FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

SUBMARINE HYDROKINETIC AND RIVERINE KILO-MEGAWATT SYSTEMS (SHARKS)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002334
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	April 9, 2020
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, May 15, 2020
Submission Deadline for Concept Papers:	9:30 AM ET, May 27, 2020
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:	November 2020
Total Amount to Be Awarded	Approximately $38 million, subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002334 and DE-FOA-0002335.
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 4 pages in length including graphics, figures, and/or tables. Concept Papers are allowed an Appendix with maximum length equal to 1 page per case study (S1 to S4) for which the design meets the LCOE targets. Each page of the Appendix may contain a plot of the Metric Space for the new design, and the descriptions and justifications for the parameters used to calculate the M1 and M2 metrics and LCOE isoline for the particular case study. The Concept Paper must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities ○ Appendix • Each Applicant must fill out and submit a Metric Space Workbook for each application (S1 to S4) that the project is claiming the new device meets the LCOE targets for. Applicants are strongly encouraged to use the SHARKS Metric Space Workbooks named *S1_SHARKS_MetricSpaceWorkbook.xlsx*, *S2_SHARKS_MetricSpaceWorkbook.xlsx*, *S3_SHARKS_MetricSpaceWorkbook.xlsx*, and *S4_SHARKS_MetricSpaceWorkbook.xlsx* that are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov).	Mandatory	IV.C	9:30 AM ET, May 27, 2020
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]	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 to 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 or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an 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 SHARKS[2] Program seeks to develop new designs for economically attractive Hydrokinetic Turbines (HKT) for tidal and riverine currents. Tidal and riverine energy resources are renewable, have the advantage of being highly reliable and predictable, and are often co-located with demand centers, while HKT devices can be designed with low visual profiles and minimal environmental impact. These energy-producing devices are also uniquely suited for micro-grid applications, supplying energy to remote communities and other "blue economy" or utility-scale applications. This Program is aimed at applying Control Co-Design (CCD), Co-Design (CD) and Designing-for-OpEx (DFO) methodologies to HKT design. These three design methodologies require the concurrent (rather than sequential) application of a wide range of disciplines, starting at the conceptual design stage. The technical challenges that inhibit the development of highly efficient HKT designs are mutually dependent, and require expertise

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

[2] SHARKS is the acronym for "*Submarine Hydrokinetic And Riverine Kilo-megawatt Systems.*"

from a range of scientific and engineering fields for optimization. These codependent technical challenges make HKT design a perfect candidate for CCD, CD and DFO, and will necessitate the formation of multi-disciplinary teams to resolve their inherently coupled design considerations.

This Program seeks to fund the development of new HKT designs that include, but are not limited to, hydrodynamics, mechanical structures, materials, hydro-structural interactions, electrical energy conversion systems, control systems, numerical simulations and experimental validations. Simultaneous consideration of the full problem can result in operational designs that are optimal, and suitable for deployment in a wide variety of tidal and riverine energy environments. The SHARKS Program seeks new HKT designs that are optimized within a *Metric Space* that quantifies the swept rotor area per unit of equivalent mass and the water-to-electron power generation efficiency, while navigating across LCOE (*Levelized Cost of Energy*) contours of constant value or isolines. Projects in this Program will develop radically new HKT designs that offer a significant reduction in LCOE (~60%) compared to the current state-of-the-art –see Table 9. These designs will need to reduce the LCOE through a multi-faceted approach that includes increasing generation efficiency, increasing rotor area per unit of equivalent system mass, lowering operating and maintenance costs, and minimizing potential negative impacts on the surrounding environment, among other considerations. It is expected that projects will include physical testing of the critical systems and sub-systems in the water to prove the assumptions underlying the device's design.

2. MOTIVATION

Hydrokinetic energy is a renewable energy resource whose characteristics present unique opportunities and benefits. It is forecastable over long time periods and in many cases co-located with existing electrical loads. The short- and long-term variations in power (daily and seasonal) of hydrokinetic systems are not typically time-correlated with other sources of renewable energy. This allows them to complement other renewable energy generation systems that are already integrated into grids. The distribution of the resource, including its proximity to population centers of various sizes, gives it the potential to be used in grids that range from micro-grids in remote areas that lack economically attractive sources of power to utility scale applications.

The scale of the hydrokinetic energy resource is also considerable. The theoretical amount of energy available in tidal streams, ocean currents, and riverine currents is estimated at 2051 TWh/yr (7 Quad/yr in Table 1). Even when conservative estimates are made to determine the amount of the resource that is practically extractable (i.e., once areas with environmental, social and economic conflicts are removed), there is 615 TWh/yr (2.1 Quad/yr in Table 1) of harvestable energy. It is important to note that the full scale of this resource is difficult to accurately quantify. There are limitations to the computational models that are used to analyze it, such as the characterization of the tidal zones (with significant variation in site-to-site bathymetry) and the assumed characteristics of riverbeds. There are fewer accessible observation sites compared to other renewable sources such as wind energy, which makes it difficult to correlate and validate numerical models with field data. Finally, some assumptions made to estimate the amount of power that is practically extractable, such as the possibility of sharing the water for different needs, or the minimum current velocities needed for HKTs to operate, can be improved via technological innovation, expanding the percentage of power that can be practically harvested. This indicates that the actual size of these theoretical and practical resources is likely larger than current estimations.

***Table 1**: Hydrokinetic Energy Resources in the U.S., both Theoretically Extractable and Practically Extractable (once areas with environmental and social conflicts are removed)*[3]

	Quads of Energy (Theoretical)	Quads of Energy (Practical)
Tidal Streams	1.5	1.1
Riverine Currents	4.7	0.4
Ocean Currents	0.7	0.6
Total	**7.0**	**2.1**

Hydrokinetic energy also has the potential to serve a market larger than just providing power to conventional utility scale electrical grids. The Organization for Economic Co-operation and Development (OECD) predicts that the international "Blue Economy" will grow into a three trillion dollar industry by 2030[4]. The World Bank defines the Blue Economy as "*the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystems*." This industry captures technology integrated into expanding ocean-based infrastructure for needs ranging from climatological observation, aquaculture, desalination, ocean floor and seawater mining, disaster recovery, powering isolated communities, and autonomous underwater vehicle support. The nature of these markets means they are co-located with marine energy sources. This rapidly expanding market sector will require power, and hydrokinetic energy is uniquely suited to fill that need.

