FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

AERODYNAMIC TURBINES, LIGHTER AND AFLOAT, WITH NAUTICAL TECHNOLOGIES AND INTEGRATED SERVO-CONTROL (ATLANTIS)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002051
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	Thursday, January 31, 2019
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Friday, March 8, 2019
Submission Deadline for Concept Papers:	9:30 AM ET, Monday, March 18, 2019
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	9:30 AM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	TBD
Total Amount to Be Awarded	Approximately $28 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

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REQUIRED DOCUMENTS CHECKLIST

For an overview of the application process, see Section IV.A of the FOA.

For guidance regarding requisite application forms, see Section IV.B of the FOA.

For guidance regarding the content and form of Concept Papers, Full Applications, and Replies to Reviewer Comments, see Sections IV.C, IV.D, and IV.E of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed four (4) pages in length including graphics, figures, and/or tables and must include the following. (Concept papers in Area 1 (*New designs*) are allowed one additional page for Appendix 1 that contains a plot of the Metric Space for the new design, and the description and justification for the parameters used to calculate the M1 and M2 metrics and LCOE front.) ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities ○ Appendix 1 (Area 1 *New designs* only) • Metric Space Workbook (no page limit, Microsoft Excel Format): Applicants to Area 1 (New Designs) may use the ATLANTIS Metric Space Workbook template available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov)	Mandatory	IV.C	9:30 AM ET, Monday, March 18, 2019
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
(i) reductions of imports of energy from foreign sources;
(ii) reductions of energy-related emissions, including greenhouse gases; and
(iii) improvement in the energy efficiency of all economic sectors; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E issues this Funding Opportunity Announcement (FOA) under the programmatic authorizing statute codified at 42 U.S.C. § 16538. The FOA and any awards made under this FOA are subject to 2 C.F.R. Part 200 as amended by 2 C.F.R. Part 910.

ARPA-E funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector and it can be spurred by early-stage R&D supported by the applied energy offices in DOE. By contrast, ARPA-E supports high-risk, potentially transformative research that has the potential to create fundamentally new learning curves. ARPA-E R&D projects typically start with cost/performance estimates for the proposed technology that are well above the level of the competitive incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as an "original investigation undertaken in order to acquire new knowledge…directed primarily towards a specific practical aim or objective" and defines "experimental development" as "creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products or processes or improving existing products or processes."[1] Applicants interested in receiving financial assistance for basic research should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E Applicants and awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on early-stage R&D for the improvement of technology along defined roadmaps may be more appropriate for support through the DOE applied energy offices including: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy (http://fossil.energy.gov/), the Office of Nuclear Energy (http://www.energy.gov/ne/office-nuclear-energy), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. Program Overview

1. Summary

The ATLANTIS[2] Program seeks to develop new technical pathways for the design of economically competitive Floating Offshore Wind Turbines (FOWT). The program urges the application of Control Co-Design (CCD) methodologies that (1) bring together engineering disciplines to work concurrently, as opposed to sequentially, and (2) consider control-engineering principles from the start of the design process. By analyzing the numerous sub-system dynamic interactions that comprise the FOWTs, CCD methodologies can propose control solutions that enable optimal FOWT designs that are not achievable otherwise. Design optimization is defined here as the maximization of the specific swept-rotor-area per unit of

[1] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.

[2] ATLANTIS is the acronym for "*Aerodynamic Turbines, Lighter and Afloat, with Nautical Technologies and Integrated Servo-control*". The Greek philosopher Plato (428-348 BC) cited Atlantis in his dialogues as the lost continent of the ancient times that disappeared in the depths of the sea.

total-mass (m^2/kg) of the FOWT for a given power generation efficiency. The program offers a new *Metric Space* that quantifies this specific area per unit of mass and the air-to-electron power generation efficiency of the FOWT, and guides the research to navigate across LCOE (*Levelized Cost of Energy*) Pareto-optimal fronts. Projects in this program will cover three fundamental areas: (1) radically new FOWT designs with significantly lower mass/area, (2) a new generation of computer tools to facilitate control co-design of the FOWTs, and (3) generation of real-data from full and lab-scale experiments to validate the FOWT designs and computer tools. The program structure includes these three fundamental areas in two phases. Phase I, described by this document, is expected to cover the first two years with an anticipated $28M in funded projects. Based on the results achieved in this first phase, a second phase, subject to the availability of appropriated funds, is tentatively planned to be announced for another two years, with additional funds to continue the research in the three fundamental areas and with more emphasis on experimental testing. See Section II.B (Renewal Awards) of the FOA for further information applicable to Phase II funding.

2. MOTIVATION

Several comprehensive analyses[3,4] estimate that the gross offshore wind resource in the U.S. is over 151 quads/yr ("gross potential"). This number is still as large as ~25 quads/yr (or 7,203 TWh/yr in Table 1) even when accounting for losses and including conservative assumptions about what would be feasible to recover given technical, legal, regulatory and social inhibiting factors ("technical potential").[5] Fifty-eight percent of this "technical potential" lies in waters deeper than 60 m, accounting for ~14 quads/yr (or 4,178 TWh/yr) for floating offshore wind, which exceeds the entire U.S. annual electricity consumption in 2017 (13 quads/yr or 3,911 TWh/yr).[6] This energy resource is the focus of this FOA.

Table 1. Technical resource potential for floating offshore wind in the U.S. (TWh/yr)[6]

	North Atlantic	South Atlantic	Great Lakes	Gulf Coast	Pacific Coast
Technical Resource Potential	2,081	1,955	492	1,806	869

The viability of offshore wind projects depends on future wholesale electricity prices and capacity market prices within their local electricity market region. These factors can be represented through the *Levelized Avoided Costs of Energy* (LACE), which defines the cost for

[3] Musial, W., Heimiller, D., Beiter, P., Scott, G., Draxl, C. *2016 Offshore Wind Energy Resource Assessment for the United States*. NREL/TP-5000-66599. National Renewable Energy Laboratory, 2016 (for US mainland and Hawaii).
[4] Doubrawa, P., Scott, G., Musial, W., Kilcher, L., Draxl, C., Lantz, E. *Offshore Wind Energy Resource Assessment for Alaska*. NREL/TP-5000-70553. National Renewable Energy Laboratory, 2017 (for Alaska).
[5] The technical potential was calculated at 3 MW/km^2, and reducing the gross potential using technology exclusion filters that remove areas of wind speeds <7 m/s, water depths >1,000 m, water depths <60 m, competitive-use, environmental constraints and ice constraints.
[6] *National Offshore Wind Strategy: Facilitating the Development of the Offshore Wind Industry in the United States*. U.S. Department of Energy (DOE) and the U.S. Department of the Interior (DOI). September 2016.

the grid to generate the electricity that would be displaced by a new FOWT project in the region.

Figure 1 shows the comparison of LCOE and LACE for FOWT over the next few years, as well as the main target for the ATLANTIS Program. See Section I.D.2 for more details. When the LCOE falls in the LACE area, then the project has a positive economic potential.

Additionally, the inherent design advantages[7] of FOWTs over bottom-fixed offshore wind turbines create a plausible pathway for them to achieve a cost advantage in the long term. This is shown in DOE's projections, where the LCOE for FOWTs becomes lower than that of bottom-fixed around the year 2027 –see also Fig.1.

State of the art FOWT technology has achieved an average LCOE of approximately $0.15-0.18/kWh, which it is still too high in comparison to the current $0.03-0.05/kWh for land-based wind turbine technologies.[8] High capital expenditures (CAPEX) are the key driver of the LCOE of a FOWT. A significant portion of these CAPEX is the cost of the steel that existing floating platforms incorporate. Floating platforms are designed to be large and heavy in an effort to (a) imitate the onshore wind turbine dynamics, (b) keep the system as stable as possible and (c) maximize system survivability during events such as large sea storms. Internal ARPA-E analysis shows that the cost of steel accounts for between 50% and 70% of the overall CAPEX for existing FOWT designs.[9] Consequently, this program seeks to design radically new FOWTs that maximize the specific rotor area per unit of total mass (m^2/kg), while maintaining, or ideally increasing, the turbine generation efficiency. To this end, some technical barriers need to be overcome, including (a) insufficient knowledge of dynamic sub-system interaction, (b) insufficient computer tools for simulation, and (c) insufficient experimental data.

[7] Since they are not fixed systems, FOWTs can be much more easily deployed and retrieved; they are towed out to and from their site for both, installation and major maintenance, and do not required massive deployment vessels.
[8] Stehly, T., Beiter, P., Heimiller, D., Scott, G. (2018). *2017 Cost of Wind Energy Review*. National Renewable Energy Laboratory. Technical Report NREL/TP-6A20-72167 (including cost of substation and electrical lines).
[9] Floating platform mass as percentage of overall system mass is over 70%, based on analysis developed from Myhr, A., Bjerkseter, C., Ågotnes, A., Nygaard, T. (2014). *Levelised cost of energy for offshore floating wind turbines in a life cycle perspective*. Renewable Energy, Vol. 66, pp. 714-728.

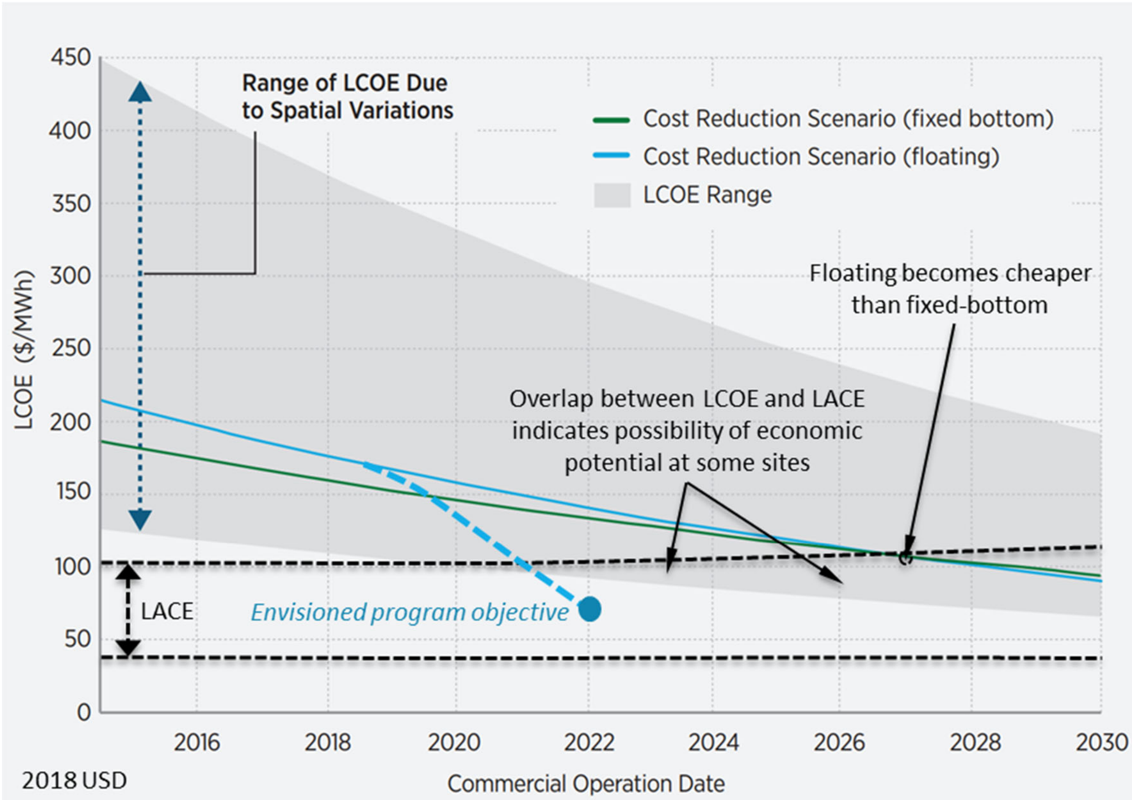

Fig. 1. LCOE and LACE for floating offshore wind. Predictions and objectives.[10]

Insufficient fundamental knowledge. The operational profile of a FOWT system involves coupled nonlinear aero-, hydro-, elastic-, electric-, economic- and servo-dynamics. Industry does not yet have a good understanding of the implications of these coupled dynamics, and therefore these dynamics are not fully incorporated into existing computer tools. Common practice in today's industry is to design the wind turbine and the floating platform separately, by independent teams. The turbine manufacturer usually provides the maximum mechanical torques and/or platform angles the turbine can support, and the platform manufacturer designs the floating system accordingly, without further coupling considerations. However, it is this complex coupling of multidisciplinary dynamics that makes proper, comprehensive, design of the full FOWT "ARPA-E hard".

Insufficient computer tools. Today's leading computer tools for wind energy system design[11] were created for onshore systems, as opposed to offshore systems, with a more limited set of dynamics to consider. Many of the tools use simplified representations for aerodynamics (Blade Element Momentum Theory), limited description of the hydrodynamics (Morison Equation and first order approximations), and rigid-body equations for the submerged bodies.

[10] *National Offshore Wind Strategy: Facilitating the Development of the Offshore Wind Industry in the United States*. U.S. Department of Energy (DOE) and the U.S. Department of the Interior (DOI). September 2016.
[11] Primarily Bladed and various versions of FAST. Bladed, DNV-GL, https://www.dnvgl.com/services/bladed-3775. OpenFAST. (2018). National Renewable Energy Lab, NREL, https://nwtc.nrel.gov/OpenFAST.

In addition, leading computer tools do not have modular capabilities (libraries), do not incorporate control co-design optimization techniques, do not integrate electrical and/or economic problems, and are not ready for parallel algorithm implementation.

Insufficient experimental FOWT data. At present, there is almost no experimental data of FOWTs accessible to research and engineering teams other than the 1/8th scale experiment developed by the University of Maine some years ago.[12] The FOWT community needs more experimental data to validate computer tools and improve new designs. This problem has been also largely emphasized in the OC3-OC6 international efforts.[13]

C. APPROACH

1. CONTROL CO-DESIGN DEFINITION AND EXAMPLES

Control engineering is the application of mathematics, physics and technology towards autonomous control of physical systems. Control engineers take data about system status and performance, and use microprocessors, various sensors, algorithms, circuits and actuators to improve system conditions and, ultimately, regulate variables automatically. The system can include mechanical and electrical components, chemical and biological characteristics, thermodynamics and fluid dynamics, aero- and hydro-dynamics, network interactions, and more –see Fig.2.

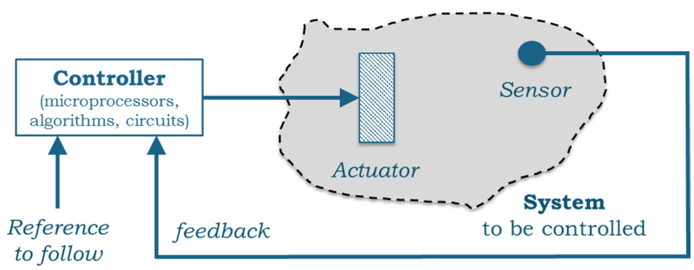

Fig. 2. Control system.

Fundamental to this program is that control engineering is not limited to finding algorithms to regulate existing systems. It can be used to design an entirely new system from the ground up. Instead of the classical design method, where each engineering team (mechanical, electrical, electronics, control, etc.) is an independent step in a sequential process –see Fig.3a, *Control Co-Design* (CCD), also known as *Integrated Control* or just *Co-Design*, brings together various technical disciplines to work concurrently from the start –see Fig.3b.

[12] Dagher, H., Viselli, A., Goupee, A., Kimball, R., Allen, C. (2017). The VolturnUS 1:8 Floating Wind Turbine: Design, Construction, Deployment, Testing, Retrieval, and Inspection of the First Grid-Connected Offshore Wind Turbine in US. United States. Web. doi:10.2172/1375022

[13] International Energy Agency (IEA) Wind Tasks 23 and 30, Offshore Code Comparison Collaboration (OC3/OC4/OC5/OC6 programs) for offshore wind modeling tools.

