described. The large chamber may be achieved by using flapped airfoils.

Upon completion of the design, TTU will perform sub-scale wind tunnel testing where the flow in the wind tunnel at TTU will be mapped using an advance laser based measurement system (PIV). These results are comparable to the CFD and will provide a 1st order validation of the simulation to the extent that the wind tunnel capabilities at TTU is insufficient to achieve satisfactory inclusion of the air jets. Accurate is proposed in Task 3 to 5.

Task 3. 1st-Generation Aero-MINE Airfoil-pair Simulations and Optimization in 3D

The 2D modeling of the Aero-MINE airfoil-pair will be expanded in to 3D. While valuable insights can be gained from the initial 2D, there will be also be significant 3D effects that need to be understood such as any affects that turbulence might have on the pair interactions, since turbulence is 3D in nature. We are also expecting the flow between and around the top of the airfoils to have a highly unusual complex 3D multi-scale flow.

We will also utilize Sandia's powerful optimization code, DAKOTA. This toolkit was developed to interface between simulation codes and analysis methods. A parameterization study will create a surrogate model using either Polynomial Chaos Expansion or Latin Hypercube sampling. This surrogate model will be used to locate the parameters, such as size of vents, pipes, angle of the airfoils, and separation between the airfoil pair, which produces the maximum pressure differential. We will also take into account maximizing the "swept area" which can be associated with the distance between the airfoil trailing edges while still balancing the increased interactions between the airfoils.

The supercomputing clusters like what are available at Sandia are necessary for this type of complex 3D computational fluid dynamics.

Task 4. 1st-Generation Aero-MINE Prototype Airfoil-pair 3D Printing

Sandia California's on-site additive manufacturing facility provides high-quality, convenient, and rapid-response 3D printed plastic parts and assemblies directly from computer aided design (CAD) files. The capabilities include multiple Stratasys Fortus 3D printers, including one that has a printing footprint of 2' by 3' by 3', which would be used to print the models to be used in both the wind tunnel testing and outside. A variety of printable materials are available, and we will use ASA for this project due to its resistance to UV light and durability.

The materials and machine cost of producing an additive manufacturing part is leveraged through internal capabilities sustainment funding. Funding would need to be provided to cover the labor for manipulation of the CAD model and subsequent processing of the CAD file for use by the 3D printer. We would expect this to only be a few hours of chargeable labor for the CAD Designers.
In order to produce smooth internal duct work so that frictional losses are minimized, it is possible to embed pre-fabricated piping to the printing process. This method will also help install any fittings or connections between the airfoils and the generator.

Task 5. 1st-Generation Aero-MINE Prototype Airfoil-pair Wind Tunnel Testing

The prototype manufactured in Task 4 will be tested in the UC Davis Aeronautical Wind Tunnel. Wind tunnel tests will examine the performance of the device under various conditions including a range of wind speeds and flow angles. The focus will be on validating the ability of the Aero-MINE prototype to generate a pressure difference that is capable of driving a fan.

The performance of the prototype will be characterized by a variety of measurements which may include the static pressure on the airfoil surface, aerodynamic loads, and flow properties in the wake of the model. The test will be split into two parts: a) a single airfoil will be used for validation of methodology, b) an airfoil-pair will be tested to uncover actual 3D behavior and demonstrate "real life" performance

Results of the wind tunnel tests will be compared with simulation results from Task 3 to validate the numerical results and identify any behaviors that are not captured by the simulations.

Task 6. 1st-Generation Aero-MINE Prototype Airfoil-pair Field Testing

The initial field testing will take place in two primary locations. The first stage will take place on Sandia's Livermore campus. This will allow for easy access and rapid response during the initial field testing of the pair.

We will use the same airfoil pair that was tested in the wind tunnel (Task 5) so that comparisons between controlled and real world conditions can be made. It will also be more efficient to not wait for a second model to be printed.