Despite the attractive qualities of marine and hydrokinetic energy, it remains a largely untapped resource. This is primarily due to a high *levelized cost of energy* (LCOE) for current hydrokinetic energy conversion systems. State of the art technology ranges from about \$0.17/kWh and \$0.10/kWh for riverine and tidal stream systems at utility scale respectively, to \$0.21/kWh and \$0.25/kWh for riverine and tidal stream systems in remote areas respectively (all without submarine electrical lines and substations) –see Section I.C.2. This high cost of energy is driven by technical challenges and harsh environmental conditions that have prevented designs from maturing and converging within the industry. Hydrokinetic energy systems must work to accomplish the technical feats that helped reduce the cost of more mature systems, such as wind turbines, including increasing their efficiency and their swept-area-to-mass ratio; however, they also need to operate in harsh aquatic environments where they may encounter marine and riverine debris, ice, and wildlife, requiring expensive

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[3] Quadrennial Energy Review 2015: Marine and Hydrokinetic Energy, U.S. Department of Energy, Washington, DC.
[4] Organization for Economic Co-Operation and Development, (2016). The Ocean Economy in 2030. OCED Publishing.

installation and maintenance. This is made more difficult given that these systems need to harvest energy from a variety of flow average speeds and distributions.

Overcoming these challenges requires a multi-disciplinary approach. The low technical readiness of hydrokinetic energy systems means that it is necessary to consider the holistic problem space, including hydrodynamics, structural dynamics, control systems, power electronics, grid connections, and the optimization of performance alongside the minimization of negative effects on the environment, all with a system-level approach. Currently the industry lacks computer tools that facilitate these multi-disciplinary CCD, CD and DFO methodologies. Moreover, many proposed systems have not moved beyond the "paper study" phase of design. Consequently, this program aims to make a transformational change in the LCOE of hydrokinetic energy systems by addressing these industry-wide limitations. ARPA-E seeks to fund the development of new system designs, optimized for deployment in tidal streams, riverine currents, or both, that represent a radical improvement over the state-of-the art, along with experimental validation of key novel components as detailed later in this document. To this end, it is necessary that HKT designs work to address the following challenges:

1) An increase in the turbine and/or array generation efficiency.
2) Maximized rotor area per unit of equivalent mass.
3) A drastic reduction in the operation and maintenance, installation and decommissioning costs, possibly including but not limited to autonomous methods of installation, predictive maintenance and/or remote diagnostics, and debris avoidance measures.
4) Approaches to minimize the environmental impact of the systems, possibly including but not limited to autonomous sensing of aquatic wildlife presence, reduction of effects on sediment transport in the local ecosystem, minimization of likelihood of collisions with marine species, minimization of acoustic noise and prevention of water pollution.
5) Testing *in water*, to prove their underlying performance and operational assumptions.

C. METRIC SPACE DEFINITION, CASE STUDIES AND PERFORMANCE TARGETS

1. METRIC SPACE DEFINITION

The SHARKS Program uses the *LCOE Metric Space*[5,6] developed for the ARPA-E's ATLANTIS Program. This two-dimensional *Metric Space* considers the power generation efficiency and the swept-rotor-area per equivalent mass of the system (m^2/kg), which are internal properties of the machine, and guides the research to navigate across resulting LCOE isolines –see Figs. 1 and 3 to 7. This *Metric Space*, detailed in this Section, facilitates the application of CCD, CD and DFO

[5] Garcia-Sanz, M., (2020). A Metric Space with LCOE Isolines for Research Guidance in wind and hydrokinetic energy systems. Wind Energy, Vol.23, No.2, pp.291-311, Wiley.
[6] ARPA-E ATLANTIS Program for Floating Offshore Wind Turbines, Founding Opportunity Announcement. https://arpa-e.energy.gov/?q=arpa-e-programs/atlantis

paradigms and will help ARPA-E evaluate new design concepts. All the variables and parameters of this Section are expressed in the Metric System.

Metric M1

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 hydrokinetic turbine to the internal grid of the system array (output of the hydrokinetic turbine) in Watts –see eq.(2). P_{w1} is the power of the water in Watts –see eq.(3). Both powers, P_{e1} and P_{w1}, are calculated at the same below-rated water flow speed V_1 (e.g., V_1 = 1.4 m/s), which is selected so that the maximum power point tracking (MPPT) control strategy is keeping the hydrodynamic 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 hydrodynamic interaction of turbines in the array, electrical losses L_e (substation and electrical lines, intra-array and array-to-shore), hydrokinetic turbine availability A_v and other losses L_o –see eq.(5). In summary, the main equations for M1 are:

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

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

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

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

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

where:

→ ρ = 1000 or 1025 kg/m^3 is the density of the water in the river or sea, respectively
→ A_r = swept area of the rotor (in m^2) [7]
→ V_1 is the selected undisturbed upstream below-rated water velocity (for example = 1.4 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 hydrodynamic interaction of turbines in the array,
- L_e: electrical losses (substation and electrical lines, intra-array and array-to-shore),
- L_o: other losses, including cavitation effects and other aspects,
- A_v: availability, which also considers the months per year the HKT is in the water.

Physically speaking, M1 represents the power generation efficiency of the hydrokinetic turbine ($C_p\ \mu$), from the upstream-undisturbed water to the electrical output of the turbine. Also, M1 is

[7] For both, Parallel-Axis Hydrokinetic Turbines (PAHKT) and Orthogonal-Axis Hydrokinetic Turbines (OAHKT), A_r is the area of the cross-section of the rotor, perpendicular to the water direction. For Kite-type Energy Systems, A_r is the area of the annular path described by the tethered system.

proportional to the electrical power per unit area of the rotor (W/m^2) at the selected below rated water speed V_1: i.e., M1 = $k\ (P_{e1}/A_r)$, with $k = 1/(0.5\ \rho\ V_1^3)$. [8]

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 HKT –see eq.(6). M_{eq} is the equivalent mass of steel (*steel-of-reference* type) of the HKT in kilograms –see eqs.(7) and (8),

$$M_2 = \frac{A_r}{M_{eq}} \quad (6)$$

$$M_{eq} = \sum_{j=1}^{z} m_j \quad (7)$$

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

where: f_t is the material factor, f_m is the manufacturing factor, f_i is the installation factor, m_c is the mass of the component in kg, and z is the number of main components for the HKT.[9]

The equivalent mass M_{eq} is typically composed of six elements, z = 6, m_j with j = 1 to z, which represent each major component of the HKT from the water flow to the electrical output: m_1 = rotor (blades, hub), m_2 = nacelle (generator, drive-train, PTO, yaw, bearings, pitch, …), m_3 = structure (tower, cross-arm, columns, ...), m_4 = floating system (floaters, ballast, …), m_5 = mooring system (ropes, connection, …), and m_6 = anchoring/foundation system, all in kg (note that the machine could be composed of other elements). 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 ($/kg) divided by the cost of one kilogram of *steel-of-reference* C_{sref} ($/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

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

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

[9] In case of arrays or 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 = 6 for the HKT system (see Tables 3-6) and *n* the number of turbines.

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* C_{sref} ($/kg). See values in Tables 3 to 8.