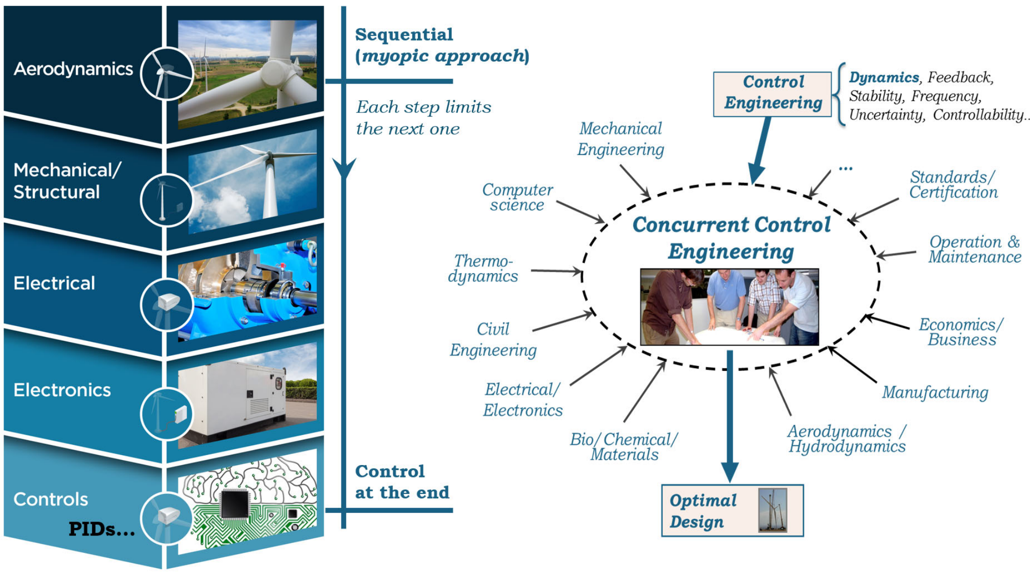

Fig. 3. (a) Classical sequential design process vs. (b) Control Co-Design.

Multidisciplinary systems cannot be fully optimized unless sub-system interactions are considered in the system optimization, which is particularly difficult when system dynamics are involved. CCD techniques consider these dynamic sub-system interactions from the very beginning of the design, and proposes optimal solutions that are not achievable otherwise. This methodology enables a more optimal design—with better system dynamics and controllability, among other advantages – that often results in lower system cost and improved reliability.

Figure 4 presents a CCD example. It is composed of a direct-drive, variable-speed, pitch-controlled 1.65 MW wind turbine. The machine, a type-4 turbine, does not need a gearbox and incorporates a full-power converter to control the aerodynamic efficiency and the grid variables simultaneously and independently. By applying CCD concepts to the pitch control system, the turbine achieved very smooth and robust rotor speed control, reducing also the tower vibration and the corresponding mechanical fatigue of the system. This second achievement allowed the company to introduce in the market a machine with a tower significantly cheaper (less steel) than the immediate competitor, with also better reliability and robust control characteristics.[14]

Other CCD examples have been proposed over the last few years. Among others, they include smart blades, active control floating systems, new rotor configurations, generators, drive-trains, etc. See Section I.C.4.a for additional details.[15]

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[14] Torres, E., Garcia-Sanz, M. (2004). *Experimental results of the variable speed, direct drive multipole synchronous wind turbine TWT1650*. Wind Energy, Vol. 7, No. 2, pp. 109-118, Wiley.

[15] Starting in January 2018, ARPA-E began challenging the research and industrial communities to develop new and disruptive Control Co-Design solutions for a large variety of applications (2018 Summit, CCD Workshop for "Wind, Tidal and Wave Energy Systems", ATLAS competition, ATLANTIS Industry day, ATLANTIS Program).

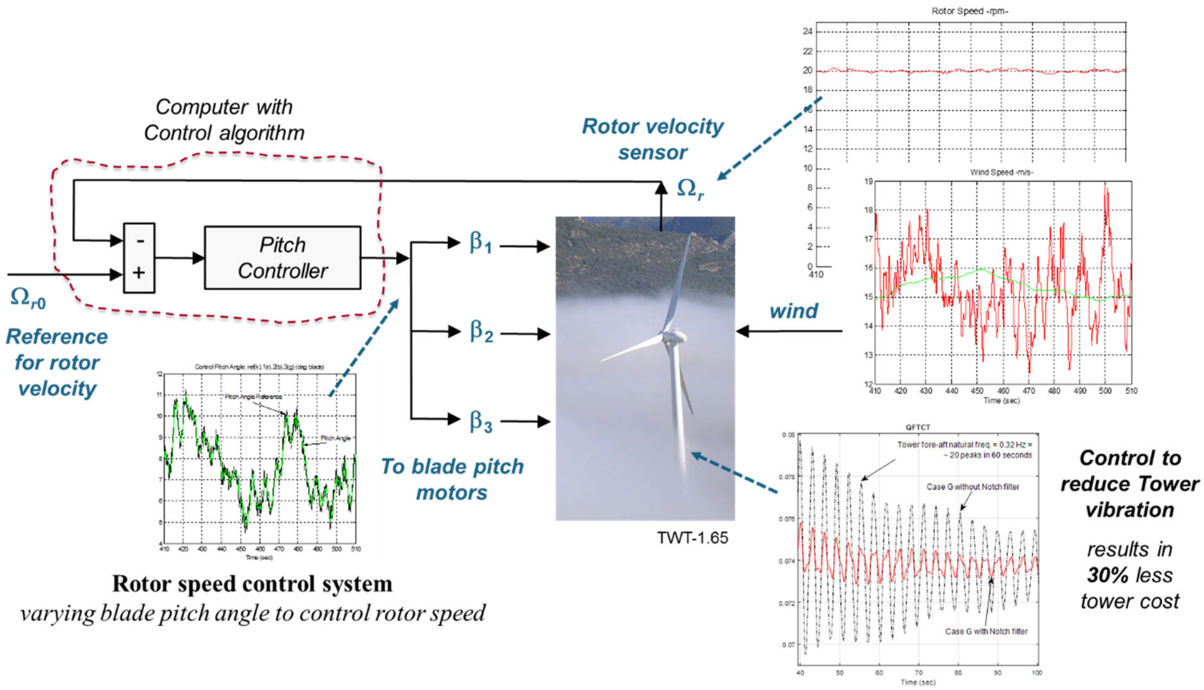

Fig. 4. Example: Control Co-Design of Wind turbine.

2. Control Co-Design methodologies

Several CCD techniques to design new optimal FOWT solutions are considered in this program, including: (a) control/bio-inspired principles,[16,17] (b) co-optimization techniques[18,19] and (c) co-simulation methods.[20,21]

Control/bio-inspired principles incorporate basic control concepts and bio-inspired ideas in the design, including stability principles, resonance mode damping, bandwidth, non-minimum

[16] Garcia-Sanz, M. (2009). *Special Issue. Wind Turbines: New Challenges and Advanced Control Solutions*. International Journal of Robust and Non-Linear Control, Vol.19, No. 1, pp. 1-116, Wiley.
[17] Mazumdar, A., Asada, H.H. (2014). *Control-configured design of spheroidal, appendage-free, underwater vehicles*. IEEE Transactions on Robotics, Vol. 30, No. 2, pp. 448-460.
[18] Allison, J.T., Guo, T., Han, Z. (2014). *Co-Design of an Active Suspension Using Simultaneous Dynamic Optimization*. ASME. Journal of Mechanical Design, Vol.136, No.8, pp. 081003.1 – 081003.14.
[19] Kamadan, A., Kiziltas, G., Patoglu, V. (2017). *Co-Design Strategies for Optimal Variable Stiffness Actuation*. IEEE/ASME Transactions on Mechatronics, Vol. 22, No.6, pp. 2768-2779.
[20] Kaslusky,S., Sabatino,D., Zeidner,L. (2007). *ITAPS: A process and toolset to support aircraft level system integration studies*. 45th AIAA Aerospace Sciences Meeting and Exhibit, AIAA 2007-1394, Reno, Nevada.
[21] Reeve, H., Finney, A. (2008). *Probabilistic Analysis for Aircraft Thermal Management System Design and Evaluation*. 46th AIAA Aerospace Sciences Meeting and Exhibit, AIAA 2008-148, Reno, Nevada.

phase characteristics, multi-input multi-output coupling, observability, controllability and others.[22,23]

Co-optimization techniques propose an optimization exercise where the plant configuration, plant dynamics and controller design are incorporated in a global cost function or in a nested-iterative optimization process, with the possibility of experiments to adjust variables.[24,25]

Co-simulation methodologies deal with iterative multi-physics dynamic simulation processes.[26,27]

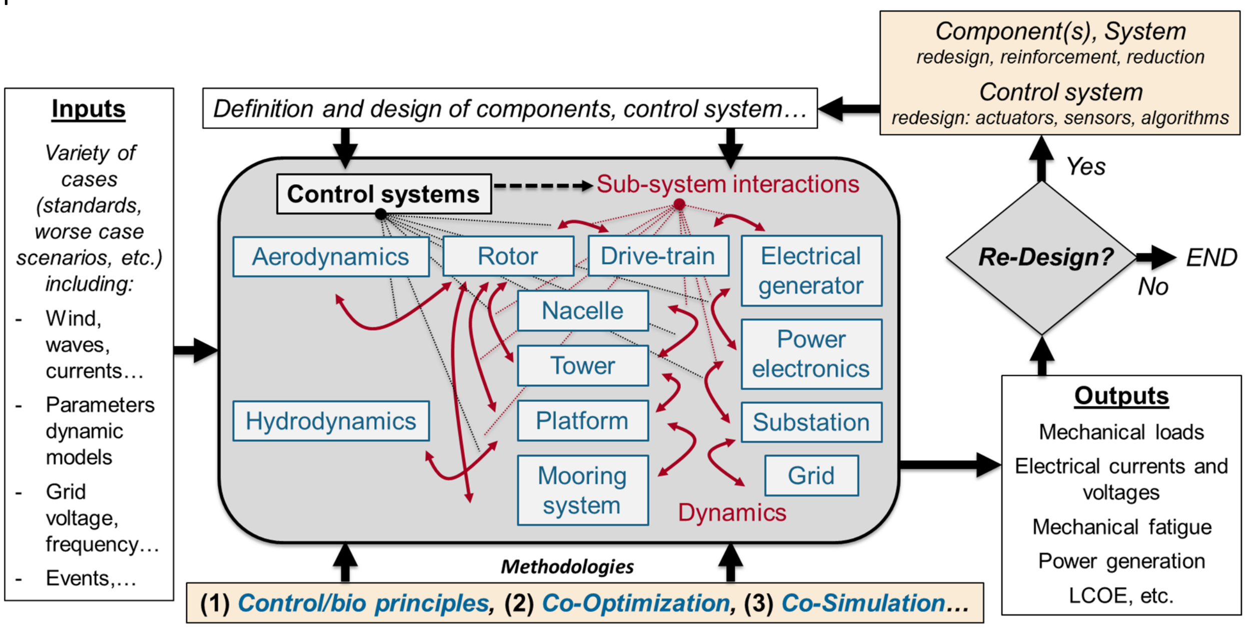

Fig. 5. Control Co-Design diagram.

Figure 5 exemplifies a CCD general methodology that includes a representation of the sub-systems of a floating offshore wind turbine. After applying a set of inputs to the system (wind, waves, grid, etc.), the CCD methodologies analyze the dynamics and sub-system interactions and evaluate the mechanical loads and fatigue, power generation and associated LCOE. Based

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[22] Garcia-Sanz, M. (2009). *Special Issue. Wind Turbines: New Challenges and Advanced Control Solutions*. International Journal of Robust and Non-Linear Control, Vol.19, No. 1, pp. 1-116, Wiley.
[23] Mazumdar, A., Asada, H.H. (2014). *Control-configured design of spheroidal, appendage-free, underwater vehicles*. IEEE Transactions on Robotics, Vol. 30, No. 2, pp. 448-460.
[24] Allison, J.T., Guo, T., Han, Z. (2014). *Co-Design of an Active Suspension Using Simultaneous Dynamic Optimization*. ASME. Journal of Mechanical Design, Vol.136, No.8, pp. 081003.1 – 081003.14.
[25] Kamadan, A., Kiziltas, G., Patoglu, V. (2017). *Co-Design Strategies for Optimal Variable Stiffness Actuation*. IEEE/ASME Transactions on Mechatronics, Vol. 22, No.6, pp. 2768-2779.
[26] Kaslusky,S., Sabatino,D., Zeidner,L. (2007). *ITAPS: A process and toolset to support aircraft level system integration studies*. 45th AIAA Aerospace Sciences Meeting and Exhibit, AIAA 2007-1394, Reno, Nevada.
[27] Reeve, H., Finney, A. (2008). *Probabilistic Analysis for Aircraft Thermal Management System Design and Evaluation*. 46th AIAA Aerospace Sciences Meeting and Exhibit, AIAA 2008-148, Reno, Nevada.

on these outputs, the methodology looks for potential optimization ideas and re-designs components and control solutions in an iterative process.

3. Sub-systems Interaction in Floating Offshore Wind Turbines

The highly coupled dynamics involved in the design of FOWTs make this problem an ideal candidate for the CCD approach. Figure 6 shows the main sub-systems of a floating offshore wind turbine: rotor, drive-train, electrical generator, power electronics, substation, nacelle, tower, platform, mooring system, aerodynamics, hydrodynamics, grid and control systems. It also shows the inputs: wind, waves, grid voltage and frequency, etc. The figure emphasizes the multiple sub-system interactions. As a rule, the higher the sub-system interaction, the more effective and needed the control co-design methodology.

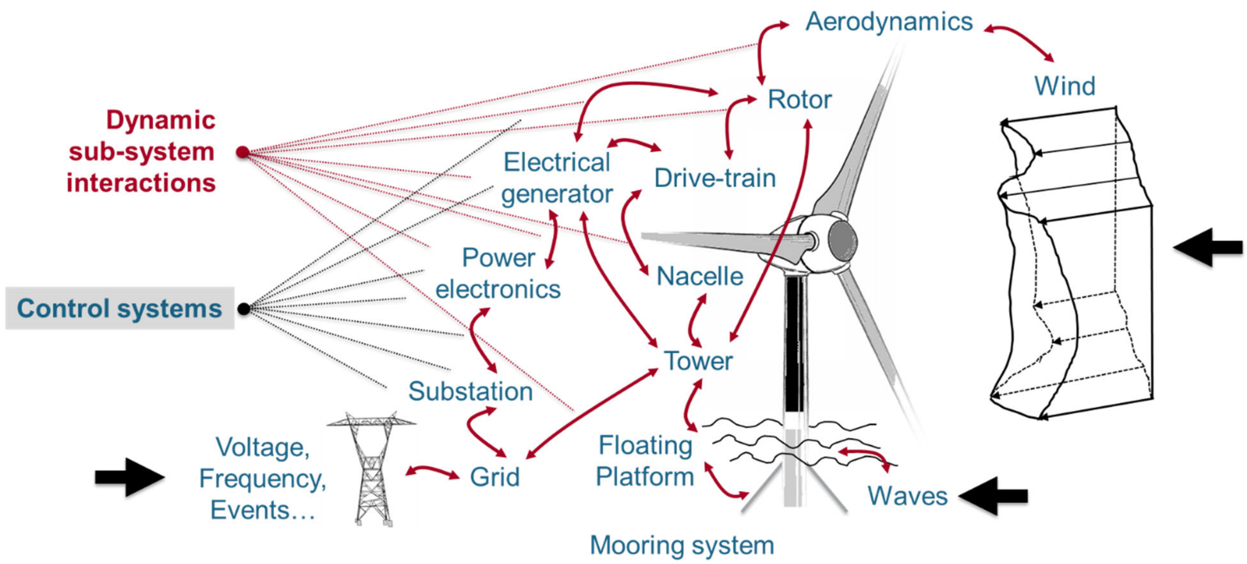

Fig. 6. FOWT sub-system interactions.

Figure 7 presents an example of sub-system interaction in FOWTs. It illustrates the strong interaction among the aerodynamics, the hydrodynamics and the mechanical structure. As the figure shows, the wind moves the rotor of the turbine at a given rotational speed Ω_r. This rotor typically has a very large moment of inertia I_r, especially in multi-megawatt systems. The rotational speed and moment of inertia of the rotor define its angular momentum ($L = I_r \Omega_r$). At the same time, with the turbine working with this angular momentum, a wave is incident upon the system, applying a torque that moves the floating platform, changing the pitch angle of the platform. As a result, a gyroscopic effect will rotate the platform about an axis perpendicular to both the angular momentum and the torque, changing the yaw angle of the floating platform to keep the angular momentum constant (law of conservation of angular momentum).