For the initial field testing we will first measure the pressure drop across the system and check against the predicted pressure drop from the models. The second test will consist of attaching the internal turbine unit with a generator to measure the produced voltage. Finally, to verify the long term energy production of the pair, we will connect the turbine generator to a portable battery which will be installed in conjunction with the Aero-MINE. With the battery, we will be able to monitor the energy production over diurnal cycles and for varying weather conditions.

Tasks for Design, Optimization and Testing of 2nd-Generation Aero-MINE Array

Task 7. 2nd-Generation Aero-MINE Array Simulations and Optimization in 3D

By adding two more pairs, so there will be six airfoils in total, we will be able to determine the effects of the interplay between the airfoil pairs. Halving several pairs in a row will create a feedback the will increase the pressure drop at the slit locations. We are anticipating that this will increase the efficiency of the energy production. By starting the testing process of the array using CFD, we can narrow down several design parameters such as distance between the pairs and angles of the pairs with respect to one another. The angle of individual airfoils could also be optimized, as this might be different from the airfoil angles of just one pair.
Again we will be able to use the DAKOTA optimization tools to efficiently determine the best solution.

Task 8. 2nd-Generation Aero-MINE Array 3D Printing

Two sets of Aero-MINE arrays will be needed. One that is scaled down to fit inside the wind tunnel for testing as well as a set that is the size of the original pair to be tested outside.

Task 9. 2nd-Generation Aero-MINE Array Wind Tunnel Testing

The second round of wind tunnel testing will utilize the Aero-MINE array built in Task 8. The focus of this round of tests will be on characterizing the interaction between multiple pairs of airfoils. The array performance will be compared with results of the single prototype from Task 5, as well as with relevant results from the simulations in Task 7.

Task 10. 2nd-Generation Aero-MINE Array Field Testing

The second and third pair of Aero-MINE airfoils will be added to the first at the Sandia campus. We will design an adjustable mounting system so that we can test the optimum configuration that was outlined in the 3D modeling. We will again measure the pressure differences, the voltage of the system and the produced energy stored in the battery.

Tasks for Maximization of Long-term Impact

Task 11. Evaluation of Project Benefits

The project benefit evaluation is detailed in Attachment 6.

Task 12. Technology/Knowledge Transfer Activities

The technical and practical knowledge learned during this project will be disseminated through both peer-reviewed publications and periodic reporting to the CEC. It is envisioned that three technical conference or journal papers will be submitted and three periodic reports will be generated, as detailed in Attachment 6.

Task 13. Educational Outreach

The 1st-generation Aero-MINE system will be donated to Latitude High School. Latitude is a new school in the *Education for Change* network, scheduled to open in fall 2018. It will serve primarily low-income students from backgrounds underrepresented in science, technology, engineering and mathematics fields. Dr. Houchens has a 10-year track-record of outreach to such schools through his founding and directing of the DREAM-Achievement through Mentorship program (http://dream.rice.edu), originally operating in Houston, TX and recently having expanded to Atlanta, GA. Dr. Houchens will provide teacher training and direct mentoring to the Latitude students, as described in the attached letter of support.

Task 14. Production Readiness Plan

The inventor, Dr. Westergaard has acquired the license rights from Texas Tech University to the technology. Upon successful completion of Task 2 at Texas Tech University, the license will be transferred to his own company Westergaard Solutions, Inc. or a new affiliated entity solely owned by Dr. Westergaard, in order to initiate commercialization based on his own initial funds. This will occur in the middle of 2018. In parallel to this project, Westergaard will raise additional angle and venture funding to create this entity. This phase could be initiated with the additional support of the Texas Tech University Spark fund and innovation hub, but it is not dependent on this additional support, there are no geographical constraint for this effort. The fund raised will be used to start the engineering and manufacturing development, as well as initiate business development with early adaptors. Dr. Westergaard has 23 years of experience from the utility scale wind industry and have accumulated elaborate experience with start-up companies in the wind energy space over the past 5 years. The experience spans both technical and business development.