LCOE Isolines

LCOE is a function of the internal properties of the machine (M1 and M2) and additional external factors (site, flow velocity distribution, economic rates and costs, etc.). The LCOE expression depends on 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).

$$LCOE = \frac{FCR\ CapEx + OpEx}{AEP} \quad (9)$$

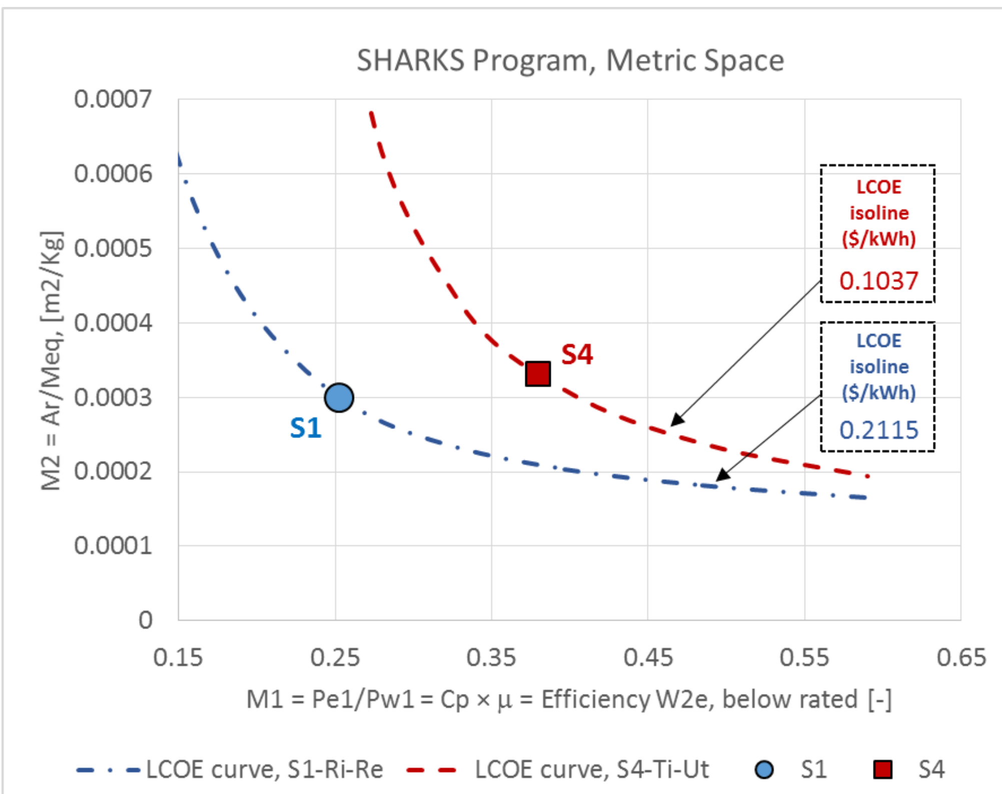

Fig. 1. Metric Space example.

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 for a fixed swept area, CapEx decreases, and LCOE decreases ($M_2 \uparrow \rightarrow CapEx \downarrow \rightarrow LCOE \downarrow$).

Putting the two metrics M1 and M2 together in a two-dimension orthogonal space, we can identify LCOE contours of constant value or isolines for each case study. Figure 1 shows the Metric Space with the LCOE isolines of two systems, a riverine energy system in a remote area (S1) and a tidal energy system at utility scale (S4), both in Alaska. In these two examples, the calculations exclude the substation costs and the electrical line costs (intra-array or array -to-shore lines). More details are provided in the next Sections.

2. Case studies

The SHARKS Program defines four case studies, as shown in Table 2. They include small HKTs in remote areas without grid connection, both for Riverine (S1) and Tidal (S2) currents, and large utility scale HKTs for grid connection, both for Riverine (S3) and Tidal (S4) currents.

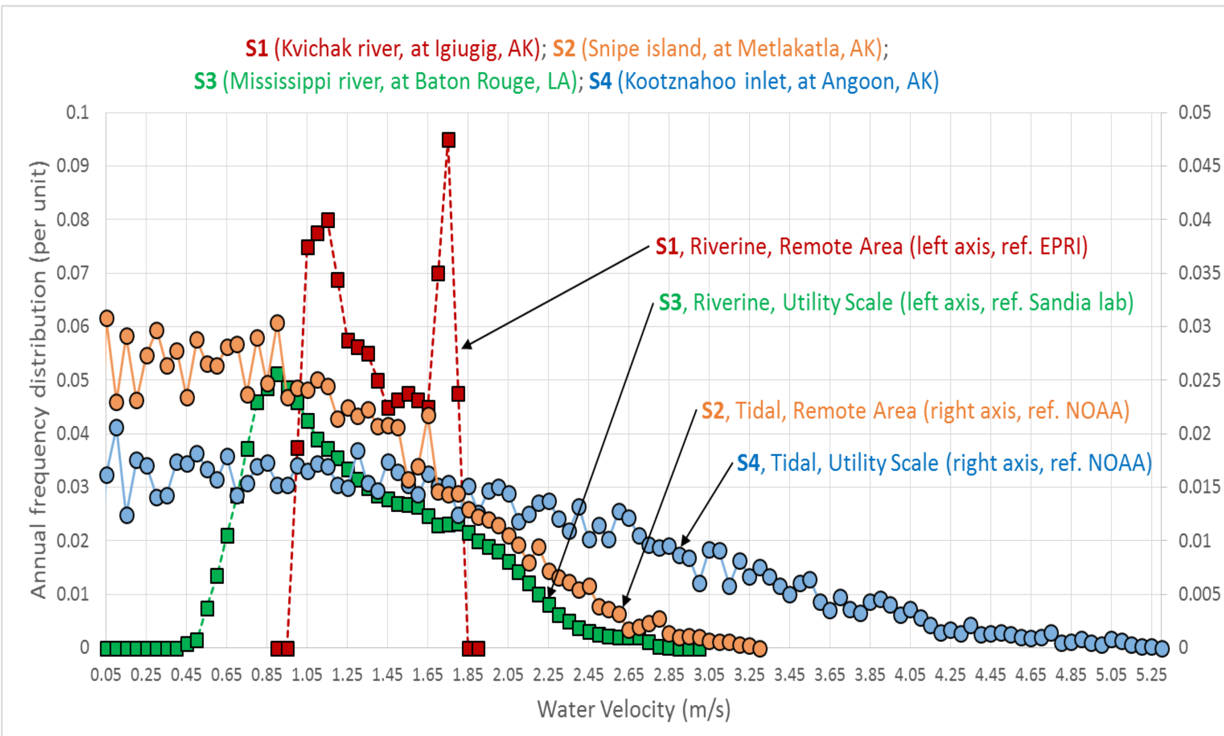

Fig. 2. Annual frequency distribution of water velocity for sites in the four case studies.

***Table 2**: Case studies*

	Riverine Currents	Tidal Streams
Remote areas (for micro-grid)	**S1**	**S2**
Utility scale (connected to the grid)	**S3**	**S4**

The selected sites for the analysis are: the Kvichak river at Igiugig, in Alaska[10], for S1; the Snipe island at Metlakatla, in Alaska[11], for S2; the Mississippi river at Baton Rouge, in Louisiana[12], for S3; and the Kootznahoo inlet at Angoon, in Alaska[13], for S4. Figure 2 shows the annual frequency distribution of the water velocity for these four sites.