This aero-hydro-mechanical-control interaction shows the need for a CCD approach to optimize the system. Current industry practices, with independent designs of turbine and platform, cannot achieve an optimal system solution. Moreover, FOWTs have many other important interactions between aerodynamics, hydrodynamics, mechanical structure, mooring system, electrical systems and control systems. The analysis of all these sub-system interactions and the design of innovative control solutions to deal with those interactions in a concurrent control engineering approach (Control Co-Design) are critical to achieve optimal solutions.

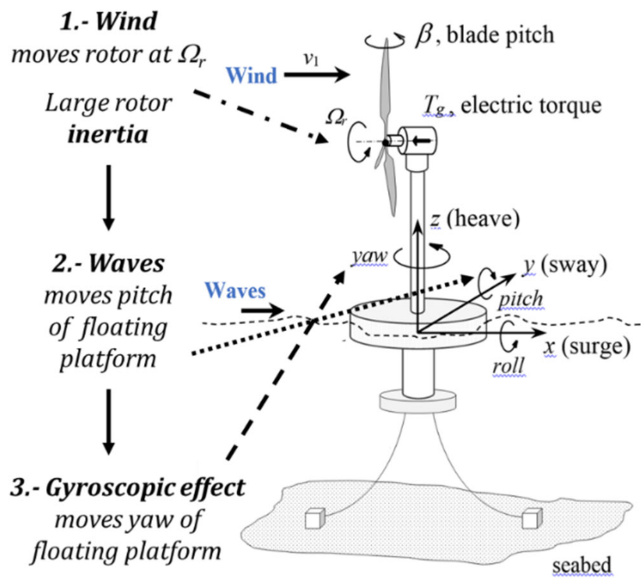

Fig. 7. Example of FOWT sub-system interactions.

4. FUNDAMENTAL AREAS

The ATLANTIS Program seeks to support the development of enabling technologies that establish a new, more promising, technical learning curve for the FOWT industry to pursue further. Projects within the Program are classified into three fundamental areas: (1) radically new FOWT designs, (2) new computer tools to facilitate CCD of the FOWTs, and (3) real-data from full and lab-scale experiments to validate the FOWT designs and computer tools –see Fig.8. Advances in all three of these fundamental areas are vital for this new technical pathway to succeed.

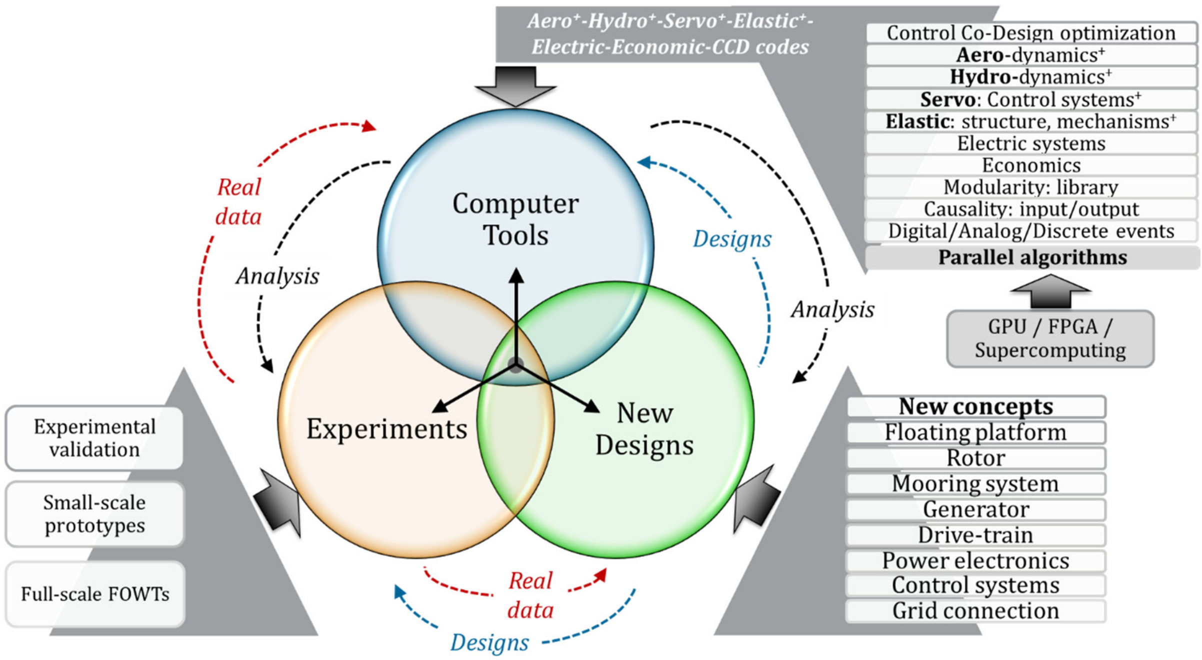

Fig. 8. ATLANTIS Program fundamental areas.

a. NEW DESIGNS

The first fundamental area deals with radically new FOWT designs. The program encourages designs that significantly deviate from the traditional approach of a "stable" or "reinforced" FOWT with an enormous floating platform (conventional spar, semi-submersible or tension leg platforms). In contrast, the new designs are likely to accept and account for some inherent instability and higher compliance, requiring the incorporation of control principles at the core of the design. The underlying hypothesis of the program is that doing so will shift the burden away from the mechanical system, enabling drastic reductions in mass and associated cost.

Practical FOWT designs have to work in different scenarios, which can be classified in five operational modes: (O1) working mode, (O2) storm mode, (O3) transportation mode, (O4) installation mode, and (O5) maintenance mode. This program encourages FOWT designs that offer competitive CCD solutions that consider these five operational modes –see Design Load Cases (DLCs), IEC-61400,[28] and have the potential for upscaling to multi-megawatt installations.

Drastically new FOWT designs can be achieved by applying CCD techniques, which typically need innovative control solutions based on new actuators, sensors, algorithms and/or dynamic components. Examples for these new concepts that eventually enable a cheaper FOWT include, but are not limited to:

[28] International Electro-technical Commission, IEC 61400-3, Wind turbines – Part 3: Design requirements for offshore wind turbines. https://collections.iec.ch/std/series

1. New floating platforms: new designs that balance the main four passive floating principles (i – iv)[29] with semi-active and active structural control systems (v),[30] including:
   - (i). *Buoyancy*, or upward acting force, exerted by the fluid, that equals the weight of displaced fluid –Archimedes' principle,
   - (ii). *Ballast*, which provides vertical separation of center of gravity (lower) and center of buoyancy (higher),
   - (iii). *Mooring*, composed of cables, lines and anchors that holds the system to the seabed,
   - (iv). *Viscous damping*, which adds drag and damping to the platform movement,
   - (v). *Active control systems,* including innovative actuators, sensors and algorithms to achieve advanced floating dynamics, with adjustable platform stiffness, damping and ballast, improving efficiency, survivability and resilience, and reducing costs.

2. New turbine rotors: new configurations and control concepts to improve the aerodynamics and reduce the weight and cost of the FOWT might include:
   - (i). Smart blades with innovative plasma/air/flap actuators,[31]
   - (ii). Individual pitch control systems,[32]
   - (iii). Vertical-axis rotor configurations,[33]
   - (iv). Downwind rotors,[34]
   - (v). Multi-rotor systems,[35]
   - (vi). Flying turbines,[36,37] etc.

3. New towers, mooring and anchor systems: new configurations and control concepts to reduce the weight and cost of the FOWT might include:
   - (i). Flexible towers and systems without tower,
   - (ii). Active tension leg platforms,

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[29] Jonkman, J.M., Matha, D. (2011). *Dynamics of offshore floating wind turbines—analysis of three concepts*. Wind Energy, Vol. 14, No. 4, pp. 557-569.
[30] Lackner, M.A., Rotea, M.A. (2011). *Passive structural control of offshore wind turbines*. Wind energy, Vol. 14, No. 3, pp.373-388.
[31] Cooney, J.C., Szlatenyi, C.S., Fine, N.E. (2016). *Development and Demonstration of a Plasma Flow Control System on a 20 KW Wind Turbine*. 54th AIAA Aerospace Sciences Meeting. San Diego, CA, AIAA.
[32] Wheeler, L., Garcia-Sanz, M. (2017). *Wind turbine collective and individual pitch control using quantitative feedback theory*. ASME 2017 Dynamic Systems and Control Conference, Tysons Corner, Virginia, USA.
[33] Griffith, T., Barone,M., Paquette,J., Owens,B., Bull,D., Simao-Ferriera,C., Goupee,A., Fowler, M. (2018). *Design Studies for Deep-Water Floating Offshore Vertical Axis Wind Turbines*. Sandia Lab. Tech. Rep. SAND2018-7002.
[34] Noyes, C., Qin, C., & Loth, E. (2018). *Pre-aligned downwind rotor for a 13.2 MW wind turbine*. Renewable Energy, 116, 749-754.
[35] Jamieson, P., Branney, M. (2012). *Multi-Rotors; A Solution to 20 MW and Beyond?* Energy Procedia, Vol. 24, pp. 52-59, Elsevier.
[36] Vermillion, C., Grunnagle, T., Lim, R., Kolmanovsky, I. (2014). *Model-Based Plant Design and Hierarchical Control of a Prototype Lighter-Than-Air Wind Energy System, with Experimental Flight Test Results*. IEEE Transactions on Control Systems Technology, Vol.22, No.2, pp. 531 - 542.
[37] Griffith, S., Lynn, P., Hardham, C. (2010). *Wind power generation*. US Patent 7,847,426.

(iii). Advanced actuators to damp the tower and/or enhance the control authority of the floating platform, etc.[38]

4. New generators and drive-trains: new configurations and control concepts to reduce the weight and cost of the FOWT might include:
   (i). Reduced-weight electrical generators,[39]
   (ii). Hydraulic drive-trains,
   (iii). Advanced power electronic converters, etc.

5. New materials, manufacturing and installation methods: new control solutions that enable the reduction of weight and cost of the FOWT might include:
   (i). Advanced materials with higher compliance, feasible due to new control solutions,
   (ii). Innovative manufacturing methods for new geometries and mechanical structures,
   (iii). New installation and maintenance systems, like self-deployed controlled systems, etc.

6. New sensors, actuators and control paradigms: new control solutions that enable the reduction of weight and cost of the FOWT might include:
   (i) Advanced sensors, distributed sensors, data-fusion algorithms, observers, etc.
   (ii) Advanced actuators, high control authority systems, etc.
   (iii) Health monitoring systems, predictive maintenance systems, supervisor systems.
   (iv) Passive and active control systems, robust control and fault-tolerance solutions.

Section I.D describes a new metric space that defines the technical performance targets for the radical new designs sought in this program. The *ATLAS competition*,[40] just launched by ARPA-E, is an example of how new control co-design paradigms can reduce the mass of the system and facilitate radical new designs of floating-offshore and land-based wind turbines.

b. COMPUTER TOOLS

The radical new FOWT designs presented in the previous Section will be based on CCD of today, primarily involving manually intensive incorporation of control principles during design iterations and existing co-simulation tools. Other CCD methodologies such as bio-inspired designs, co-optimization and especially advanced co-simulation will require computer tools that far exceed the capabilities of existing ones for design of FOWTs. Thus, in addition to developing the most optimal new designs via CCD of today, the program seeks to develop computer tools

[38] Tang, X., Zuo, L., (2012). *Simultaneous energy harvesting and vibration control of structures with tuned mass dampers. Journal of Intelligent Material Systems and Structures*, Vol. 23, No. 18, pp.2117-2127.
[39] Lee, D., Zheng, L., Jin, A., Min,B.H., Haran, K. (2018). *Optimization method to maximize torque density of high speed slotless PMSM in aerospace applications*. IET Electric Power Applications.
[40] ATLAS (*Aerodynamic Turbines with Load Attenuation Systems*) Competition. Open from January 11th, 2019 to April 19th 2019. See ARPA-E website, https://arpa-e.energy.gov/?q=site-page/atlas-competition

that enable enhanced CCD for even more optimal new designs. The program seeks to fund the development of enhanced computer tools that include the following elements:

(e1). CCD optimization methodologies for both, individual turbine and wind farm level, and with dynamic/control simulation capabilities and techno-economic estimates,
(e2). New aero-, hydro-, elastic-, servo- mathematical models that incorporate nonlinear dynamics, multi-disciplinary analysis and optimization beyond the OCx programs,[41]
(e3). Libraries of modular functions to allow designers to simulate a large variety of new ideas,
(e4). Tools that run under a standard software environment, like Matlab, Simulink or similar,
(e5). Linearization capabilities with the ability to derive reduced control-oriented models,
(e6). Electrical and economic modules,
(e7). Analog/digital/discrete-event/probabilistic models,
(e8). User-friendly standard interfaces, easy to use, intuitive and reliable,
(e9). Input/output causality-free codes,[42] instead of pre-defined input/output causality codes,
(e10). IEC-61400 standard inputs, cases and analysis, including the five operational modes introduced in Section I.C.4.a and other potential emergency and recovering events,
(e11). Parallel algorithms for GPU, FPGA or HPC architectures, to speed up the calculations.

Projects to develop these new computer tools must include the most critical elements, (e1) through (e5), at least four of the six remaining elements, (e6) to (e11), and must able to simulate the mechanical loads of all the main components of the FOWT, i.e. the wind turbine, the floating platform, the mooring system and the anchor system. Overall, developing advanced computer tools for FOWTs will enable the design of next generation FOWT systems.

c. EXPERIMENTS

Operational data, from both laboratory prototypes, as well as full-scale real-world commercial systems, are urgently needed in this field. Such data are essential in validating the FOWT designs and computer tools developed in this program. Maximizing the public availability of such data is a goal of this program which will facilitate:

- A better understanding of the coupled nonlinear dynamics of FOWTs,
- An experimental validation of the new FOWT designs and computer tools.

To collect such data from full and lab-scale FOWTs, new intelligent real-time systems are needed. These systems include new sensors and network of sensors, advanced data-fusion, observer, learning and classification algorithms, dynamic models and communication devices. These operational data can be classified in the following categories:

(d1). Correlated wind and wave data, simultaneously measured in the FOWT.

[41] International Energy Agency (IEA) Wind Tasks 23 and 30, Offshore Code Comparison Collaboration (OC3/OC4/OC5/OC6 programs) for offshore wind modeling tools.
[42] Like Modelica®. A non-proprietary, object-oriented, equation based language to conveniently model complex physical systems. See https://www.modelica.org

(d2). Mechanical variables of the FOWT.

- (d2.1). Mechanical loads, velocities, lift and drag and vibration of blades and rotor
- (d2.1). Mechanical loads and vibration of the hub, nacelle and tower
- (d2.3). Mechanical loads, vibration and movements of the floating platform
- (d2.4). Mechanical loads and movements of the mooring system
- (d2.3). Mechanical loads in the anchor system

(d3). Electrical variables of the FOWT.

- (d3.1). Electrical generator current and voltages
- (d3.2). Power electronics current and voltages

(d4). Other variables of interest.

Projects of this fundamental area must include data of category (d1) and at least some data of categories (d2) to (d4), all collected simultaneously with the real-time system and for some scenarios under the operational modes (O1) to (O5) defined in Section I.C.4.a. This data should be physically, qualitatively and quantitatively meaningful in order to be used for computer tools validation.

D. METRIC SPACE DEFINITION AND TECHNICAL PERFORMANCE TARGETS

1. METRIC SPACE DEFINITION

The ATLANTIS Program defines a new two-dimensional *Metric Space* that considers the specific swept-rotor-area per unit of total-mass (m^2/kg) and the power generation efficiency of the FOWT, and guides the research to navigate across resulting LCOE Pareto-optimal fronts[43] –see Figs. 9 and 10. This *Metric Space*, detailed in this Section, facilitates the application of control co-design paradigms and will help ARPA-E evaluate new design concepts. All the variables and parameters of this Section are expressed in the metric system.