Upon completion of this project, the technology concept will have been demonstrated in real life. It is expected that the results, both design and manufacturing (large scale 3D printing) will be directly applicable the engineering and manufacturing plans. Here after a larger scale pilot project can be developed applicable to the market segments identified as the first opportunities.

c. Factors Critical for Success, and Risks, Barriers, and Limitations

Preliminary 2D CFD studies of an un-optimized airfoil-pair have already demonstrated that the proposed Aero-MINE design has the capability to generate power. The TRL2 and 3 will focus on producing enough power to make Aero-MINEs viable. The most significant unknown is the optimum level of coupling between the airfoil-pair. This will be overcome through rapid iterations on 2D simulations, which guide larger 3D simulations. The CFD and optimization software will be run in massively parallel jobs on Sandia clusters, providing sufficient resources to

d. Dissemination of Knowledge, Results and Lessons Learned to Public and Decision-makers

The results will be published in peer-reviewed technical conferences and journals. Results will also be presented to the CEC in periodic reports as described in the Scope of Work.

e. Complete Scope of Work and Project Schedule

In addition to the technical tasks (Tasks 2-10), the administrative project management (Task 1) and knowledge dissemination, outreach and commercialization tasks (Tasks 12, 13 and 14) and associated sub-tasks are detailed in the Scope of Work (Attachment 6) and Project Schedule (Attachment 6a). These align with the tasks presented in this Project Narrative.

f. Replication and Deployment Approach including Partners and Stakeholders

The full project team has involvement at every stage of the work. Even before wind tunnel testing begins, co-PIs from UC-Davis will be involved in initial design meetings. As the technology patent is already held by Dr. Westergaard, there is a strong foundation for eventual commercialization. It is expected that additional patents will be pursued during the project, with representatives from every organization.

3. Impacts and Benefits to California Ratepayers

a. Explain how the proposed project will benefit California Investor-Owned Utility (IOU) electricity ratepayers with respect to the EPIC goals of <u>greater reliability</u>, <u>lower costs</u>, and/or <u>increased safety</u>).

Renewables, and wind energy renewables specifically, have become increasingly popular as individuals, businesses, and communities seek to reduce their environmental footprints and become more efficient. However, wind energy renewables continue to have many issues and challenges, especially within proximity of buildings or integrated with buildings. A non-exhaustive list that ordinary wind turbines face in this environment are that they are visual intrusive, often noisy, introduce vibrations into the building structure, reflect light disturbances (flicker) and more. Further, the turbine itself is subject to a very high level of turbulence from its placement on the buildings, which poses both performance issues and life consuming fatigue issues of moving parts. The latter can pose a direct safety risk to the surroundings, especially because the wind turbines are on the rim of the building. Because of these problems, there are many examples of failed small, distributed wind turbine systems.[1,4]

For these reasons, solar panels are the preferred solution in the residential and commercial building space. This is evident when comparing the status of solar versus wind installations. In fact, as of October 31st, 2016, there were 5,100 MW of installed self-generation solar in

[4] 2015 Distributed Wind Market Report, Alice C Orrell and Nikolas F Foster, August 2016, prepared for U.S. Department of Energy

California as compared to the total installed wind distributed generation resources (including self-generation) of only 318 MW.

Our Aero-MINE wind system solves the fundamental challenges that ordinary wind turbine systems normally suffer from when implemented in proximity of buildings or integrated with buildings. The Aero-MINE wind system removes all of the above-mentioned issues because the wind energy is extracted by passive surfaces. Compared to existing wind turbines, the Aero-MINE wind system is much safer due to its passive exterior. A second benefit of the Aero-MINE concept is that it will greatly increase the efficiency of the conversion system. Specifically, the electrical conversion can be achieved from multiple turbines through pneumatic connection, similar to an air vent duct system. The conversion will take place in one central unit, which is a reversed operating HVAC fan. Cost efficiency can also be achieved through existing HVAC supply chain opportunities and therefore also easily scalable to various system sizes accommodating different applications. Further, the conversion unit can be placed at an easily accessible location on the building and even on the ground in many cases; eliminating access challenges and thereby lowering maintenance cost significantly. Maintenance can now be performed by an existing and cost-effective local California HVAC industry, which is already present. A final discussed benefit of the Aero-MINE wind system is that it will greatly increase the reliability of the system, as there are fewer moving parts that could malfunction. As demonstrated, an Aero-MINE wind system increases safety, efficiency, and reliability compared to a traditional system of wind turbines with many moving parts.