System S1. (*Riverine energy system for a remote area*)

The Metric Space for a riverine energy system in a remote area in Alaska is shown in Fig.3. Details of the calculations are in the document "S1_SHARKS_MetricSpaceWorkbook.xlxs". The metrics M1 and M2 (circle) and the associated LCOE (solid line) are calculated next.

- *Metric M1*:
  The HKT of this example has a hydrodynamic coefficient of C_{pmax} = 0.45, efficiency losses of L_g = 0.03, L_{dt} = 0.035, L_w = 0, L_e = 0 and L_o = 0.0298, and an availability of A_v = 0.6192, which includes the limitation that the machine is in the water only 8 months/year due to potential harsh conditions during the ice melting season. Applying eqs.(4) and (5) gives C_p = 0.45 and μ = 0.5623, which in eq.(1) gives M1 = $C_p \mu$ = 0.2530.

- *Metric M2*:
  In addition, the turbine has a swept area of A_r = 7.07 m^2, and the masses and factors shown in Table 3 –see also Tables 7, 8. Applying eqs.(7) and (8) results in M_{eq} = 23,621 kg, which with the swept area A_r = 7.07 m^2 gives a metric M2 = 0.0299×10^{-2} m^2/kg.

Table 3. Information for M_{eq}, System S1

j	*Component*	m_j	f_{tj}	f_{mj}	f_{ij}	m_{cj}
1	Rotor (blades, hub)	3849	4.0	2.80	0.06	249
2	Nacelle (generator, drive-train, PTO, yaw, bearings, pitch…)	3461	1.0	2.80	0.06	896
3	Structure (tower, cross-arm, columns...)	3992	1.0	8.03	0.06	439
4	Floating system (floaters, ballast…)	4751	1.0	7.84	0.06	534
5	Mooring system (ropes, connection…)	244	1.0	1.72	0.12	86
6	Anchoring/foundation system	7324	0.3	1.72	0.12	8598

[10] Kvichak river at Igiugig, in Alaska. Frequency distribution from reference: Previsic M., Bedard, R., Polagye B. (2008). *System Level Design, Performance, Cost and Economic Assessment – Alaska River In-Stream Power Plants*. EPRI RP 006 Alaska.
[11] Snipe island at Metlakatla, in Alaska. Frequency distribution from reference: https://tidesandcurrents.noaa.gov/noaacurrents/Regions
[12] Mississippi river at Baton Rouge, in Louisiana. Frequency distribution from reference: Neary V., Previsic M., Jepsen R. et al. (2014). Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies. Sandia National Laboratories. Technical Report SAND2014-9040.
[13] Kootznahoo inlet at Angoon, in Alaska. Frequency distribution from reference: https://tidesandcurrents.noaa.gov/noaacurrents/Regions

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

  A pair of metrics (M1, M2) can give different LCOE results. The LCOE depends on other external parameters related to the site and economic factors. In this example, choosing the parameters given below, the associated CapEx, AEP and LCOE are: CapEx = 47,242 \$/kWe, AEP = 23,254 kWh/yr (CF = 50.09 %), and LCOE = \$0.2115/kWh (the substation and the electrical line costs are not included). The parameters are:

  → Rated electrical power per turbine, P_{er} = 5.3 kWe, at Rated water velocity V_r = 1.85 m/s
  → Number of turbines in array = 1
  → Site: Kvichak river at Igiugig, in Alaska, with water velocities of $V_{average}$ = 1.39 m/s, $V_{cut\text{-}in}$ = 1 m/s, and $V_{cut\text{-}out}$ = 1.8 m/s, and average depth of 2.4 m and width of 152 m.
  → OpEx = 197 \$/kWe/yr
  → Fixed charge rate, FCR = 8.2%
  → Project number of years = 20 years
  → Cost of *steel-of-reference* = \$2.0 /kg (high corrosion resistant austenitic stainless steel)

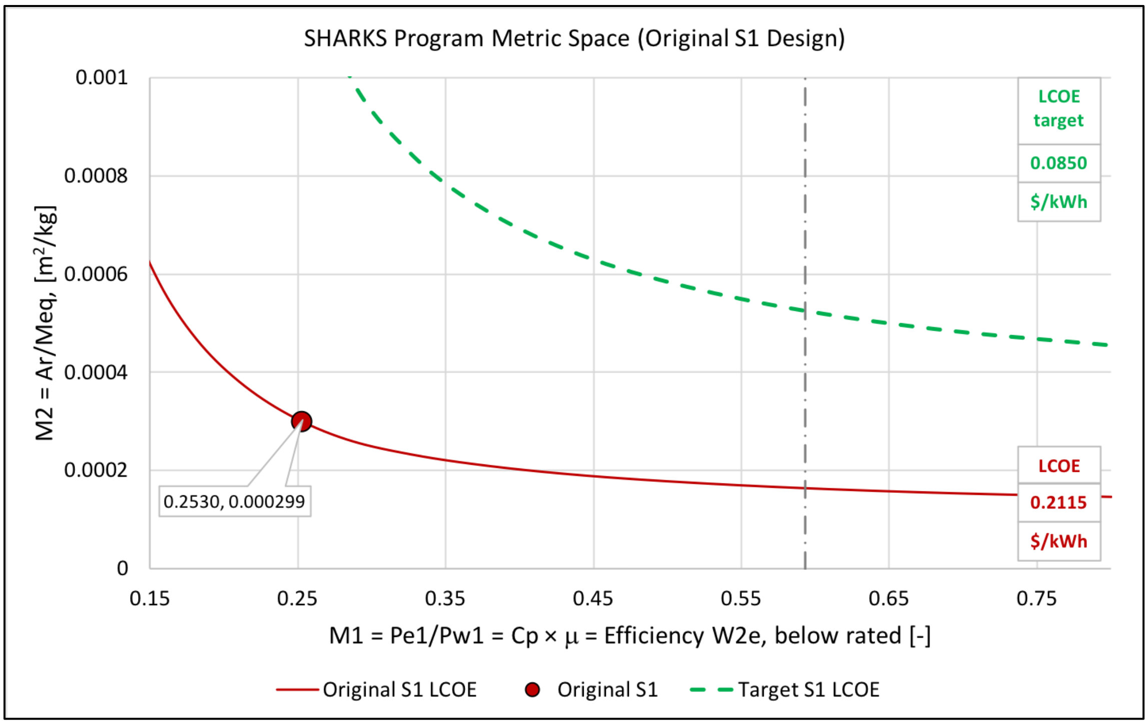

Fig. 3. System S1. A riverine energy system for a remote area.
Kvichak river at Igiugig, Alaska.

System S2. (*Tidal energy system for a remote area*)

The Metric Space for a tidal energy system in a remote area in Alaska is shown in Fig.4. Details of the calculations are in the document "S2_SHARKS_MetricSpaceWorkbook.xlxs". The metrics M1 and M2 (circle) and the associated LCOE (solid line) are calculated next.