<u>Metric M1</u>

The first metric (M1) represents the ratio between the powers P_{e1} and P_{w1}, both below rated –see eq.(1). P_{e1} is the electrical power generation at the point of interconnection of the wind turbine to the internal grid of the wind farm (output of the wind turbine) in Watts –see eq.(2). P_{w1} is the power of the wind in Watts –see eq.(3). Both powers, P_{e1} and P_{w1}, are calculated at the same below-rated wind speed V_1 (e.g. V_1 = 8 m/s), which is selected so that the maximum power point tracking (MPPT) control strategy is keeping the aerodynamic power coefficient C_p at the maximum value C_{pmax}, and with a constant pitch angle β –see eq.(4). The efficiency μ includes the generator losses L_g, drive-train losses L_{dt} (gearbox and power electronics), wake effect losses L_w due to the aerodynamic interaction of turbines in the farm, electrical losses L_e (substation and electrical lines, intra-wind-farm and farm-to-shore), wind turbine availability A_v

[43] Garcia-Sanz, M. (2019). *A metric space with LCOE Pareto-optimal fronts for research guidance in wind energy*. Submitted to Wind Energy, Wiley.

and other losses L_o, like wind shear and others –see eq.(5). In summary, the main equations for M1 are:

$$M_1 = \frac{P_{e1}}{P_{w1}}\bigg|_{at\,V_1} = C_p\,\mu \quad (1)$$

$$P_{e1} = \frac{1}{2}\,\rho\,A_r\,C_p\,\mu\,V_1^3 \quad (2)$$

$$P_{w1} = \frac{1}{2}\,\rho\,A_r\,V_1^3 \quad (3)$$

$$C_p = C_{pmax} \quad (4)$$

$$\mu = (1 - L_g)\,(1 - L_{dt})\,(1 - L_w)\,(1 - L_e)\,(1 - L_o)\,A_v \quad (5)$$

where:

→ ρ = 1.225 kg/m^3 is the density of the air,

→ $A_r = \pi R^2$ = swept area of the rotor (in m^2) [44]

→ V_1 is the selected undisturbed upstream below-rated wind velocity without any wind shear effect (for example = 8 m/s)

→ μ is the efficiency of the system, including (all in per unit):

- L_g: generator losses,
- L_{dt}: drive-train (gearbox and power electronics) losses,
- L_w: wake effect losses due to the aerodynamic interaction of turbines in the farm,
- L_e: electrical losses (substation and electrical lines, intra-wind-farm and farm-to-shore),
- L_o: other losses, including wind shear and others,
- A_v: wind turbine availability.[45]

Physically speaking, M1 represents the power generation efficiency of the wind turbine ($C_p\,\mu$), from the upstream-undisturbed wind to the electrical output of the turbine. Also, M1 is proportional to the electrical power per unit area of the rotor (W/m^2) at the selected below rated wind speed V_1: i.e. M1 = $k\,(P_{e1}/A_r)$, with $k = 1/(0.5\,\rho\,V_1^3)$.

Metric M2

The second metric (M2) represents the ratio between the swept area A_r of the rotor and the equivalent mass M_{eq} of the FOWT –see eq.(6). M_{eq} is the equivalent mass of steel (steel of reference type) of the FOWT in kilograms –see eqs.(7) and (8),

[44] For both, Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT), A_r is the area of the cross-section of the rotor, perpendicular to the wind direction. For Airborne Wind Energy Systems (AWES), A_r is the area of the annular path described by the tethered system.

[45] In case of wind farms, eqs. (1) to (5) are: $M_1 = \frac{\sum_{k=1}^{n} P_{e1}(k)}{\sum_{k=1}^{n} P_{w1}(k)}\bigg|_{at\,V_1} = \frac{1}{n}\,\sum_{k=1}^{n} C_p(k)\,\mu(k) = \overline{C_p\,\mu}$;

$P_{e1}(k) = \frac{1}{2}\,\rho\,A_r\,C_p(k)\,\mu(k)\,V_1^3$; $P_{w1}(k) = \frac{1}{2}\,\rho\,A_r\,V_1^3$; $C_p(k) = C_{pmax}(k)$;
$\mu(k) = (1 - L_g(k))\,(1 - L_{dt}(k))\,(1 - L_w(k))\,(1 - L_e(k))\,(1 - L_o(k))\,A_v(k)$,
with n the number of WTs in the wind farm, and A_r the same for all WTs.

$$M_2 = \frac{A_r}{M_{eq}} \tag{6}$$

$$M_{eq} = \sum_{j=1}^{z} m_j \tag{7}$$

$$m_j = f_{tj}\left(1 + f_{mj} + f_{ij}\right) m_{cj}\,, \tag{8}$$

being f_t the material factor, f_m the manufacturing factor, f_i the installation factor, m_c the mass of the component in kg, and z = 7 the number of components for the FOWT.[46]

The equivalent mass M_{eq} is composed of seven elements m_j, j = 1 to z, which represent each major component of the FOWT from the air to the electrical output: m_1 = rotor, m_2 = hub, m_3 = nacelle, m_4 = tower, m_5 = floating platform, m_6 = mooring system and m_7 = anchor system, all in kg. Each element m_j denotes the equivalent mass of the component j as made of steel of reference. In other words, by multiplying the equivalent mass (kg) of each component m_j by the cost of the steel of reference ($/kg), we obtain the cost of each component j ($), regardless of the type of material it is made of, and including all the manufacturing and installation costs. The *steel of reference* for this program is defined as a high corrosion resistant austenitic stainless steel.

The actual mass of each component, made of its original material, is represented by m_c and is expressed in kg. The material factor f_t is non-dimensional, and represents the ratio between the cost of one kilogram of the original material ($/kg) divided by the cost of one kilogram of steel of reference ($/kg). The manufacturing factor f_m is also non-dimensional, and represents the ratio between the cost per kilogram of the manufacturing of the component ($/kg) divided by the cost of one kilogram of the original material of the component ($/kg). Finally, the installation factor f_i, also non-dimensional, represents the ratio between the cost per kilogram of the installation of the component ($/kg) divided by the cost of one kilogram of the original material of the component ($/kg). Excluding the financial costs, the equivalent mass M_{eq} can also be calculated by dividing the CapEx ($) by the cost of one kilogram of steel of reference ($/kg). See values in Tables 2 to 4.

<u>LCOE Pareto-optimal fronts</u>

LCOE is a function of the capital expenditures CapEx ($), the fixed charge rate FCR (1/year), the operation and maintenance expenditures OpEx ($/year), and the annual energy production AEP (kWh) –see eq.(9).

$$LCOE = \frac{FCR\ CapEx + OpEx}{AEP} \tag{9}$$

[46] In case of wind farms, eqs. (6) to (8) are: $M_2 = \frac{n\,A_r}{\sum_{k=1}^{n} M_{eq}(k)}$; $M_{eq}(k) = \sum_{j=1}^{z} m_j(k)$ and $m_j(k) = f_{tj}\left(1 + f_{mj} + f_{ij}\right) m_{cj}\Big|_k$ with z = 7 for the FOWT system (see Table 2) and n the number of turbines.

M1 affects the annual energy production. As M1 increases, AEP also increases, and LCOE decreases ($M_1 \uparrow \rightarrow AEP \uparrow \rightarrow LCOE \downarrow$). At the same time, M2 affects CapEx. As M2 increases, CapEx decreases, and LCOE decreases ($M_2 \uparrow \rightarrow CapEx \downarrow \rightarrow LCOE \downarrow$).

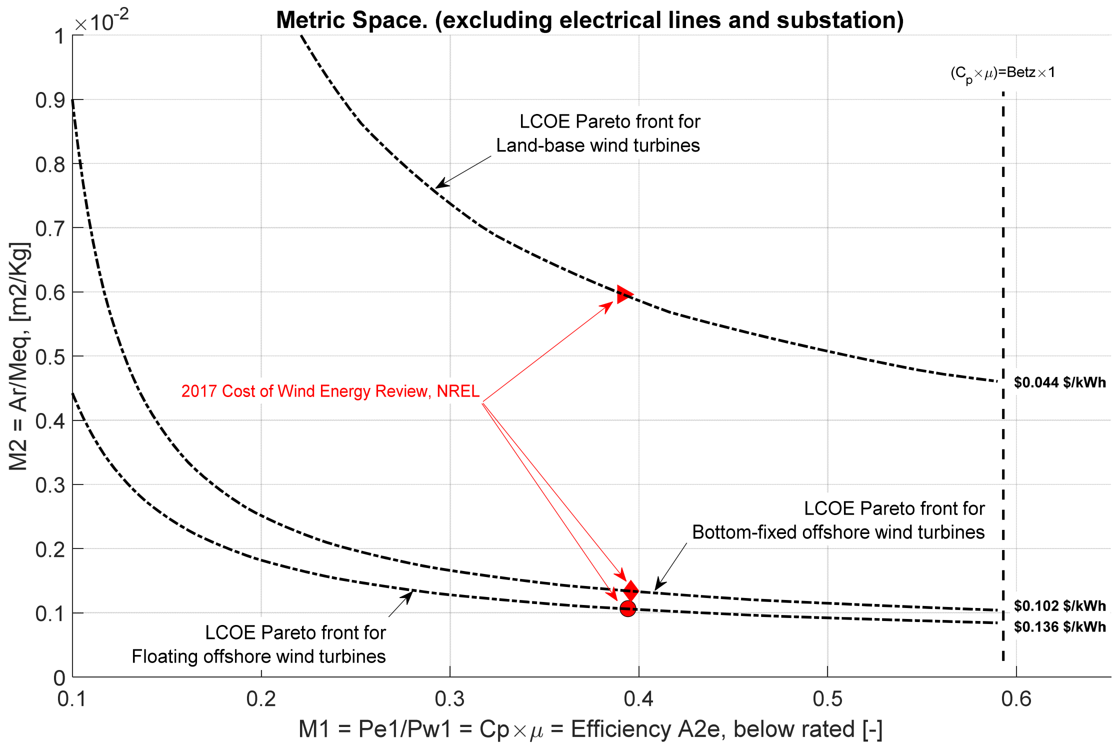

Fig. 9. Metric space definition.

Putting the two metrics M1 and M2 together in a two-dimension orthogonal space, we can identify LCOE Pareto-optimal type fronts for each case of study. Figure 9 shows the new metric space and the LCOE Pareto fronts based on three systems of the most recent NREL market study,[47] including floating offshore wind turbines (circle), bottom-fixed offshore wind turbines (diamond), and onshore wind turbines (right-pointing triangle). The calculations exclude the substation costs and the electrical line costs (intra-wind-farm, farm-to-shore lines).

Example 1. (Original case - *average FOWT in NREL 2017 Cost of Wind Energy Review*)
The case corresponding to the circle in Fig.9 is presented here as an illustrative example to understand how to calculate the new metrics. This case is the average floating offshore wind turbine presented in the NREL 2017 Cost of Wind Energy Review.

[47] Stehly, T., Beiter, P., Heimiller, D., Scott, G. (2018). *2017 Cost of Wind Energy Review*. National Renewable Energy Laboratory. Technical Report NREL/TP-6A20-72167.

- *Metric M1*:
  The FOWT of this example has the following aerodynamic coefficient and losses: C_{pmax} = 0.47, L_g = 0.04; L_{dt} = 0.02; L_w = 0.05; L_e = 0; L_o = 0 and A_v = 0.9387. Applying eqs.(4) and (5) gives C_p = 0.47 and μ = 0.839, which in eq.(1) gives M1 = $C_p\ \mu$ = 0.3943.
- *Metric M2*:
  In addition, the turbine has a rotor diameter R = 140 m, which gives a swept area of A_r = 15,394 m^2, and the masses and factors shown in Table 2.

Table 2. Information for M_{eq}, Example 1

j	*Component*	m_j	f_{tj}	f_{mj}	f_{ij}	m_{cj}
1	Rotor (blades)	1.25591e6	4	3.87	0.10	6.32061e4
2	Hub (with bearings and pitch systems)	7.63601e5	1	11.00	0.10	6.31076e4
3	Nacelle (generator, drive-train, yaw…)	2.81488e6	1	9.49	0.10	2.65710e5
4	Tower	1.01191e6	1	1.69	0.10	3.62860e5
5	Floating platform	8.30277e6	1	2.00	0.13	2.65366e6
6	Mooring system	1.11380e5	1	0.14	0.52	6.70963e4
7	Anchor system	2.64380e5	0.3	6.70	3.48	7.88500e4

Applying eqs.(7) and (8) results in M_{eq} = 14.5248e6, which with the swept area A_r = 15,394 m^2 gives a metric M2 = 0.1060×10^{-2} m^2/kg.

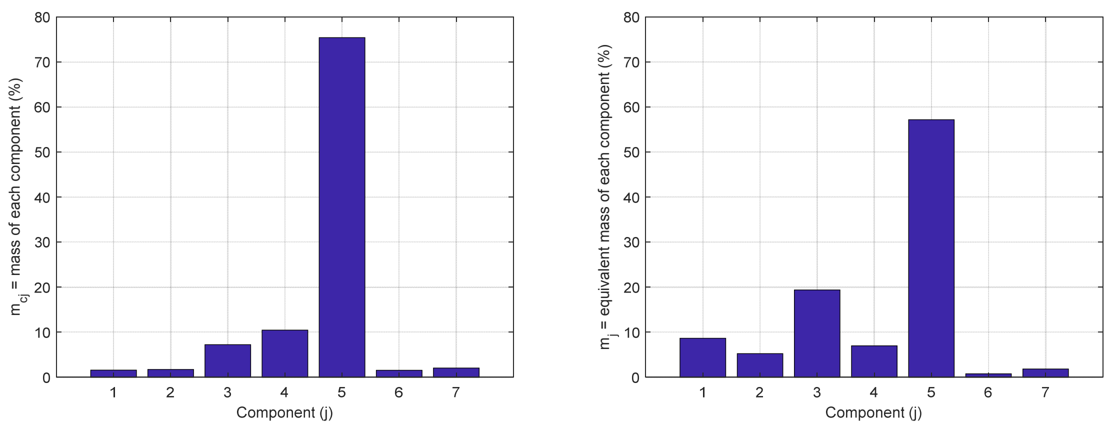

Fig. 10. (a) Mass m_{cj} and (b) equivalent mass m_j of each component j of Table 2, (in %).

Note: As Table 2 shows, the principal components in the total mass and total equivalent mass M_{eq} are the floating platform (m_{c5} ≈ 75%, m_5 ≈ 58%), nacelle (m_{c3} ≈ 7%, m_3 ≈ 19%), rotor (m_{c1} ≈ 2%, m_1 ≈ 9%) and tower (m_{c4} ≈ 10%, m_4 ≈ 7%). Figure 10 compares the effect of each component. As this program attempts to increase the specific rotor area per unit of total mass, new designs that reduce significantly the equivalent mass of the floating platform, and some of the tower, rotor and nacelle are encouraged.

- *Associated LCOE calculation* (not needed for M1, M2):

  A pair of metrics (M1,M2) can give different LCOE results. The LCOE depends on other additional parameters related to the site and economic factors.

As an example, by choosing the parameters given below, the associated CapEx and LCOE are: CapEx = 5151 $/kWe, LCOE = $0.1362/kWh (the substation and the electrical line costs are not included)[48].