In summary, this project will enable the Aero-MINE technology and provide significant proof by the authority of the participating organizations. As indicated by this report, Aero-MINE can benefit California taxpayers by improving reliability, increasing safety, and increasing efficiency.

b. Provide clear, plausible and justifiable quantitative estimates of potential benefits to California IOU electricity ratepayers.

Individuals, businesses, and communities could also employ the Aero-MINE system in conjunction with solar. A reason that the two renewable energy sources could be good complements is that solar is diurnal, where wind in many places is more regular throughout the diurnal cycle and year. Combining solar and wind gives the opportunity to have renewable energy delivered to the building in a more constant stream, thus increasing the 24/7 value of the energy and essentially reducing peak load requirements, while increasing the total impact of renewables for the building. Large retailers such as Walmart and Target have implemented solar panels on numerous buildings, meeting as much as 30% of the building’s need. If these locations were supplemented with the Aero-MINE wind systems, those buildings could exceed the California 2030 50% RPS goal.

c. Describes the applicability of proposed work and/or technology to California’s wind resources and associated challenges and barriers.

A challenge that wind energy renewables in the built environment face is a lack of robust siting data, which can aid in accurately quantifying an opportunity. However, there are some basic principles that can describe siting opportunities for Aero-MINE. For simplicity, it is preferred (but not required) that the Aero-MINE wind system is deployed at wind unidirectional sites. While this sounds overwhelmingly restrictive, it is actually quite normal and reliable directional data are often available where the wind speed can be a bit more inaccurate. The greatest example of such sites can be found near Texas Tech and most of the US mid-west, where it is normal that around 80% of the time the wind comes from the South. Specific to California, one will find very strong, highly unidirectional, and diurnal cycles near the coast and near mountainous regions. As an example, quantitatively comparing the wind energy map below with the actual distributed generation, we can see how underserved regions, such as Santa Barbara, have a high wind potential and may pose a coastal opportunity. Additionally, the NE side of the bay area poses an inner region opportunity. Both examples suggest a more detailed study.

Concerning the wind resource potential itself, California has large regions blessed with high wind resource potential which is available in general wind maps. However, converting such data into the building environment and combined with the directional information relative to the building in question needs to be part of the commercialization efforts to have reasonable accuracy.

d. State the timeframe, assumptions, and calculations for the estimated benefits, and explain their reasonableness.

It is anticipated that Aero-MINEs will be commercialization-ready upon completion of the project. Deployment will therefore depend on the manufacturing of the devices. Individual customers will immediately benefit from energy production, but it is too early to know the cost of an array an therefore the potential break-even pay-back period.

e. Identify impacted market segments in California, including size and penetration or deployment rates, and underlying assumptions.

The first impacted market will be that which currently utilizes distributed solar, with most tied to warehouses and data-centers. It is anticipated that Aero-MINEs can double the 5100 MW related to this generation.

f. Discuss any qualitative or intangible benefits to California IOU electricity ratepayers, including the timeframe, assumptions and environmental considerations.