- *Metric M1*:
  The HKT of this example has a hydrodynamic coefficient of C_{pmax} = 0.45, efficiency losses of L_g = 0.03, L_{dt} = 0.035, L_w = 0, L_e = 0 and L_o = 0.0298, and availability of A_v = 0.9288. Applying eqs.(4) and (5) gives C_p = 0.45 and μ = 0.8435, which in eq.(1) gives M1 = C_p μ = 0.3796.

- *Metric M2*:
  In addition, the turbine has a swept area of A_r = 21.21 m^2, and the masses and factors shown in Table 4 –see also Tables 7, 8. Applying eqs.(7) and (8) results in M_{eq} = 70,619 kg, which with the swept area A_r = 21.21 m^2 gives a metric M2 = 0.0300×10^{-2} m^2/kg.

Table 4. Information for M_{eq}, System S2

j	*Component*	m_j	f_{tj}	f_{mj}	f_{ij}	m_{cj}
1	Rotor (blades, hub)	11546	4.0	2.80	0.06	747
2	Nacelle (generator, drive-train, PTO, yaw, bearings, pitch…)	10383	1.0	2.80	0.06	2687
3	Structure (tower, cross-arm, columns…)	11975	1.0	8.03	0.06	1317
4	Floating system (floaters, ballast…)	14254	1.0	7.84	0.06	1601
5	Mooring system (ropes, connection…)	488	1.0	1.72	0.12	172
6	Anchoring/foundation system	21973	0.3	1.72	0.12	25794

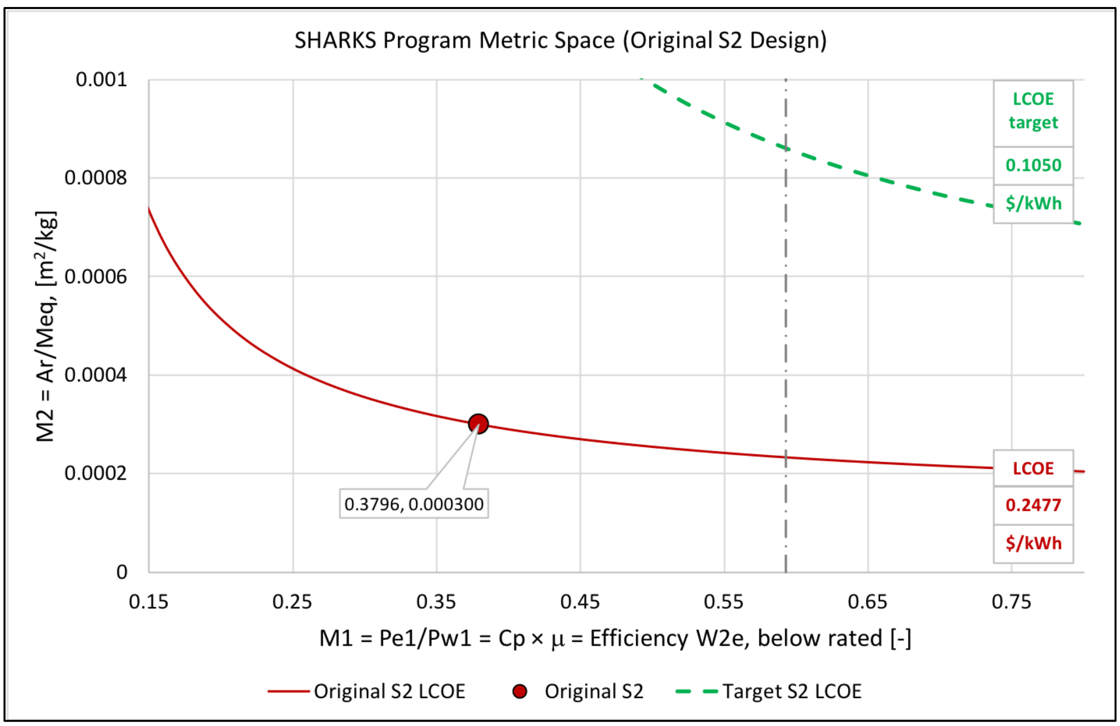

Fig. 4. System S2. A tidal energy system for a remote area.
Snipe Island at Metlakatla, Alaska.

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

  A pair of metrics (M1, M2) can give different LCOE results. The LCOE depends on other external parameters related to the site and economic factors. In this example, choosing the parameters given below, the associated CapEx, AEP and LCOE are: CapEx = 141,238 $/kWe, AEP = 62,655 kWh/yr (CF = 35.76 %), and LCOE = $0.2477/kWh (the substation and the electrical line costs are not included). The parameters are:

  → Rated electrical power per turbine, P_{er} = 20 kWe, at Rated water velocity V_r = 1.70 m/s
  → Number of turbines in array = 1
  → Site: Snipe Island at Metlakatla, in Alaska, with water velocities of $V_{average}$ = 1.04 m/s, $V_{cut\text{-}in}$ = 0.55 m/s, and $V_{cut\text{-}out}$ = 3.1 m/s, and low-tide depth of 60 m and width of 3500 m.
  → OpEx = 197 $/kWe/yr
  → Fixed charge rate, FCR = 8.2%
  → Project number of years = 20 years
  → Cost of *steel-of-reference* = $2.0 /kg (high corrosion resistant austenitic stainless steel)

System S3. (*Riverine energy system at utility scale*)

The Metric Space for a riverine energy system at utility scale in Louisiana is shown in Fig.5. Details of the calculations are in the document “S3_SHARKS_MetricSpaceWorkbook.xlxs”. The metrics M1 and M2 (circle) and the associated LCOE (solid line) are calculated next.

- *Metric M1*:
  The HKT of this example has a hydrodynamic coefficient of C_{pmax} = 0.45, efficiency losses of L_g = 0.03, L_{dt} = 0.035, L_w = 0, L_e = 0 and L_o = 0.0298, and availability of A_v = 0.9288. Applying eqs.(4) and (5) gives C_p = 0.45 and μ = 0.8435, which in eq.(1) gives M1 = $C_p\ \mu$ = 0.3796.

- *Metric M2*:
  In addition, the turbine has a swept area of A_r = 61.44 m^2, and the masses and factors shown in Table 5 –see also Tables 7, 8. Applying eqs.(7) and (8) results in M_{eq} = 184,473 kg, which with the swept area A_r = 61.44 m^2 gives a metric M2 = 0.0333×10^{-2} m^2/kg.