Parameters

→ Wind: site with average speed of V = 8.97 m/s at hub height, Weibull probability distribution with shape factor = 2.1 and scale factor = 10.13, turbulence intensity = 16%, $V_{cut\text{-}in}$ = 3 m/s, $V_{cut\text{-}out}$ = 25 m/s, and a wind shear effect = 0.90593.
→ Sea conditions: North Atlantic
→ Fixed charge rate, FCR = 8.2%
→ OpEx = 86 $/kWe/yr
→ Water depth = 100 m
→ Distance from shore = 30 km
→ Wind farm power density = 3 ≥ 2.5 MWe/km^2 (required instead of electrical lines cost)
→ Area wind farm = 201 km^2
→ Rated electrical power of wind farm = 603 MWe
→ Number of turbines in wind farm = 107
→ Rated electrical power per turbine, P_{er} = 5.64 MWe (calculated from 603 MWe of total power of wind farm, with 107 machines in 201 km^2)
→ Hub height = 96.2 m
→ Project number of years = 20 years
→ Cost of Steel of reference = $2.0 /kg (high corrosion resistant austenitic stainless steel)

2. Technical Performance Targets

The new FOWT designs proposed for the ATLANTIS Program have to be above the LCOE Pareto-optimal front of $0.075/kWh, as shown in example of Fig.11. The program objective is expressed in terms of the two metrics M1 and M2, and for the polynomial and inequalities defined by the following expressions (for Example 1):

$$M_2 \geq a_{11}\, M_1^{11} + a_{10}\, M_1^{10} + \cdots + a_2\, M_1^2 + a_1 M_1 + a_0 \qquad (10)$$

with:

$a_{11} = -45900.51$, $a_{10} = 192532.82$, $a_9 = -361557.13$, $a_8 = 401082.11$,
$a_7 = -291963.06$, $a_6 = 146438.25$, $a_5 = -51660.06$, $a_4 = 12830.70$,
$a_3 = -2202.94$, $a_2 = 249.92$, $a_1 = -16.99$, $a_0 = 0.54$
and: $0.15 \leq M_1 \leq 0.593$

[48] LCOE is $0.146/kWh if the substation and the electrical line costs, intra-wind-farm and farm-to-shore lines, are included, or m_8 = 1.2856e6 ≠ 0. This would give CapEx = 5605 $/kWe instead of 5151 $/kWe. However, this eigth component (m_8) is not included in the equivalent mass M_{eq}. The effect of the substation and electrical line costs is considered by requesting a wind farm power density equal to or greater than 2.5 MW electrical in the parameter list instead.

These coefficients have been calculated for the same assumptions and parameters of Example 1 above, with P_{er} = 5.64 MW, R = 70 m (A_r = 15,394 m^2), and for a LCOE of \$0.075/kWh.

Example 2. (Improved case, *substantial mass reduction in traditional FOWT design*)

To illustrate the program performance targets, an improved design based on the conventional average floating offshore wind turbine case introduced in Example 1 (Section I.D.1) is presented here. The original case is at M1 = 0.3943, M2 = 0.1060×10^{-2} m^2/kg.

The improved design, which meets the program objectives, is at M1 = 0.3775, M2 = 0.2458×10^{-2} m^2/kg, and gives a LCOE = \$0.073/kWh –see small blue square in Fig.11. This can be achieved by reducing the mass of the floating platform (0.25 × m_5), rotor (0.50 × m_1) and nacelle (0.50 × m_3), and loosing aerodynamic efficiency to C_{pmax} = 0.45 –see also Figs. 16 to 18 in Section IV.C.2.

Example 3. (Improved case, *radically new design - airborne*)

A second improved case, based on an unconventional design, is also shown in Fig.11. The design is an airborne-type FOWT, with tethers instead of a tower, a small floating platform and a lightweight rotor. In this case, the electrical and mechanical losses are considered the same as in Example 1, but with a lower aerodynamic coefficient C_{pmax} = 0.35.

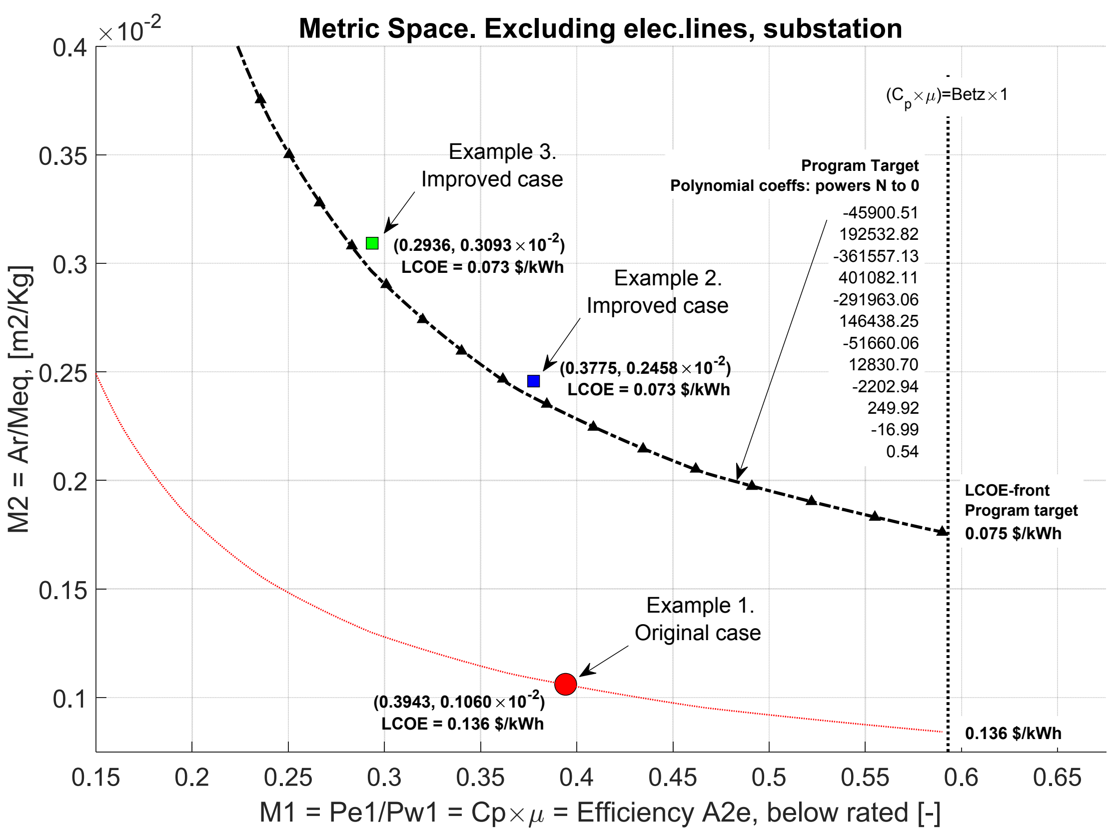

Fig. 11. Program performance target. New FOWT designs have to be above the LCOE Pareto-optimal front represented by the solid line with triangles.

For simplicity, the equivalent masses m_2, m_6 and m_7 are calculated from Example 1 (Table 2). At the same time, the equivalent masses of the floating platform, tower, nacelle and rotor are significantly reduced, being: (0.20 × m_5), (0.14 × m_4), (0.50 × m_3) and (0.50 × m_1) respectively. This improved case also meets the program objectives, with M1 = 0.2936, M2 = 0.3093×10^{-2} m^2/kg, with a LCOE = \$0.073/kWh –see small green square in Fig.11.

3. DESIGN VALIDATION

The calculation of the equivalent mass M_{eq} needs three factors for each component: the material factor f_t, the manufacturing factor f_m, and the installation factor f_i. Table 3 shows the material factors f_t to be used in the calculations of this program by default. If the new design of the FOWT needs another material that is not shown in Table 3, a new material factor f_t for that new material must be proposed and justified.

Table 4 shows the manufacturing factors f_m and installation factors f_i of the seven main components of the FOWT. Factors in Table 4 should be used by default unless a reasonable change is proposed and justified. If the new design of the FOWT does not include some of these seven components, they can be removed from the summation of the equivalent mass –eq.(8). Also, if the new design of the FOWT needs different components, new manufacturing f_m and installation f_i factors for the new components will be proposed and justified by the applicants.

The new FOWT designs proposed for this program must have the point (M1,M2) above the \$0.075kWh LCOE-front in the Metric Space under the following <u>*conditions*</u>:

- (c1) Material factors f_t using Table 3. For materials not included in this Table, new material factors can be proposed and justified.
- (c2) Manufacturing factors f_m and installation factors f_i for the seven main components of the FOWT using Table 4. For new components, new manufacturing and installation factors can be proposed and justified. If the design does not need a particular component, it can be removed from the calculation of the equivalent mass.
- (c3) Wind: site with average speed of V = 8.97 m/s at hub height, Weibull probability distribution with shape factor = 2.1 and scale factor = 10.13, turbulence intensity = 16%, $V_{cut\text{-}in}$ = 3 m/s, $V_{cut\text{-}out}$ = 25 m/s, and a wind shear effect = 0.90593.
- (c4) Sea conditions in North Atlantic.[49,50,51,52]
- (c5) Fixed charge rate, FCR = 8.2%
- (c6) OpEx ≤ 86 \$/kWe/yr (this should be achieved with the proposed M_{eq}).

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[49] Lee, W.T., Bales, S.L., Sowby, S.E. (1985). *Standardized wind and wave environments for North Pacific Ocean Areas*. Report, Defense Technical Information Center.
[50] Faltinsen, O. (1993). *Sea loads on ships and offshore structures*. Vol. 1. Cambridge University Press.
[51] Myhr, A., Bjerkseter, C., Ågotnes, A., Nygaard, T. (2014). *Levelised cost of energy for offshore floating wind turbines in a life cycle perspective*. Renewable Energy, Vol. 66, pp. 714-728.
[52] Jonkman, J. (2007). *Dynamics Modeling and Loads Analysis of an Offshore Floating Wind Turbine*. NREL/TP-500-41958.

(c7) Water depth = 100 m
(c8) Distance from shore = 30 km
(c9) Wind farm power density ≥ 2.5 MWe/km^2 (Needed to balance electrical line costs).
(c10) Area wind farm = 200 km^2
(c11) Rated electrical power of wind farm ≥ 500 MW (Needed to balance electrical line costs)
(c12) Rated electrical power per turbine, Per ≥ 5.64 MWe (calculated from 603 MWe of total power of wind farm, with 107 machines in 201 km^2)
(c13) Hub height ≥ 96 m. This value was used to calculate the average wind speed in (c3).
(c14) Project number of years = 20 years
(c15) Cost of Steel of reference = $2.0 /kg (high corrosion resistant austenitic stainless steel)
(c16) Accepted computer tools for load calculations (OpenFast,[53] Bladed[54] or similar).
(c17) Design Load Cases (DLCs) according to the IEC-61400-3 standards for offshore wind, including operational cases, mechanical fatigue cases and extreme load cases (five operational modes, Section I.C.4.a).

Table 3. Material factors (raw materials)[55]
f_t = cost original material ($/kg) / cost steel of reference ($/kg)

Material	Material factor f_t
Aluminum alloys	4.0
Brass (70Cu30Zn, annealed)	1.1
CFRP Laminate (carbon fiber reinforce polymer)	80.0
Copper alloys	1.5
GFRP Laminate (glass-fiber reinforced plastic or fiberglass)	4.0
Lead alloys	0.6
Nickel alloys	3.0
Pre-stressed concrete	0.3
Titanium alloys	22.5
Steel of reference, to calculate f_t factors	**1.0**

[53] OpenFAST. (2018). National Renewable Energy Lab, NREL. https://nwtc.nrel.gov/OpenFAST
[54] Bladed, DNV-GL, https://www.dnvgl.com/services/bladed-3775
[55] Price of stainless steel 304, 316. https://www.vishalsteel.net/stainless-steel/stainless-steel-304/stainless-steel-304/. Price of aluminum, copper and nickel alloys. High Performance Conductors Inc. (2018). http://www.iwghpc.com/pricing/Copper%20Query%202.pdf. Price of CFRP (carbon fiber reinforced polymer) laminate. https://www.compositesworld.com/blog/post/the-vexing-economics-of-carbon-fiber-manufacturing. Price of GFRP (glass fiber reinforced polymer) laminate. https://www.compositesworld.com/articles/wind-turbine-blades-glass-vs-carbon-fiber. Price of pre-stressed concrete. http://ijstc.shirazu.ac.ir/article_948_4270c00657d8397cf331af742e43ec93.pdf. Price of brass, lead and titanium alloys. http://web.mit.edu/course/3/3.11/www/modules/props.pdf

Table 4. Manufacturing and installation factors[56]
f_m = cost manufacturing of component ($/kg) / cost original material of the component ($/kg)
f_i = cost installation of component ($/kg) / cost original material of the component ($/kg)

j	Component (*j* = 1 to 7)	Manufacturing factor f_{mj}	Installation factor f_{ij}
1	Rotor (blades)	3.87	0.10
2	Hub (with bearings and pitch system)	11.00	0.10
3	Nacelle (with drive-train, electrical generator, power converters, yaw, etc.)	9.49	0.10
4	Tower	1.69	0.10
5	Floating platform	2.00	0.13
6	Mooring system	0.14	0.52
7	Anchor system	6.70	3.48

Applicants to the ATLANTIS Program in the first fundamental area (*New designs*, see below) are required to provide details of the performance of the new FOWT in the metric space, including the graphic representation and the numerical values of M1 and M2 using the factors given in Tables 3 and 4, with the conditions (c1) to (c17), and with an LCOE front for $0.075/kWh. If the new FOWT design needs some changes in the factors presented in Tables 3 and 4, in the conditions (c1) to (c17), and in the resulting LCOE front, an explanation of each change is required. An Excel workbook file template, named *ATLANTIS_MetricSpaceWorkbook.xlsx*, to assist with the calculations of the M1 and M2 metrics and the LCOE front is provided on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov). ARPA-E encourages applicants in the first fundamental area (*New designs*) to use this workbook file with the details of the new FOWT design (See Section IV.C.2).

E. ATLANTIS PROGRAM STRUCTURE

1. PROGRAM

Projects under the ATLANTIS Program will cover three fundamental areas: (1) radically new FOWT designs, (2) computer tools to co-design the FOWTs, and (3) real-data from full and lab-scale experiments to validate the FOWT designs and computer tools.

[56] Factors based on several references, including: (1) Myhr, A., Bjerkseter, C., Ågotnes, A., Nygaard, T. (2014). *Levelised cost of energy for offshore floating wind turbines in a life cycle perspective*. Renewable Energy, Vol. 66, pp. 714-728; (2) Stehly, T., Beiter, P., Heimiller, D., Scott, G. (2018). *2017 Cost of Wind Energy Review*. Technical Report NREL/TP-6A20-72167; (3) Jonkman, J., Butterfield, S., Musial, W., Scott, G. (2009). Definition of a 5-MW Reference Wind Turbine for Offshore System Development. National Renewable Energy Laboratory. Technical Report NREL/TP-500-38060; (4) Ebenhoch, R., Matha, D., Marathe, S., Cortes-Muñoz, P., Molins, C. (2015). Comparative Levelized Cost of Energy Analysis. Energy Procedia, vol. 80, pp. 108-122; and (5) Ashuri, T., Zaaijer, M., Martins, J., Zhang, J. (2016). Multidisciplinary design optimization of large wind turbines: technical, economic, and design challenges. Energy Conversion and Management, vol. 123, pp. 56-70.

The program structure includes three fundamental areas in two phases –see Fig.12. Projects addressing the first fundamental area (*New designs*) must be independent submissions, without the other two fundamental areas. However, projects addressing the second and third fundamental areas (*Computer tools* and *Experiments*) can be independent submissions or combined in one submission.

Phase I, described in this document, is expected to cover the first two years with an anticipated $28M in awards. Based on the results achieved in this first phase, a second phase, subject to the availability of appropriated funds, is anticipated to be announced for an additional two years, with additional funds to continue the research in the three fundamental areas and with more emphasis on experimental testing. Only Phase I awardees will be elgible to apply for anticipated funding under Phase II.

Selection of projects for Phase II funding would be based, in part, on (1) the degree of achievement against the objectives defined for Phase I for each fundamental area, and (2) the objectives for each fundamental area of the ATLANTIS Program during Phase II, as described in general below. (See also Section II.B (Renewal Awards) of the FOA for further information applicable to Phase II funding.)

- Projects in the first fundamental area (*New designs*) must, at a minimum, include the following: (a) a new design that achieves the program target metrics described in Section I.D.2 (the point M1,M2 must be above the $0.075kWh LCOE-front in the Metric Space) and (b) the calculations for the design of a small-scale prototype(s), to be potentially developed and experimentally tested in the planned Phase II of the program, if selected. The objective of this small-scale prototype(s) would be to prove experimentally the main concepts of the new design, in order to achieve the program targets at full-scale. Selection of *New designs* projects for Phase II funding would be based, in part, on (1) the degree of achievement on the program target metrics defined above, (2) the characteristics, feasibility and necessity of the proposed small-scale prototype(s), (3) the tech-to-market potential of the new design, and (4) the new objectives proposed for the project during Phase II. Limited experimental work to support the proposed concept and inform continued design and development is allowed during Phase I of the program. However, more detailed experimental testing of integrated systems is reserved for Phase II.