Given the early TRL level of the technology, it is difficult or speculative to quantify the expected efficiency benefits. There are, however, efficiency benefits when you compare the Aero-MINE technology to other renewable energy sources, such as solar systems. First, solar panels deliver, as a rule of thumb, about 200 kWh/year per square meter rooftop area in California. At reasonable wind sites, the energy concentration (MWh delivered per used rooftop space used) is higher for the Aero-MINE system, because it only uses the rim of the building. So, Aero-MINE enables more efficient use of space than solar while still enabling the same amount of energy generation. Second, solar is diurnal, whereas wind in many places is more regular throughout the diurnal cycle and year. Wind could afford many geographic areas more reliable access to renewables. Third, solar panels have a high use of energy and water during manufacturing. The Aero-MINE will be constructed of either 3D printed plastics, ordinary plastics with some reinforced fibers on par with ordinary wind turbine blades, or building grade fiber wood, depending on the unit size. All of the manufacturing processes have a rather benign environmental impact and generous recycling opportunities. Whereas solar used to be the only option in this space, now wind energy is a more efficient option for residential and commercial self-generation segments.

g. Provide a cost-to-benefit analysis that compares project costs to anticipated benefits and including how costs and benefits will be calculated and quantified and the underlying assumptions.

Because the cost of manufacturing, installation and maintenance of Aero-MINEs is low relative to other technologies, and because the systems are scalable, it is anticipated that the optimized arrays will beat solar PV in a cost/kWh basis.

h. Explains the technology readiness level and the status of the proposed project whether it involves pilot testing/demonstration or an earlier stage of research that involves equipment installation and testing beyond the laboratory, and confirms, for both cases, that the project location is within the IOU territory.

As this proposed work will move the technology from TRL2 to TRL6, it is anticipated that Aero-MINEs will be commercialization-ready upon completion of the project. There will be pilot field test for both a single pair of airfoils as well as an array of up to 6 airfoils. Both tests will be in Livermore, which is in PG&E's IOU territory.

4. Team Qualifications, Capabilities and Resources

a. Describe the organizational structure of the applicant and the project team. Include an <u>organizational chart</u> that illustrates the structure.

Sandia CA will manage all aspects of the project, collaborating with UC-Davis on experiments (wind tunnel and field) and Texas Tech on computations. However, this will be a true collaboration between all participants, and all co-PIs will be involved from start to finish. Both occasional in-person and regular virtual meetings will ensure good communication between participants. It is expected that all participants will contribute to all publications and presentations as each has been selected for unique subject matter expertise that will provide the deepest overall understanding.

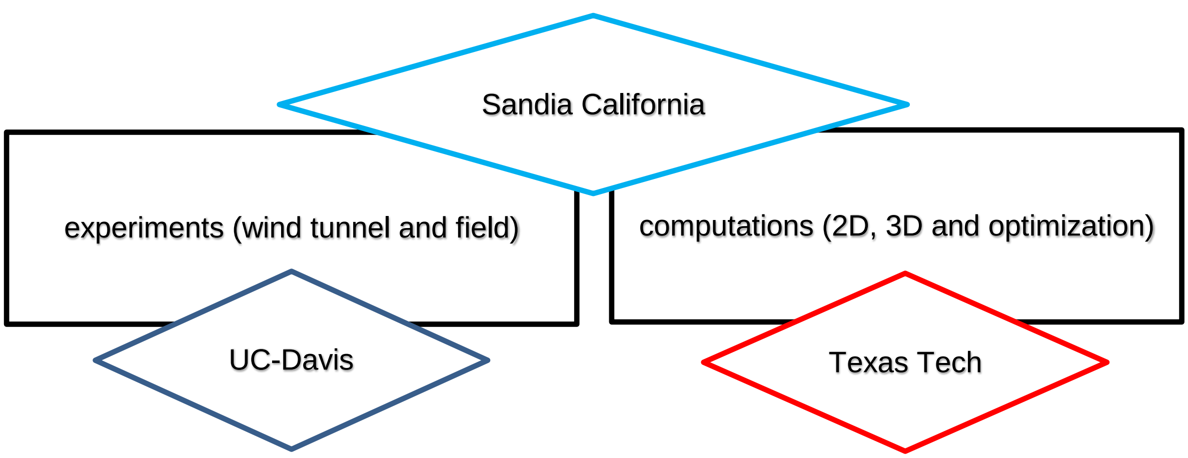


Figure 5 Project team organizational chart.

b. Identify key team members, including the project manager and principal investigator.