Table 5. Information for M_{eq}, System S3

j	Component	m_j	f_{tj}	f_{mj}	f_{ij}	m_{cj}
1	Rotor (blades, hub)	30056	4.0	2.80	0.06	1944
2	Nacelle (generator, drive-train, PTO, yaw, bearings, pitch…)	27029	1.0	2.80	0.06	6995
3	Structure (tower, cross-arm, columns...)	31175	1.0	8.03	0.06	3427
4	Floating system (floaters, ballast…)	37106	1.0	7.84	0.06	4169
5	Mooring system (ropes, connection…)	1907	1.0	1.72	0.12	671
6	Anchoring/foundation system	57200	0.3	1.72	0.12	67148

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

  A pair of metrics (M1, M2) can give different LCOE results. The LCOE depends on other external parameters related to the site and economic factors. In this example, choosing the parameters given below, the associated CapEx, AEP and LCOE are: CapEx = 368,946 $/kWe, AEP = 298,962 kWh/yr (CF = 34.13 %), and LCOE = $0.1671/kWh (the substation and the electrical line costs are not included). The parameters are:

  → Rated electrical power per turbine, P_{er} = 100 kWe, at Rated water velocity V_r = 2.05 m/s
  → Number of turbines in array = 1
  → Site: Mississippi river at Baton Rouge, in Louisiana, with water velocities of $V_{average}$ = 1.31 m/s, $V_{cut\text{-}in}$ = 0.5 m/s, and $V_{cut\text{-}out}$ = 2.85 m/s, average depth of 12 m and width of 800 m.
  → OpEx = 197 $/kWe/yr
  → Fixed charge rate, FCR = 8.2%
  → Project number of years = 20 years
  → Cost of *steel-of-reference* = $2.0 /kg (high corrosion resistant austenitic stainless steel)

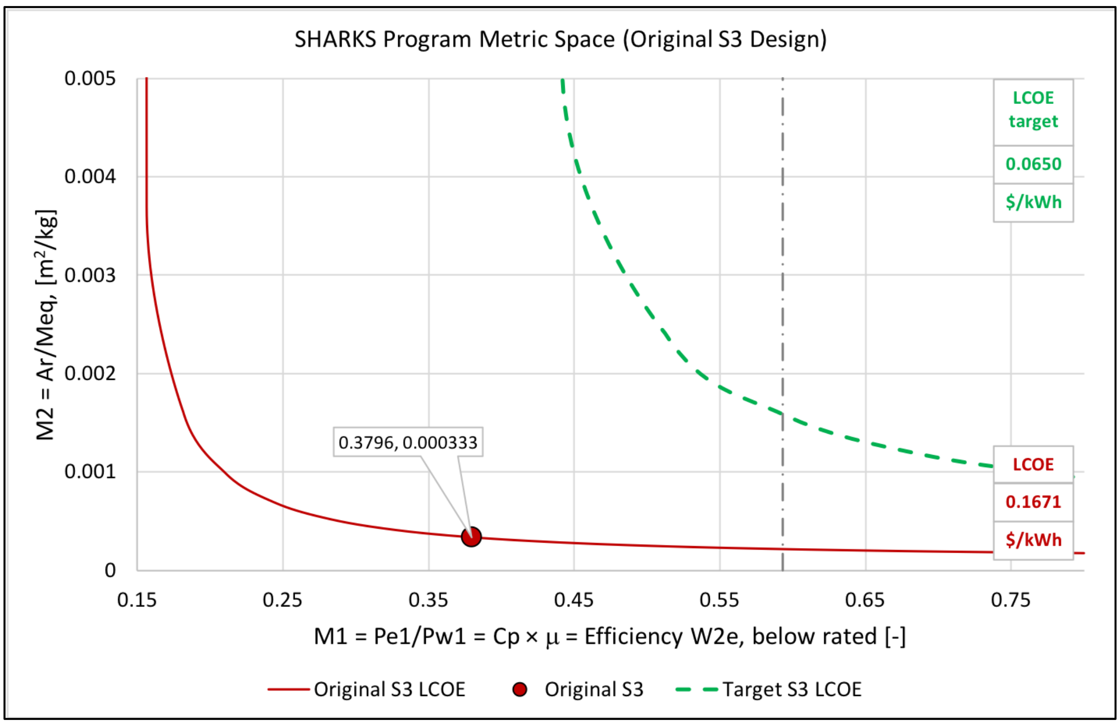

Fig. 5. System S3. A riverine energy system at utility scale.
Mississippi river at Baton Rouge, Louisiana.

System S4. (*Tidal energy system* at utility scale)

The Metric Space for a tidal energy system at utility scale in Alaska is shown in Fig.6. Details of the calculations are in the document "S4_SHARKS_MetricSpaceWorkbook.xlxs". The metrics M1 and M2 (circle) and the associated LCOE (solid line) are calculated next.

- *Metric M1*:
  The HKT of this example has a hydrodynamic coefficient of C_{pmax} = 0.45, efficiency losses of L_g = 0.03, L_{dt} = 0.035, L_w = 0, L_e = 0 and L_o = 0.0298, and availability of A_v = 0.9288. Applying eqs.(4) and (5) gives C_p = 0.45 and μ = 0.8435, which in eq.(1) gives M1 = $C_p\ \mu$ = 0.3796.

- *Metric M2*:
  In addition, the turbine has a swept area of A_r = 100 m^2, and the masses and factors shown in Table 6 –see also Tables 7, 8. Applying eqs.(7) and (8) results in M_{eq} = 300,737 kg, which with the swept area A_r = 100 m^2 gives a metric M2 = 0.0333×10^{-2} m^2/kg.

Table 6. Information for M_{eq}, System S4

j	*Component*	m_j	f_{tj}	f_{mj}	f_{ij}	m_{cj}
1	Rotor (blades, hub)	47492	4.0	2.80	0.06	3073
2	Nacelle (generator, drive-train, PTO, yaw, bearings, pitch…)	51958	1.0	2.80	0.06	13446
3	Structure (tower, cross-arm, columns…)	49260	1.0	8.03	0.06	5416
4	Floating system (floaters, ballast…)	58631	1.0	7.84	0.06	6587
5	Mooring system (ropes, connection…)	3013	1.0	1.72	0.12	1061
6	Anchoring/foundation system	90383	0.3	1.72	0.12	106101