- Projects in the second fundamental area (*Computer tools*) must include elements (e1) through (e5) presented in Section I.C.4.b, and at least four of the remaining elements, (e6) to (e11). Selection of *Computer tools* projects for Phase II funding would be based, in part, on (1) the degree of achievement on the elements e1 through e11 defined above, and (2) the new elements e6 to e11 proposed for the project during Phase II.

- Projects in the third fundamental area (*Experiments*) must indicate in their submission what operational data, from both laboratory prototypes and full-scale real-world commercial systems, will be made publicly available and how this data will be made publicly available.

Projects in this area must include: (a) the development of an intelligent real-time systems to collect these experimental data from full and/or lab-scale FOWTs, and (b) experimental data of category d1 and at least some data of categories d2 to d4, as presented in Section I.C.4.c, all collected simultaneously with the real-time system and for some scenarios under the operational modes (O1) to (O5) defined in Section I.C.4.a. Selection of *Experiments* projects for Phase II funding would be based, in part, on (1) the degree of development of the intelligent real-time system, (2) the experimental data collected during Phase I, and (3) the new proposed data to be collected during Phase II.

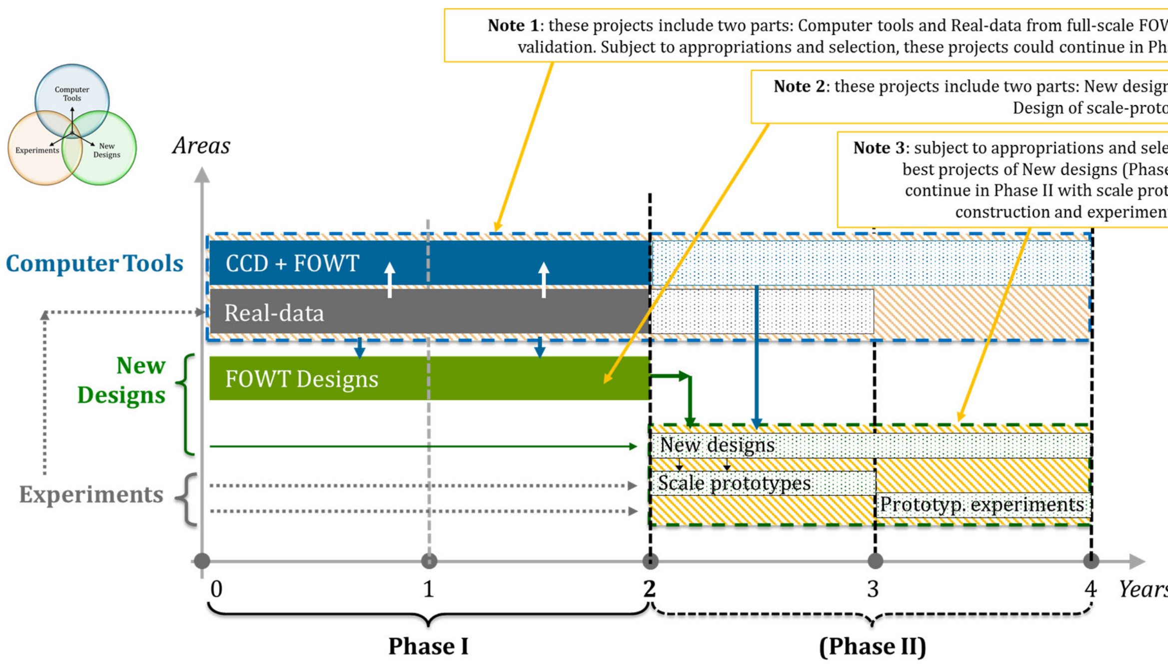

Fig. 12. ATLANTIS Program structure.

2. MULTIDISCIPLINARY RESEARCH COLLABORATION

The success of the ATLANTIS Program depends on a broad range of technical communities working together. These communities include, but are not limited to control and systems engineering, control co-design, aerodynamics, hydrodynamics, electrical and mechanical systems, power electronics, electrical generators, structural engineering, naval engineering, modeling, optimization, economics, multi-scale and multi-physics computer algorithms, parallel computing, distributed sensors, intelligent signal processing and actuator networks; as well as developers of offshore wind energy systems and electrical utilities.

Applying CCD demands teams to work together in a truly multidisciplinary way –see Figs. 8 and 13. Ideal teams for this program include team members or institutions that cover both, specific aspects within each area (*New designs*, *Computer tools* and *Experiments*), and/or intersections between the three areas.

Managing research projects across multidisciplinary and organizational boundaries is a subject of substantial discussion in the research community and funding agencies. Aspects like trade-offs between the amount of management needed for collaboration and scientific work, optimal costs of coordination and relationship development, and tools to organize work and be productive in these projects are some of the key characteristics that have to be addressed at the beginning of the collaboration.[57,58,59]

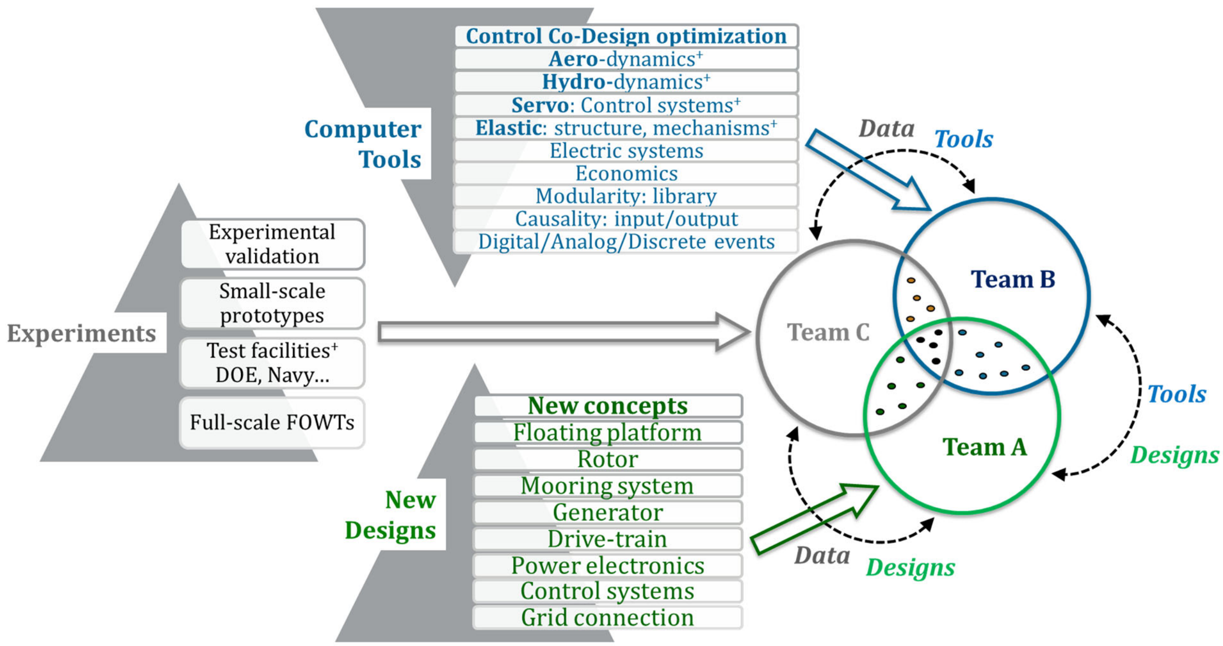

Fig. 13. Multi-disciplinary team composition and program collaboration.

Applicants to the ATLANTIS Program are required to provide details on their planned collaboration approach and justify that it is sufficiently integrated. This includes details on the following considerations on project coordination and program collaboration:

- An advanced multi-disciplinary collaboration across institutions and members of each team, and across the teams of the program, is encouraged. Participation of wind turbine manufacturers and floating platform manufacturers is highly encouraged, either as team members or in industry advisory boards.
- As sharing information and tools about some aspects of the design, computer tools and experiments is a key part of the anticipated collaborations between project teams, some models or discussion specifying how the project teams will facilitate successful collaborations and overcome potential obstacles that could hamper the effectiveness of these collaborations. These models can facilitate the following collaboration scenarios.

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[57] Cummings, J., Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. Social Studies of Science, vol. 35, no. 5, pp. 703-722.
[58] Adams, J. (2012). The rise of research networks. Nature, vol. 490, pp. 335-336.
[59] Lustig, L., Ponzielli, R., Tang, P., Sathiamoorthy, S., Inamoto, I., Shin, J., Penn, L., Chan, W. (2015). Guiding principles for a successful multidisciplinary research collaboration. Future Sci. OA, vol.1, no. 3.

- Projects in the first fundamental area (*New designs*) will be encouraged to make a description of the main characteristics and challenges of the new designs available to the teams of the second fundamental area (*Computer tools*) and third fundamental area (*Experiments*) by the end of the first year of Phase I, and to the end of Phase II –see Fig.13.
- Projects in the second fundamental area (*Computer tools*) will be encouraged to make the new simulation tools available to the teams of the first fundamental area (*New designs*) and third fundamental area (*Experiments*) by the end of the first year of Phase I, and to the end of Phase II –see Fig.13. Subject to intellectual property related provisions in the award, such availability may be made subject to restrictions on further use and dissemination. ARPA-E is prepared to consider authorizing greater intellectual property rights in such computer tools as appropriate to maximize their commercialization. In addition, submissions should indicate what proprietary computer tools, if any, not developed under this program the applicants are prepared to make available to the project teams under reasonable terms and conditions, and for which terms and conditions should be outlined.
- Projects in the third fundamental area (*Experiments*) will be encouraged to make the real-world FOWT data available to the teams of the first fundamental area (*New designs*) and second fundamental area (*Computer tools*) by the end of the first year of Phase I, and to the end of Phase II –see Fig.13.
- Any data made available to other teams in other fundamental areas may, subject to approval by ARPA-E, be entitled to protection from public release.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $28 million available for new awards under Phase I of this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 10 awards under Phase I of this FOA. ARPA-E may issue one, multiple, or no awards.

Individual awards may vary between $250,000 and $10 million.

The period of performance for funding agreements in Phase I may not exceed 24 months. ARPA-E expects the start date for funding agreements to be December 2019, or as negotiated.

ARPA-E encourages applications stemming from ideas that still require proof-of-concept R&D efforts as well as those for which some proof-of-concept demonstration already exists.

Submissions requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metric at the conclusion of the period of performance. These submissions must contain an appropriate cost and project duration plan that provides sufficient technical detail to allow reviewers to evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration. Alternatively, submissions requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

Applicants proposing projects for which some initial proof-of-concept demonstration already exists should submit concrete data that supports the probability of success of the proposed project.

ARPA-E will provide support at the highest funding level only for applications with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

ARPA-E will accept only new applications under this FOA. Applicants may not seek renewal or supplementation of their existing awards through this FOA.

ARPA-E plans to fully fund negotiated budgets at the time of award.

B. RENEWAL AWARDS

At ARPA-E's sole discretion, awards resulting from this FOA may be renewed by adding one or more budget periods and/or extending the period of performance of the initial award. Renewal funding is contingent on: (1) availability of funds appropriated by Congress for the purpose of this program; (2) substantial progress towards meeting the objectives of the approved application; (3) submittal of required reports; (4) compliance with the terms and conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by the Agency at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

Through cooperative agreements, other transactions, and similar agreements, ARPA-E provides financial and other support to projects that have the potential to realize ARPA-E's statutory mission. ARPA-E does not use such agreements to acquire property or services for the direct benefit or use of the U.S. Government.

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[60] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.C below.

[60] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).

1. Cooperative Agreements

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[61]

Cooperative Agreements involve the provision of financial or other support to accomplish a public purpose of support or stimulation authorized by Federal statute. Under Cooperative Agreements, the Government and Prime Recipients share responsibility for the direction of projects.

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at https://arpa-e.energy.gov/?q=site-page/funding-agreements.

2. Funding Agreements with FFRDCs/DOE Labs, GOGOs, and Federal Instrumentalities

Any Federally Funded Research and Development Centers (FFRDC) involved as a member of a Project Team must provide the information requested in the "FFRDC Lab Authorization" and "Field Work Proposal" Section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

When a FFRDC/DOE Lab (including the National Energy Technology Laboratory or NETL) is the *lead organization* for a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the rest of the Project Team. Notwithstanding the use of multiple agreements, the FFRDC/DOE Lab is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

When a FFRDC/DOE Lab is a *member* of a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the rest of the Project Team. Notwithstanding the use of multiple agreements, the Prime Recipient under the Cooperative Agreement is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S. Government and the Laboratory. Any funding agreement with a FFRDC or GOGO will have

[61] The Prime Recipient is the signatory to the funding agreement with ARPA-E.

similar terms and conditions as ARPA-E's Model Cooperative Agreement (https://arpa-e.energy.gov/?q=site-page/funding-agreements).

Non-DOE GOGOs and Federal agencies may be proposed to provide support to the project team members on an applicant's project, through a Cooperative Research and Development Agreement (CRADA) or similar agreement.

3. OTHER TRANSACTIONS AUTHORITY

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 to enter into an other transaction agreement with Prime Recipients, on a case-by-case basis.

ARPA-E may negotiate an other transaction agreement when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

In general, an other transaction agreement would require a cost share of 50%. See Section III.B.2 of the FOA.

D. STATEMENT OF SUBSTANTIAL INVOLVEMENT

ARPA-E is substantially involved in the direction of projects from inception to completion. For the purposes of an ARPA-E project, substantial involvement means:

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or tehnical milestones and deliverables.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.338 and 200.339.

- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

This FOA is open to U.S. universities, national laboratories, industry and individuals.

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[62] as the lead for a Project Team,[63] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. DOMESTIC ENTITIES

For-profit entities, educational institutions, and nonprofits[64] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs/DOE Labs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team that includes institutions of higher education, companies, research foundations, or trade and industry research collaborations, but not as a Standalone Applicant.

State, local, and tribal government entities are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

Federal agencies and instrumentalities (other than DOE) are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

3. FOREIGN ENTITIES

U.S. incorporated subsidiaries of foreign entities, whether for-profit or otherwise, are eligible to apply for funding under this FOA as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team, subject to the requirements in 2 C.F.R. § 910.124, which includes requirements that the entity's participation in this FOA's Program be in

[62] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.

[63] The term "Project Team" is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

64 Nonprofit organizations described in Section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Prime Recipient or Subrecipient.

the economic interest of the U.S. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate.

Entities not incorporated in the U.S., whether for-profit or otherwise, are not eligible to apply for funding, but may be proposed by an Applicant as a member of a Project Team.

All work under an ARPA-E award must be performed in the U.S. The Applicants may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Project Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

Unincorporated consortia must provide the Contracting Officer with a collaboration agreement, commonly referred to as the articles of collaboration, which sets out the rights and responsibilities of each consortium member. This collaboration agreement binds the individual consortium members together and shall include the consortium's:

- Management structure;
- Method of making payments to consortium members;
- Means of ensuring and overseeing members' efforts on the project;
- Provisions for members' cost sharing contributions; and
- Provisions for ownership and rights in intellectual property developed previously or under the agreement.

B. COST SHARING[65]

Applicants are bound by the cost share proposed in their Full Applications.

[65] Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.

1. Base Cost Share Requirement

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.C.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[66] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[67]

2. Increased Cost Share Requirement

Large businesses are strongly encouraged to provide more than 20% of the Total Project Cost as cost share. ARPA-E may consider the amount of cost share proposed when selecting applications for award negotiations (see Section V.B.1 of the FOA).

Under an "other transaction" agreement, the Prime Recipient must provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this minimum cost share requirement, as appropriate.

3. Reduced Cost Share Requirement

ARPA-E has reduced the minimum cost share requirement for the following types of projects:

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is not required to provide cost share.
- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs/DOE Labs/Federal agencies and instrumentalities (other than DOE) are not required to provide cost share.
- Small businesses – or consortia of small businesses – will provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[68] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

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[66] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs and FFRDCs.

[67] Energy Policy Act of 2005, Pub.L. No. 109-58, § 988.

[68] Small businesses are generally defined as domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80%, but less than 100%, of the total work under the funding agreement (as measured by the Total Project Cost) the Project Team are entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.[69]
- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.
- Projects that do not meet any of the above criteria are subject to the minimum cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. Legal Responsibility

Although the cost share requirement applies to the Project Team as a whole, the funding agreement makes the Prime Recipient legally responsible for paying the entire cost share. The Prime Recipient's cost share obligation is expressed in the funding agreement as a static amount in U.S. dollars (cost share amount) and as a percentage of the Total Project Cost (cost share percentage). If the funding agreement is terminated prior to the end of the period of performance, the Prime Recipient is required to contribute at least the cost share percentage of total expenditures incurred through the date of termination.