Dr. Houchens will serve as the project manager, with Drs. Blaylock, van Dam, Westergaard, Cooperman and Pol all considered co-PIs. Further details are included in Attachment 5.

c. Summarize the qualifications, experience, capabilities, and credentials of the key team members.

The project manager and five co-PIs bring hundreds of years of experience in wind energy to bear on this project. Details of individual expertise are included in Attachment 5.

d. Explain how the various tasks will be managed and coordinated, and how the project manager's technical expertise will support the effective management and coordination of all projects in the application.

The project manager, Dr. Houchens, has more than a decade of experience managing successful research collaborations in academia, industry and now at Sandia National Laboratory. Further details are included in Attachments 5 and 9.

e. Facilities, Infrastructure, and Resources available to the Team

The facilities, infrastructure and resources available to the team include extensive hardware and software resources for computational studies, wind tunnel experimental resources tailored to wind energy, and space and existing infrastructure for field studies.

Computational Resources at Sandia, CA

Sandia's computing resources will be available for running our CFD calculations. For this type of unclassified research, there are two clusters at our disposal. Chama is a 19,712 processor machine and with 1,232 compute nodes, operating at 392 teraflops. Skybride is a new Cray machine equipped with 1,848 compute nodes, operating at 600 teraflops.

In order to fully take advantage of the parallel computing, we will use the highly parallelizable computational fluid dynamics codes, Nalu and Fuego, both developed at Sandia. Nalu is a generalized, unstructured, massively-parallel, low-Mach flow code designed to support a variety of energy applications of interest (most notably Wind ECP) built on the Sierra Toolkit and Trilinos solver Tpetra/Epetra stack. This code has both finite element and finite difference capabilities, and can be run with either Reynolds Averaged Naiver Stokes (RANS), Detached Eddy Simulation (DES), or Large Eddy Simulation (LES) options. The main developer, Dr. Stephan Domino, is located at Sandia in Albuquerque, NM. While the current version of Nalu has all of the features that we will need to perform these calculations, we will have access to Dr. Domino's expertise if questions arise. Fuego is designed to simulate turbulent reacting flow and heat transfer on massively parallel computers and is well suited for most low Mach number flows.

Computational Resources at Texas Tech University

Texas Tech will use standard commercial CFD software (ANSYS FLUENT and supplementary smaller packages) for preliminary design improvement in 2D simulations. These simulations will be run on a dedicated work station and supplemented with Texas Tech computing facilities as needed.

Experimental Resources at UC Davis

The UC Davis Aeronautical Wind Tunnel is a low turbulence, open circuit wind tunnel manufactured by Aerolab. It shares many design similarities with the NASA Langley Basic Aerodynamics Research Tunnel, although the wind tunnel at UC Davis has a larger test section and lower turbulence levels.

The test section dimensions are 33.6 in. × 48 in. (0.85 × 1.2 m), with a length of 12 feet (3.7 m). Tapered fillets in the test section allow for boundary layer growth and maintain a constant pressure along the test section length. The tunnel fan is driven by a 125 hp AC motor and employs an electronic speed controller that is able to maintain a chosen RPM to within ±0.2% of full scale. Typical test air speeds are between 20 and 150 mph. A honeycomb and four anti-turbulence screens at the tunnel inlet result in a turbulence intensity of less than 0.1% within 80% of the test section.

The wind tunnel test section contains two turntables that allow for accurate positioning of test models, with instrumentation on the forward turntable for force measurement. An airfoil model is typically installed in the tunnel such that it vertically bisects the test section, with its base fixed to the center of the forward turntable. Model positioning is performed by three digital stepper motors. Aerodynamic forces on models are measured by a pyramidal balance which is installed below the forward turntable. Various instruments including pitot-static probes and differential pressure transducers are available to measure flow properties on and around a model.