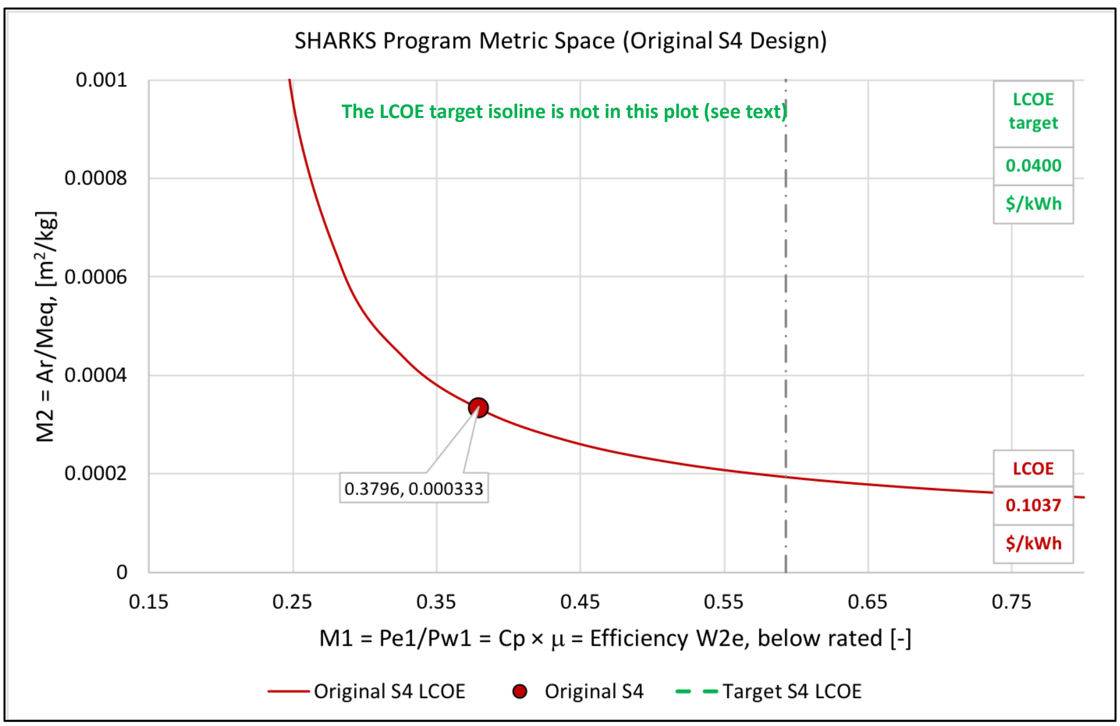

Fig. 6. System S4. A tidal energy system at utility scale.
Kootznahoo Inlet at Angoon, Alaska.

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

  A pair of metrics (M1, M2) can give different LCOE results. The LCOE depends on other external parameters related to the site and economic factors. In this example, choosing the parameters given below, the associated CapEx, AEP and LCOE are: CapEx = 601,474 $/kWe, AEP = 1,424,888 kWh/yr (CF = 32.53 %), and LCOE = $0.1037/kWh (the substation and the electrical line costs are not included). The parameters are:

  → Rated electrical power per turbine, P_{er} = 500 kWe, at Rated water velocity V_r = 3.00 m/s
  → Number of turbines in array = 1
  → Site: Kootznahoo Inlet in Angoon, in Alaska, with water velocities of $V_{average}$ = 1.71 m/s, $V_{cut\text{-}in}$ = 0.50 m/s, $V_{cut\text{-}out}$ = 5.00 m/s, and low-tide depth of 11 m and width of 300 m.
  → OpEx = 197 $/kWe/yr
  → Fixed charge rate, FCR = 8.2%
  → Project number of years = 20 years
  → Cost of *steel-of-reference* = $2.0 /kg (high corrosion resistant austenitic stainless steel)

Factors

The material factors used in the previous case studies are shown in Table 7. The manufacturing and installation factors are shown in Table 8.

Table 7. Material factors (raw materials)[14]
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 reinforced 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**

[14] 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 8. Manufacturing and installation factors[15]
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, hub)	2.80	0.06
2	Nacelle (generator, drive-train, PTO, yaw, bearings, pitch…)	2.80	0.06
3	Structure (tower, cross-arm, columns...)	8.03	0.06
4	Floating system (floaters, ballast…)	7.84	0.06
5	Mooring system (ropes, connection…)	1.72	0.12
6	Anchoring/foundation system	1.72	0.12

3. Program Performance Targets

The State-Of-the-Art LCOE for the four case studies (S1 to S4) discussed in the previous sections are summarized in the second column of Table 9. The corresponding LCOE Program Targets for these cases are shown in the third column, and in Figures 3 to 6 (dashed green lines). Note that if a LCOE target isoline is not visible, as in Figure 6, it is because there is no mathematical solution for that isoline for a system with physically meaningful parameters (in Figure 6, the 0.040 $/kWh LCOE target cannot be achieved with an OpEx = 197 $/kW/yr. A smaller OpEx is needed in this case). Applicants to this SHARKS Program should propose new systems that achieve an LCOE equal or less than the values of the third column, or be above the corresponding LCOE isoline (Figures 3 to 6, dashed green lines), for at least one selected case study (S1 to S4). If a proposal claims a technology is applicable in multiple case studies, they must show how it meets the target LCOE in each scenario. Proposals that show an ability to achieve the target LCOE for more than one application (S1 to S4) are of special interest.

Table 9. Current and Program Targets, LCOE

System (Case studies)	Current LCOE ($/kWh)	LCOE Targets ($/kWh)
S1. *River, Remote area*	0.2115	**0.0850**
S2. *Tidal, Remote area*	0.2477	**0.1050**
S3. *River, Utility scale*	0.1671	**0.0650**
S4. *Tidal, Utility scale*	0.1037	**0.0400**

[15] Factors based on several references, including: (1) López A., Morán J. L., Núñez L. R., & Somolinos J. A. (2020). *Study of a cost model of tidal energy farms in early design phases with parametrization and numerical values. Application to a second-generation device*. Renewable and Sustainable Energy Reviews, 117, 109497; (2) Segura E., Morales R., Somolinos J.A. (2017). *Cost Assessment Methodology and Economic Viability of Tidal Energy Projects*. Energies, MDPI, 10, 1806, pp. 1-27; (3) Neary V., Previsic M., Jepsen R. et al. (2014). *Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies*. Sandia National Laboratories. Technical Report SAND2014-9040; (4) Previsic M., Bedard, R., Polagye B. (2008). *System Level Design, Performance, Cost and Economic Assessment – Alaska River In-Stream Power Plants*. EPRI RP 006 Alaska.

4. *Technical Tasks*

The Program LCOE targets outlined above (Table 9, third column) require radically new HKT designs with new technical innovations and breakthroughs. The specific impact of these innovations on LCOE can be easily seen in the Metric Space. Figure 7 shows three different Tasks (T1, T2 and T3) that can be applied to improve the LCOE of these HKT systems. Starting at the initial point or State-Of-The-Art device, with a given $M1_i$, $M2_i$ and $LCOE_i$, the T1-T2-T3 Tasks represent a series of translations in the Metric Space that moves the device closer to the target performance metric, which is the area above the final LCOE isoline, or $LCOE_f$.

Task 1 includes technological innovations that increase M1, which is the total efficiency from the kinetic energy of water to the electrical energy at the output of the turbine. Task 2 focuses on increasing M2, which is the swept area of the rotor normalized by the equivalent mass of the system. Task 3 are innovations that move down the $LCOE_f$ isolines by decreasing operation and maintenance expenses, OpEx, from $OpEx_1$ to $OpEx_2$, with $OpEx_2 < OpEx_1$. Note that improvements in each Task affect the needed improvements in the other two Tasks to achieve a given LCOE Target: e.g., a large improvement in T3 will relax the needed improvements in T1 and T2, etc. Table 10 summarizes the effect of each of these Tasks in the Metric Space.