The Prime Recipient is solely responsible for managing cost share contributions by the Project Team and enforcing cost share obligations assumed by Project Team members in subawards or related agreements.

5. Cost Share Allocation

Each Project Team is free to determine how much each Project Team member will contribute towards the cost share requirement. The amount contributed by individual Project Team members may vary, as long as the cost share requirement for the project as a whole is met.

6. Cost Share Types and Allowability

Every cost share contribution must be allowable under the applicable Federal cost principles, as described in Section IV.G.1 of the FOA.

[69] See the information provided in previous footnote.

Project Teams may provide cost share in the form of cash or in-kind contributions. Cash contributions may be provided by the Prime Recipient or Subrecipients. Allowable in-kind contributions include but are not limited to personnel costs, indirect costs, facilities and administrative costs, rental value of buildings or equipment, and the value of a service, other resource, or third party in-kind contribution. Project Teams may use funding or property received from state or local governments to meet the cost share requirement, so long as the funding or property was not provided to the state or local government by the Federal Government.

The Prime Recipient may not use the following sources to meet its cost share obligations:

- Revenues or royalties from the prospective operation of an activity beyond the period of performance;
- Proceeds from the prospective sale of an asset of an activity;
- Federal funding or property (e.g., Federal grants, equipment owned by the Federal Government); or
- Expenditures that were reimbursed under a separate Federal program.

In addition, Project Teams may not use independent research and development (IR&D) funds[70] to meet their cost share obligations under Cooperative Agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under "other transaction" agreements.

Project Teams may not use the same cash or in-kind contributions to meet cost share requirements for more than one project or program.

Cost share contributions must be specified in the project budget, verifiable from the Prime Recipient's records, and necessary and reasonable for proper and efficient accomplishment of the project. Every cost share contribution must be reviewed and approved in advance by the Contracting Officer and incorporated into the project budget before the expenditures are incurred.

Applicants may wish to refer to 2 C.F.R. Parts 200 and 910, and 10 C.F.R Part 603 for additional guidance on cost sharing, specifically 2 C.F.R. §§ 200.306 and 910.130, and 10 C.F.R. §§ 603.525-555.

7. Cost Share Contributions by FFRDCs and GOGOs

Because FFRDCs are funded by the Federal Government, costs incurred by FFRDCs generally may not be used to meet the cost share requirement. FFRDCs may contribute cost share only if the contributions are paid directly from the contractor's Management Fee or a non-Federal source.

[70] As defined in Federal Acquisition Regulation SubSection 31.205-18.

Because GOGOs/Federal Agencies are funded by the Federal Government, GOGOs/Federal Agencies may not provide cost share for the proposed project. However, the GOGO/Agency costs would be included in Total Project Costs for purposes of calculating the cost-sharing requirements of the applicant.

8. Cost Share Verification

Upon selection for award negotiations, Applicants are required to provide information and documentation regarding their cost share contributions. Please refer to Section VI.B.3 of the FOA for guidance on the requisite cost share information and documentation.

C. Other

1. Compliant Criteria

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper complies with the content and form requirements in Section IV.C of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Concept Papers found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Concept Papers, including Concept Papers submitted through other means, Concept Papers submitted after the applicable deadline, and incomplete Concept Papers. A Concept Paper is incomplete if it does not include required information. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Full Applications are deemed compliant if:

- The Applicant submitted a compliant and responsive Concept Paper;
- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.D of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Full Applications found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploads its response to ARPA-E eXCHANGE by the deadline stated in the FOA; and
- The Replies to Reviewer Comments comply with the content and form requirements of Section IV.E of the FOA.

ARPA-E will not review or consider noncompliant Replies to Reviewer Comments, including Replies submitted through other means and Replies submitted after the applicable deadline. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information due to server/connection congestion. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be noncompliant.

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Concept Papers and Full Applications. The following types of submissions may be deemed nonresponsive and may not be reviewed or considered:

- Submissions that fall outside the technical parameters specified in this FOA.
- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to other currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.

- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by other government agencies or the private sector.
- Submissions that do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. Submissions Specifically not of Interest

Submissions that propose the following may be deemed nonresponsive and may not be merit reviewed or considered:

- **In Area 1, New designs**:
    - Incremental improvements to existing FOWT designs.
    - Efforts that do not consider the control co-design approach.
    - Projects that do not meet the program performance target (metrics) under the assumptions described in this document.
    - Projects that only deal with some specific new devices but do not apply them to the new design of the FOWT and show the program performance target (metrics).
    - Devices that produce electrical energy from tidal or wave energy (i.e. PTO devices) are not of interest. However, systems that leverage wave/tidal energy to reduce weight (e.g. dampening floating platform motion) are of interest.
    - Submissions that include in the same project this Area 1 (New designs) and any of the other two areas (Computer tools and/or Experiments). Projects of Area 1 must be independent submissions.

- **In Area 2, Computer tools**:
    - Incremental improvements to existing computer tools to simulate FOWTs.
    - Projects that do not consider the control co-design approach.
    - Efforts that are not able to simulate the mechanical loads of all the main components of the FOWT, i.e. the wind turbine, the floating platform, the mooring system and the anchor system.

- **In Area 3, Experiments**:
    - Projects that do not provide real-data of FOWT.

4. Limitation on Number of Submissions

ARPA-E is not limiting the number of submissions from Applicants. Applicants may submit more than one application to this FOA, provided that each application is scientifically distinct.

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

The first step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.H.1 of the FOA and the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. CONCEPT PAPERS

Applicants must submit a Concept Paper by the deadline stated in the FOA. Section IV.C of the FOA provides instructions on submitting a Concept Paper.

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA.

ARPA-E will encourage a subset of Applicants to submit Full Applications. Other Applicants will be discouraged from submitting a Full Application in order to save them the time and expense of preparing an application submission that is unlikely to be selected for award negotiations. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

3. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 45 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA.

4. Reply to Reviewer Comments

Once ARPA-E has completed its review of Full Applications, reviewer comments on compliant and responsive Full Applications are made available to Applicants via ARPA-E eXCHANGE. Applicants may submit an optional Reply to Reviewer Comments, which must be submitted by the deadline stated in the FOA. Section IV.E of the FOA provides instructions on submitting a Reply to Reviewer Comments.

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.C.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

5. Pre-Selection Clarifications and "Down-Select" Process

Once ARPA-E completes its review of Full Applications and Replies to Reviewer Comments, it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings or site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for award negotiations and make awards without pre-selection meetings and site visits. Participation in a pre-selection meeting or site visit with ARPA-E does not signify that Applicants have been selected for award negotiations.

6. Selection for Award Negotiations

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

B. APPLICATION FORMS

Required forms for Full Applications are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov), including the SF-424 and Budget Justification Workbook/SF-424A. A sample Summary Slide is available on ARPA-E eXCHANGE. Applicants may use the templates available on ARPA-E eXCHANGE, including the template for the Concept Paper, the template for the Technical Volume of the Full Application, the template for the Summary Slide, the template for the Summary for Public Release, the template for the Reply to Reviewer Comments, and the template for the Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form is available on ARPA-E eXCHANGE.

C. CONTENT AND FORM OF CONCEPT PAPERS

The Concept Paper is mandatory (i.e. in order to submit a Full Application, a compliant and responsive Concept Paper must have been submitted) and must conform to the following formatting requirements.

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables. Concept papers in Area 1 (*New designs*) are allowed one additional page for Appendix 1 that contains a plot of the Metric Space for the new design, and the description and justification for the parameters used to calculate the M1 and M2 metrics and LCOE front.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.
- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category and Subcategory, Proposed Funding Requested (Federal and Cost Share), and Project Duration.
- The Concept Paper must be submitted in Adobe PDF format.
- For Concept Papers in Area 1 (*New designs*), applicants must submit a Metric Space Workbook, in a Microsoft Excel Spreadsheet, with the details of the new design that shows the calculations of M1 and M2 metrics and the LCOE front. Applicants are strongly encouraged to use the ATLANTIS Metric Space Workbook template, named *ATLANTIS_MetricSpaceWorkbook.xlsx*, that available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov).

Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award (see Section III.C of the FOA).

Each Concept Paper must be limited to a single concept or technology. Unrelated concepts and technologies must not be consolidated into a single Concept Paper.

A fillable Concept Paper template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

Concept Papers must conform to the content requirements described below. If Applicants exceed the maximum page length indicated above, ARPA-E will review only the authorized number of pages and disregard any additional pages.

1. First Component: Concept Paper

a. Concept Summary

- Describe the proposed concept with minimal jargon, and explain how it addresses the Program Objectives of the FOA.

b. Innovation and Impact

- Clearly identify the problem to be solved with the proposed technology concept.
- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA.
- Explain the concept's potential to be disruptive compared to existing or emerging technologies.
- To the extent possible, provide quantitative metrics to compare the proposed technology concept to current and emerging technologies and to the Technical Performance Targets in Section I.D of the FOA.
    - For concepts relevant to Area 1 (New designs), include the variables in M1 and M2, that are expected to be most significantly affected via the new design, an estimate of how much each will change, and a *brief* justification for each. Note that there is an opportunity to provide a more detailed and comprehensive justification in the Metric Space Workbook – this should just summarize the key details from the workbook.
    - For concepts relevant to Area 2 (Computer tools): include a list of the elements (from Section I.4.b, items e1 – e11) that you propose to enhance, and, for each, a description of how your proposed concept represents an enhancement over the relevant existing tool(s). Include both the critical elements, e1 through e5, and the four (or more) remaining secondary elements, e6 to e11 that the concept will enhance.
    - For concepts relevant to Area 3 (Experiments): describe the intelligent real-time system that you propose to develop and include a list of the data (from Section

I.4.c, items d1 – d4) and scenarios (from Section I.C.4.a, operational modes O1 – O5) that you propose to collect.

c. PROPOSED WORK

- Describe and briefly justify/motivate the proposed Phase I deliverable(s) for the project and the overall technical approach used to achieve project objectives.
- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.
- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach. Provide specific examples of supporting data and/or appropriate citations to the scientific and technical literature.
- Describe why the proposed effort is a significant technical challenge and the key technical risks to the project. Does the approach require one or more entirely new technical developments to succeed? How will technical risk be mitigated?
- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.

d. TEAM ORGANIZATION AND CAPABILITIES

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.
- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.
- Identify key capabilities provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.
- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort.

e. APPENDIX 1 (AREA 1 NEW DESIGN SUBMISSIONS ONLY)

- Plot of Metric Space from Tab: "2b. Proposed Design Plot"
- Description and Justification for the parameters used to calculate the M1 and M2 metrics and LCOE front of Area from Tab: "2c. Summary of Changes"

2. SECOND COMPONENT: METRIC SPACE WORKBOOK

In addition to the Concept Paper, Applicants to Area 1 (*New Designs*) must fill out and submit a Metric Space Workbook. Applicants are strongly encouraged to use the ATLANTIS Metric Space Workbook named *ATLANTIS_MetricSpaceWorkbook.xlsx,* which is available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/). This file includes two tabs ("1a. Original Design" and "1b. Original Design Plot") about the original design presented in Section I.D.1 (Example 1), and three additional tabs for the new FOWT proposed design ("2a. Proposed Design", "2b. Proposed Design Plot" and "2c. Summary of Changes") –see Figures 14 to 18. All Metric Space Workbooks must conform to the following content and form requirements.

Applicants are expected to adjust cells in the workbook in order to best represent their concept. Such changes might include, but are not limited to, adjusting values and/or formulas, and/or adding variables. This information must be introduced in tab "2a. Proposed Design" – see Fig.16 for Example 2, Section I.D.2. Typically, the cells to be modified in "2a. Proposed Design" are the ones with brown numbers. Cells with black numbers are calculated by equations.

Applicants must also include every such adjustment as a separate row/item in the "2c. Summary of Changes" tab –see Fig.18 for Example 2, Section I.D.2. This tab includes 4 fields to describe every adjustment made:

- Cell number, which should reference the cell number associated with the adjustment.
- Corresponding variable, which should reference the variable associated with the adjustment.
- Description of change made, which should describe what was done to the cell as part of the adjustment.
- Brief justification of change made, which should describe why the proposed concept would lead to such a change.

If the proposed design needs different equations from the ones in this document, this must be justified in tab 2c. The plots in tabs 1b and 2b are generated automatically from tabs 1a and 2a respectively. Cost of electrical lines and substation are excluded. The case proposed in "1a. Original Design" (Fig.14) and "1b. Original Design Plot" (Fig.15) is Example 1 presented in Section I.D.1. This Metric Space Workbook will be used during ARPA-E's evaluation of Concept Papers.

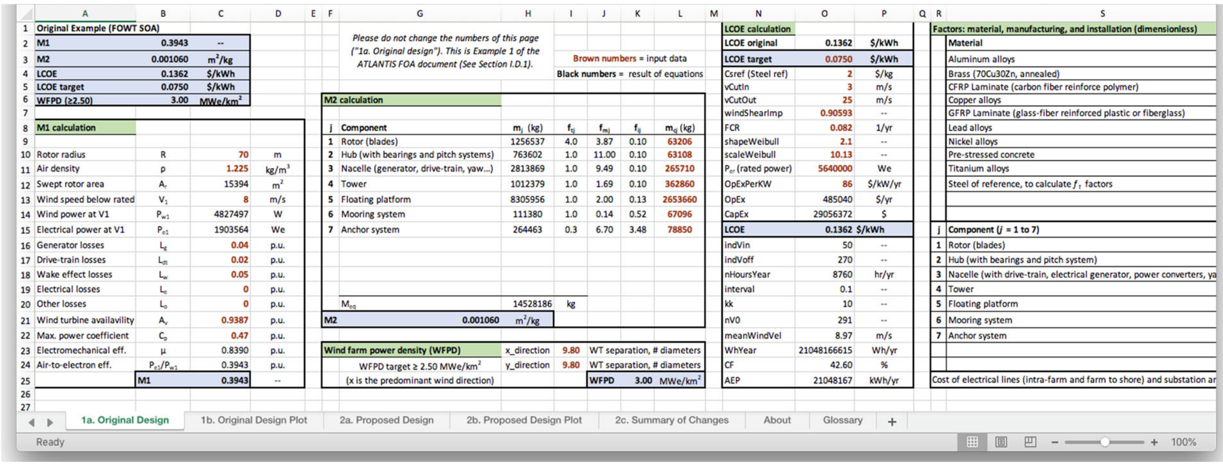

Fig. 14. Tab "1a. Original Design" in document *ATLANTIS_MetricSpaceWorkbook.xlsx*. This is Example 1, Section I.D.1.