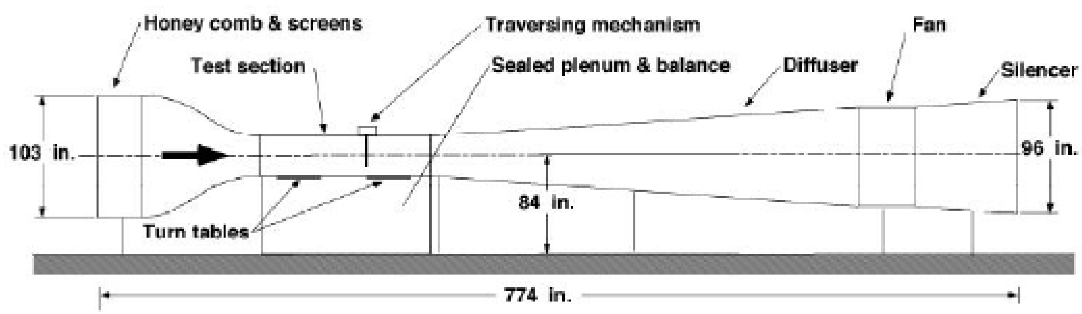


Figure 6. UC Davis Aeronautical Wind Tunnel

Space and Infrastructure for Field Testing at Sandia, CA

The Sandia National Laboratory campus in Livermore, CA sits on acres of semi-rural land that includes several open fields as well as large, empty paved areas. These would be ideal for the initial testing of the Aero-MINES. Since this stage of the testing does not involve connection to the grid and

Other infrastructure needs are minimal and include a stands to mount the airfoil pair in the first testing stage and the array in the second stage and housing for the battery and any measurement equipment to protect them from the elements.
Located adjacent to Altamont Pass, Livermore has one of the better wind resources in the state. We will be able to compare this to the more urban environment of Latitude High School in Oakland which will help us determine the effect that the

wind resource might have on the arrays.

f. Describe the team's history of successfully completing projects and commercializing and/or deploying results/products

Please see Attachment 9, Reference and Work Product Form for additional details on previous collaborations.

g. Identify past projects that resulted in a market-ready technology

Please see Attachment 9, Reference and Work Product Form.

h. Provide references that are relevant to the proposed project and are current, meaning within the past three years

Please see Attachment 9, Reference and Work Product Form.

i. Identify any collaboration with utilities, industries, or others

Dr. Westergaard has long-standing relations and experience in both utility-scale and start-up wind energy industries. This will greatly facilitate the technology transfer of Aero-MINEs, which will be proven as commercialization ready upon completion of this proposed study. Dr. van Dam has extensive experience working with utilities, industry, system operators, and government agencies on wind energy related problems including system RD&D, forecasting, outreach, education, as documented in Attachments 5 and 9.

j. Respond to the following questions

- Has your organization been involved in a lawsuit or government investigation within the past five years? NO
- Does your organization have overdue taxes? NO
- Has your organization ever filed for or does it plan to file for bankruptcy? NO
- Has any party that entered into an agreement with your organization terminated it, and if so for what reason? NO
- For Energy Commission agreements listed in the application that were executed (i.e., approved at a Commission business meeting and signed by both parties) within the past five years, has your organization ever failed to provide a final report by the due date indicated in the agreement? NO

k. Provide commitment and support letters

Please see Attachment 11 Commitment and Support Letters Form.

5. Budget and Cost Effectiveness

a. Budget by tasks:

Major budget items (direct labor) are listed below. Other costs are given in Attachment 7.

Task (by major task)	Energy Commission Funds	Match Share	Total
Administrative, dis-semination, outreach, commercialization (Tasks 1, 11-14)	$51,470 + $58,000	0	$109,470
2D simulation and optimization (Task 2)	$50,000	$130,825	$180,825
3D simulation and optimization (Tasks 3 and 7)	$412,776	$615,000	$1,027,776
Rapid prototyping (Tasks 4 and 8)	$1,994	$120,000	$121,994
Wind tunnel testing (Tasks 5 and 9)	$92,253	0	$92,253
Field testing (Tasks 6 and 10)	$60,000	0	$60,000

b. Justify the reasonableness of the requested EPIC funds relative to the project goals, objectives, and tasks.