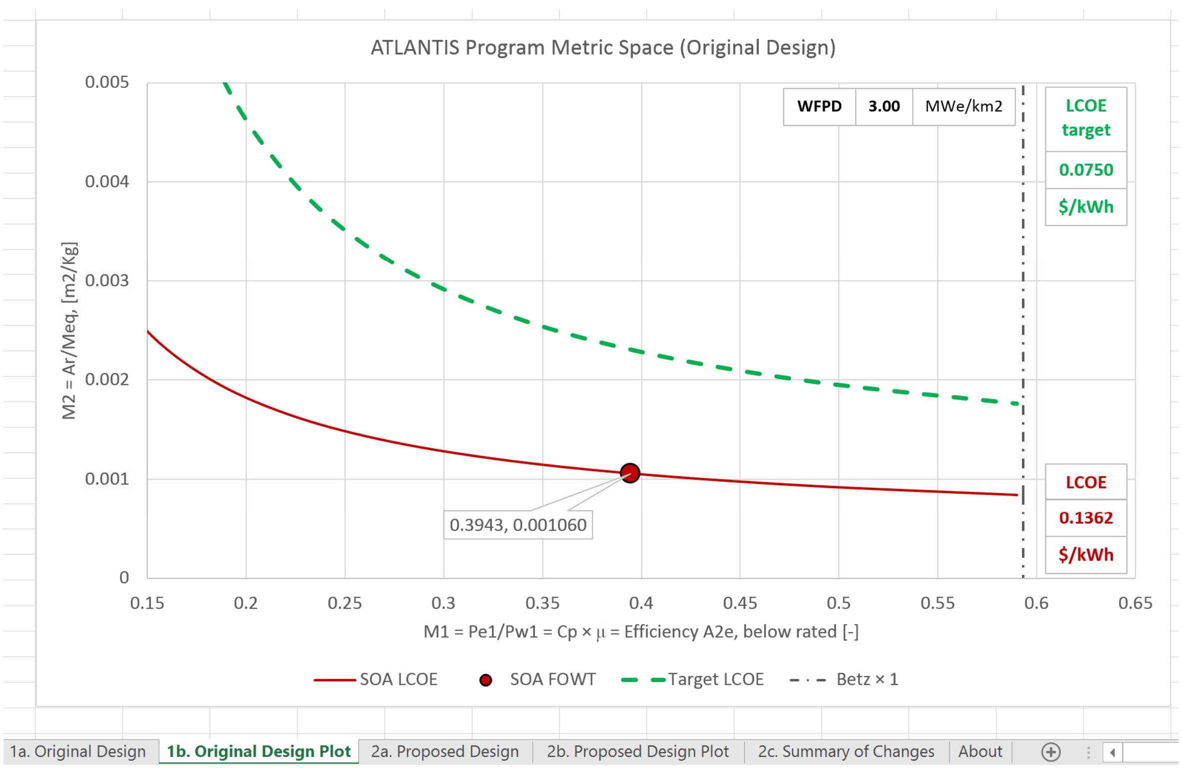

Fig. 15. Tab "1b. Original Design Plot" in document *ATLANTIS_MetricSpaceWorkbook.xlsx.* This is Example 1, Section I.D.1.

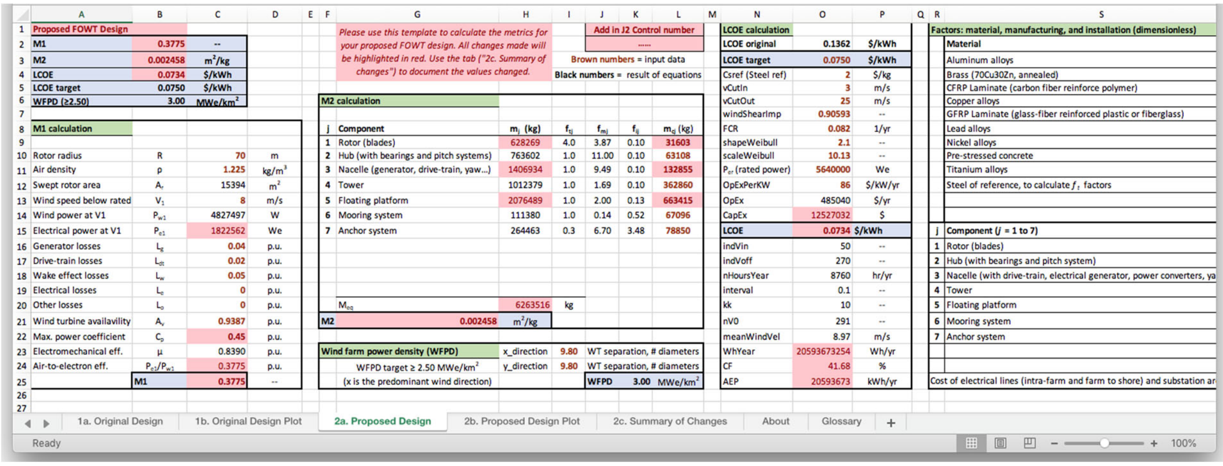

Fig. 16. Tab "2a. Proposed Design" in document *ATLANTIS_MetricSpaceWorkbook.xlsx*. This is Example 2, Section I.D.2.

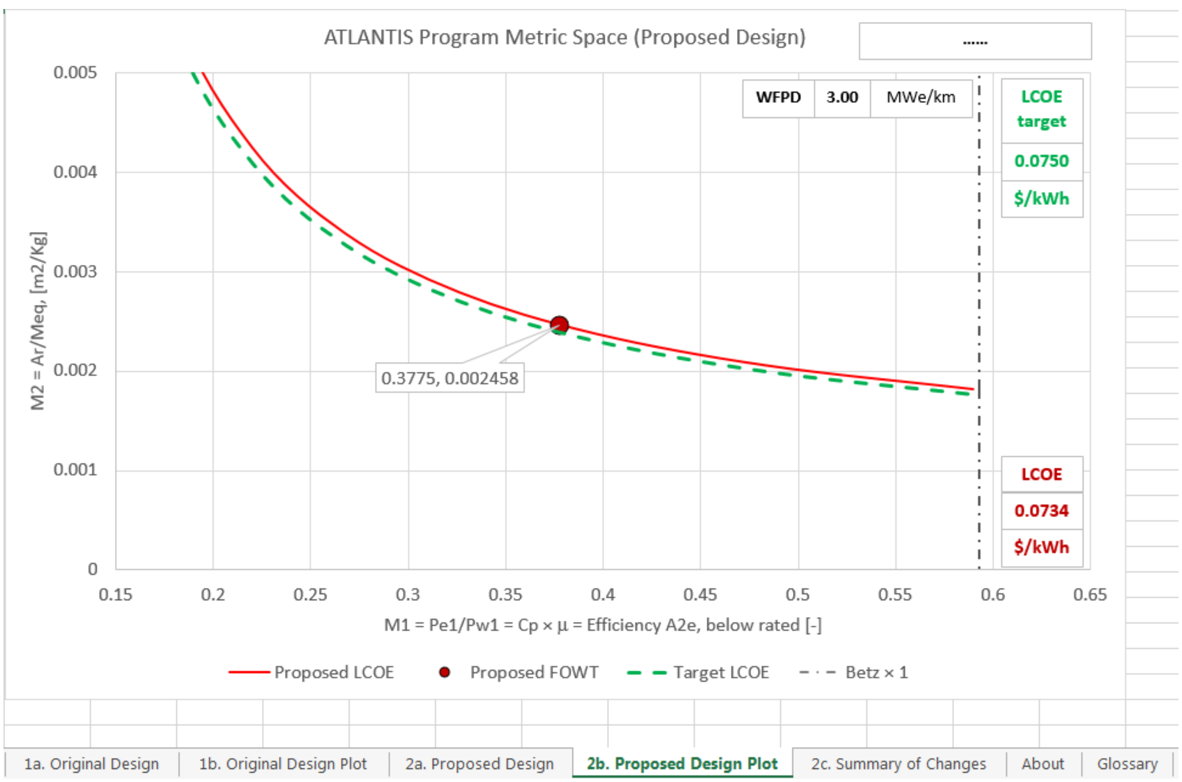

Fig. 17. Tab "2b. Proposed Design Plot" in document *ATLANTIS_MetricSpaceWorkbook.xlsx*. This is Example 2, Section I.D.2.

Summary and justification of changes		This page summarizes the changes between the "Original Design" (Sheet 1a) and the "Proposed Design" (Sheet 2a). Please use Sheet 2a as the basis for information on this sheet, including "cell number"	
Cell number	**Corresponding variable**	**Description of change made**	**Brief justification of change**
L9	*31603*	*Rotor mass (blades) decreases, m1 x 0.5*	*We propose a new blade design that …*
L11	132855	*Nacelle mass (blades) decreases, m3 x 0.5*	*We propose a new generator and drive train design that …*
L13	663415	*Floating platform mass (blades) decreases, m5 x 0.25*	*We propose a new floating platform design that …*
C22	0.45	Cpmax is reduced, from 0.47 to 0.45	The new design reduces the aerodynamic efficiency of the rotor…

Fig. 18. Tab "2c. Summary of Changes" in document *ATLANTIS_MetricSpaceWorkbook.xlsx*. This is Example 2, Section I.D.2.

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

F. INTERGOVERNMENTAL REVIEW

This program is not subject to Executive Order 12372 (Intergovernmental Review of Federal Programs).

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Concept Papers, Full Applications, and Replies to Reviewer Comments must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E may not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications may be deemed noncompliant (see Section III.C.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;
- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

ARPA-E urges Applicants to carefully review their applications and to allow sufficient time for the submission of required information and documents.

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive (see Section III.C of the FOA). ARPA-E also performs a preliminary review of Replies to Reviewer Comments to determine whether they are compliant.

ARPA-E considers a mix of quantitative and qualitative criteria in determining whether to encourage the submission of a Full Application and whether to select a Full Application for award negotiations.

1. CRITERIA FOR CONCEPT PAPERS

(1) *Impact of the Proposed Technology Relative to FOA Targets* (50%) - This criterion involves consideration of the following:

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- Achievement of the technical performance targets defined in Section I.D of the FOA;
- Identification of techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and
- Demonstration of awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

(2) *Overall Scientific and Technical Merit* (50%) - This criterion involves consideration of the following:

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;
- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;
- Clearly defined project outcomes and final deliverables; and
- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement. The above criteria will be weighted as follows:

Impact of the Proposed Technology Relative to FOA Targets	50%
Overall Scientific and Technical Merit	50%

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Concept Papers to encourage to submit a Full Application and which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity of technical personnel in the proposed Project Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;
   e. Technical or commercialization risk; or
   f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
   a. Reduction of US dependence on foreign energy sources;
   b. Stimulation of domestic manufacturing/U.S. Manufacturing Plan;
   c. Reduction of energy-related emissions;
   d. Increase in U.S. energy efficiency;
   e. Enhancement of U.S. economic and energy security; or
   f. Promotion of U.S. advanced energy technologies competitiveness.

III. **Synergy of Public and Private Efforts**.

a. Avoids duplication and overlap with other publicly or privately funded projects;
b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
c. Increases unique research collaborations.

IV. **Low likelihood of other sources of funding.** High technical and/or financial uncertainty that results in the non-availability of other public, private or internal funding or resources to support the project.

V. **High-Leveraging of Federal Funds**. Project leverages Federal funds to optimize advancement of programmatic goals by proposing cost share above the required minimum or otherwise accessing scarce or unique resources.

VI. **High Project Impact Relative to Project Cost.**

2. ARPA-E Reviewers

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

3. ARPA-E Support Contractor

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of

ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

VI. Award Administration Information

A. Award Notices

1. Rejected Submissions

Noncompliant and nonresponsive Concept Papers and Full Applications are rejected by the Contracting Officer and are not merit reviewed or considered for award. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Concept Paper or Full Application was rejected.

2. Concept Paper Notifications

ARPA-E promptly notifies Applicants of its determination to encourage or discourage the submission of a Full Application. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. ARPA-E provides feedback in the notification letter in order to guide further development of the proposed technology.

Applicants may submit a Full Application even if they receive a notification discouraging them from doing so. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. The purpose of the Concept Paper phase is to save Applicants the considerable time and expense of preparing a Full Application that is unlikely to be selected for award negotiations.

A notification letter encouraging the submission of a Full Application does not authorize the Applicant to commence performance of the project. Please refer to Section IV.G.2 of the FOA for guidance on pre-award costs.

3. Full Application Notifications

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2019]

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

Upon the issuance of a FOA, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received that have not already been addressed at the link above. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- ARPA-E will cease to accept questions approximately 10 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted approximately one business day in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- Responses are published in a document specific to this FOA under "CURRENT FUNDING OPPORTUNITIES – FAQS"" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants as necessary and appropriate. As described in Section IV.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. ARPA-E provides Applicants with a notification encouraging or discouraging the submission of a Full Application based on ARPA-E's assessment of the Concept Paper. In addition, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. Other Information

A. Title to Subject Inventions

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions. If they elect to retain title, they must file a patent application in a timely fashion.
- All other parties: The Federal Non-Nuclear Energy Research and Development Act of 1974, 42. U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below)*.
- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues "class patent waivers" under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20%, may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.
- GOGOs are subject to the requirements of 37 C.F.R. Part 501.
- Determination of Exceptional Circumstances (DEC): DOE has determined that exceptional circumstances exist that warrant the modification of the standard patent rights clause for small businesses and non-profit awardees under Bayh-Dole to maximize the manufacture of technologies supported by ARPA-E awards in the United States. The DEC, including a right of appeal, is dated September 9, 2013 and is available at the following link: http://energy.gov/gc/downloads/determination-exceptional-circumstances-under-bayh-dole-act-energy-efficiency-renewable. Please see Section IV.D.7 and VI.B.8 for more information on U.S. Manufacturing Requirements.

B. Government Rights in Subject Inventions

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. Government Use License

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. March-In Rights

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;
- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner;
- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner; or
- The U.S. Manufacturing requirement has not been met.

C. Rights in Technical Data

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

Applicants may not include any Protected Personally Identifiable Information (Protected PII) in their submissions to ARPA-E. Protected PII is defined as data that, if compromised, could cause harm to an individual such as identity theft. Listed below are examples of Protected PII that Applicants must not include in their submissions.

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;
- Mother's maiden name associated with an individual;
- Biometric record associated with an individual;
- Fingerprint;
- Iris scan;
- DNA;
- Medical history information associated with an individual;
- Medical conditions, including history of disease;
- Metric information, e.g. weight, height, blood pressure;
- Criminal history associated with an individual;
- Ratings;
- Disciplinary actions;
- Performance elements and standards (or work expectations) are PII when they are so intertwined with performance appraisals that their disclosure would reveal an individual's performance appraisal;
- Financial information associated with an individual;
- Credit card numbers;
- Bank account numbers; and
- Security clearance history or related information (not including actual clearances held).

E. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

F. OBLIGATION OF PUBLIC FUNDS

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

G. Requirement for Full And Complete Disclosure

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Concept Paper, Full Application, and/or Reply to Reviewer Comments;
- The termination of award negotiations;
- The modification, suspension, and/or termination of a funding agreement;
- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and
- Civil and/or criminal penalties.

H. Retention of Submissions

ARPA-E expects to retain copies of all Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

I. Marking of Confidential Information

ARPA-E will use data and other information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information must be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Concept Paper, Full Application, Reply to Reviewer Comments, or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

> Notice of Restriction on Disclosure and Use of Data:
>
> Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

J. COMPLIANCE AUDIT REQUIREMENT

A prime recipient organized as a for-profit entity expending $750,000 or more of DOE funds in the entity's fiscal year (including funds expended as a Subrecipient) must have an annual compliance audit performed at the completion of its fiscal year. For additional information, refer to Subpart F of: (i) 2 C.F.R. Part 200, and (ii) 2 C.F.R. Part 910.

If an educational institution, non-profit organization, or state/local government is either a Prime Recipient or a Subrecipient, and has expended $750,000 or more of Federal funds in the entity's fiscal year, the entity must have an annual compliance audit performed at the completion of its fiscal year. For additional information refer to Subpart F of 2 C.F.R. Part 200.

IX. GLOSSARY

Applicant: The entity that submits the application to ARPA-E. In the case of a Project Team, the Applicant is the lead organization listed on the application.

Application: The entire submission received by ARPA-E, including the Concept Paper, Full Application, and Reply to Reviewer Comments.

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency within the U.S. Department of Energy.

Cost Sharing: is the portion of project costs from non-Federal sources that are borne by the Prime Recipient (or non-Federal third parties on behalf of the Prime Recipient), rather than by the Federal Government.

Deliverable: A deliverable is the quantifiable goods or services that will be provided upon the successful completion of a project task or sub-task.

DOE: U.S. Department of Energy.

DOE/NNSA: U.S. Department of Energy/National Nuclear Security Administration

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

GOCOs: U.S. Government Owned, Contractor Operated laboratories.

GOGOs: U.S. Government Owned, Government Operated laboratories.

Milestone: A milestone is the tangible, observable measurement that will be provided upon the successful completion of a project task or sub-task.

Prime Recipient: The signatory to the funding agreement with ARPA-E.

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing inventive supportive work that is part of an ARPA-E project.

Standalone Applicant: An Applicant that applies for funding on its own, not as part of a Project Team.

Subject Invention: Any invention conceived or first actually reduced to practice under an ARPA-E funding agreement.

Task: A task is an operation or segment of the work plan that requires both effort and resources. Each task (or sub-task) is connected to the overall objective of the project, via the achievement of a milestone or a deliverable.

Total Project Cost: The sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

TT&O: Technology Transfer and Outreach. (See Section IV.G.8 of the FOA for more information).