This project proposes to design and prove transformative technology from TRL2 through 6, making it commercialization ready by the completion. Aero-MINEs have the potential to immediately couple with distributed solar PV to push large commercial buildings above the 50% Renewables Portfolio Standard by 2030, while providing load balancing. Furthermore, because the technology is cost-effective and safe and reliable, having no external moving parts, there is great potential to expand into the small commercial and residential sectors, influencing those rate-payers directly.

c. Justify the reasonableness of costs for direct labor, non-labor and operating expenses by task.

The most significant budget items are related to the high-fidelity CFD and optimization (Tasks 3 and 7), wind tunnel testing (Tasks 5 and 9) and field testing (Tasks 6 and 10). The costs of these tasks are kept low by employing graduate students and post-doctoral researchers who have modest overhead rates, with targeted mentoring by the experienced research team. All costs are outlined in Attachment 7. The project relies on the extensive computational resources of Sandia and wind tunnel at UC-Davis, which are extremely high-value, unique contributions.

d. Explain why the hours proposed for personnel and subcontractors are reasonable to accomplish the activities in the Scope of Work.

The most significant personnel hours are dedicated to CFD and optimization efforts. The optimization requires a design-of-experiments type study, though an advanced algorithm such as Latin-hypercube will be employed to minimize the configurations which must be investigated. Each trial configuration will require remeshing and significant computational resources on highly-parallelized (hundreds or thousands) of processors. Each CFD study will then require post-processing to guide the further optimization.

e. Explain how the applicant will maximize funds for technical tasks and minimize expenditure of funds for program administration and overhead.

Funds are maximized by employing a postdoctoral researcher and graduate students who have lower overhead rates. These personnel will still be highly knowledgeable in the fields of computational and experimental fluid dynamics, but without the cost of the subject matter expert (SME) collaborators. Sufficient SME time is requested to closely mentor and guide the graduate students and postdoctoral researcher.

6. Funds Spent in California

90% of funds will be spent in California.

7. Ratio of Direct Labor and Fringe Benefits Rates to Loaded Labor Rates

The ratio of direct labor and fringe benefits to load labor rates are estimated as follows:

$$\frac{\text{Total Direct Labor} + \text{Total Fringe}}{\text{Total Direct Labor} + \text{Total Fringe} + \text{Total Indirect Labor} + \text{Total Profit}} = \frac{\$466{,}240 + \$194{,}889}{\$466{,}240 + \$194{,}889 + \$267{,}269 + \$0} = \frac{\$661{,}129}{\$928{,}398} = \underline{0.712}$$

8. Match Funding

Match funding is provided by Sandia (in-kind) and Texas Tech University as described in the commitment letters in Attachment 11. Sandia match funding totals $735,000, comprised of $615,000 in computational resources and software and $120,000 in rapid prototyping. Texas Tech University is providing $130,825 in match funding.

9. Disadvantaged Communities

The 1st-generation Aero-MINE airfoil-pair will be donated to Latittude High School, in the *Education for Change* network of schools. This school will serve a population of low-income, first-generation college bound students in census tract 6001.4061.00 in Oakland, CA. This tract has a CalEnviroScreen 3.0 percentile range of 86-90% (reference 3 above). The donated 1st-generation Aero-MINE and associated curriculum will allow students to test their own configurations to explore optimum energy production. The entire system is estimated to weight approximately 80 pounds, and is modular and dissembles into five parts (two parts for each airfoil, and the base). Thus it is easily portable and can be stored when not in use. If the curriculum proves successful, it can be rotated to other *Education for Change* schools in Oakland. This will promote renewable energy education in this disadvantaged community that is historically underrepresented in science, technology, engineering and mathematics (STEM) fields.