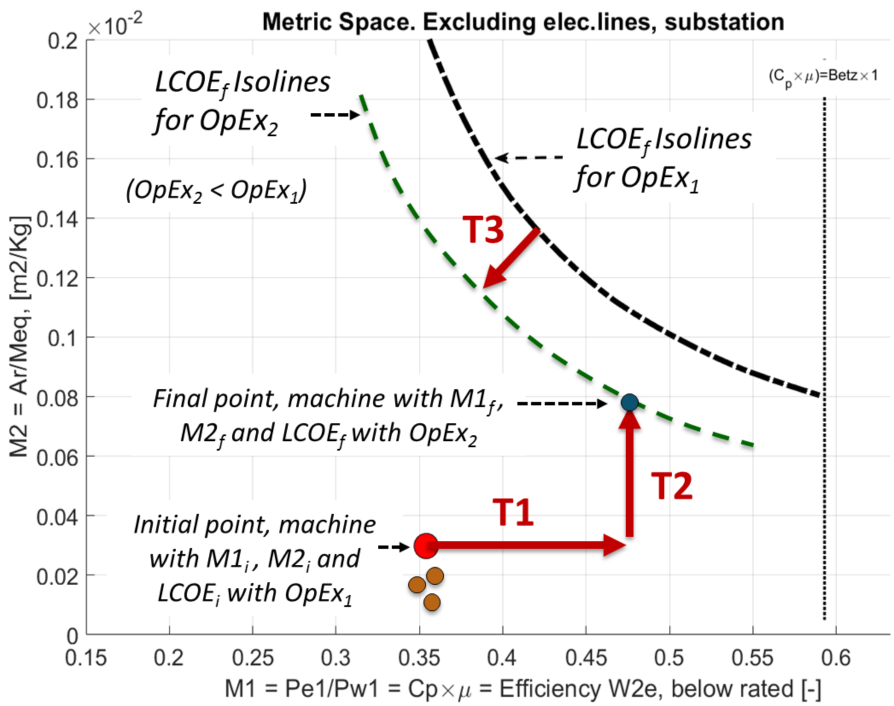

Fig. 7. Metric Space: a path example from initial (*i*) to final point (*f*), with Tasks T1, T2, T3.

The Program LCOE targets shown in Table 9 and Figures 3 to 6 can be achieved in many different ways. Following the discussion above and as an example, an improvement of about ×1.25 in M1 (Task T1), with an improvement of about ×2.0 in M2 (Task T2), and a reduction of about ×0.4 of the operation and maintenance expenses (Task T3) achieve these LCOE targets. Other combinations of improvement factors, with a different trajectory in the Metric Space, can also put the system above the corresponding $LCOE_f$ isoline and achieve these LCOE targets. The following paragraphs describe the elements that affect the T1, T2 and T3 Tasks.

Table 10. Tasks T1, T2 and T3

T1	• Increase in hydrodynamic efficiency and turbine availability • Decrease in generator, drive-train, wake and other losses → **Increase in M1**
T2	• Increase in swept area • Decrease in rotor, nacelle, cross-arm, tower, and foundation masses • Decrease in material cost, installation cost, manufacturing cost → **Increase in M2**
T3	• Decrease in OpEx → **Shift down LCOE isoline**

Task T1

Innovations in Task T1 focus on the M1 metric and result in a horizontal translation in the Metric Space. Equation (10) shows the definition of the metric M1. According to this expression, there are a number of fundamental approaches to innovations in Task T1:

1) Increase the hydrodynamic efficiency, or power coefficient C_p of the rotor.
2) Increase the turbine availability A_v, either by reducing the annual time for maintenance, or by increasing the number of months the machine is in the water, which is especially relevant for rivers that freeze or suffer harsh conditions during the melting season, or rivers that experience drastic variations in flow between seasons.
3) Decrease the losses in the electrical generator L_g, drive-train (gearbox, power electronics) L_{dt}, wake L_w, electrical lines and transformers L_e, or other losses L_o, like cavitation effects, etc.

$$\boldsymbol{M_1} = C_p\,\mu = C_p\left(1 - L_g\right)\left(1 - L_{dt}\right)\left(1 - L_w\right)\left(1 - L_e\right)\left(1 - L_o\right)A_v \qquad (10)$$

This Task T1 could include advanced turbine blade design to increase efficiency or avoid cavitation, novel drive-train or electrical generators that reduce system losses, methods to increase the system availability, or a combination of multiple innovations in these spaces. Another approaches to this Task could include optimizing an array or group of devices to take advantage of local blockage effects,[16] and improved maximum power point tracking (MPPT) control algorithms that can increase the hydrodynamic efficiency of the system.

Task T2

Task T2 works towards increasing the M2 metric to translate a design vertically in the Metric Space. In order to improve M2, projects must increase the ratio between the swept area A_r of the rotor to the equivalent mass M_{eq} of the system –see eq.(11). As explained in previous sections, *equivalent mass* includes the mass m_c of each component, and factors that represent the cost of specific materials f_t used in the device, manufacturing costs f_m, and installation costs f_i. Innovations in this Task focus on either increasing the swept area of the rotor, reducing the equivalent mass of the device, or both. This could include advanced materials that are resistant to marine/river environments, novel manufacturing techniques that reduce fabrication costs, or direct reductions in mass through approaches such as control co-design.

$$\boldsymbol{M_2} = \frac{A_r}{M_{eq}} = \frac{A_r}{\sum_{j=1}^{z} f_{tj}\left(1+f_{mj}+f_{ij}\right) m_{cj}} \qquad (11)$$

Task T2 also encompasses innovations in the installation method of hydrokinetic turbines. Installation costs for these devices remain high due to difficulties in working in aquatic environments, and a small or nonexistent window with low flow speeds. Approaches to minimize installation costs could include automatic installation systems, advanced bottom-fixing or mooring techniques, or systems designed to allow for installation within active flows.

Task T3

Technical innovations in Task T3 do not translate the device within the Metric Space, instead they move the LCOE isoline down and make the target performance metrics easier to achieve. The primary method to shift down the LCOE Isoline is to develop a system designed to reduce operation and maintenance expenditures (OpEx) –see eq.(12). OpEx is a major cost contributor for hydrokinetic turbines, and prohibitively high OpEx is a critical barrier to the growth of the industry.

$$\boldsymbol{LCOE} = \frac{FCR\ CapEx + OpEx}{AEP} \qquad (12)$$

Approaches to reducing OpEx include, but are not limited to, designing systems that are easy to access or remove from the environment for maintenance, systems that are reinforced for robust operation in harsh environments, intelligent condition monitoring and predictive maintenance approaches, and autonomous systems to transit to a maintenance facility, re-deploy after routine maintenance, or other autonomous solutions to reduce operational costs.

The case studies outlined in the previous sections, and the associated Metric Space workbooks, show that the OpEx is a critical factor in reducing LCOE for these devices (Task T3). Due to this

[16] Nishino, T and Willden R., (2012). The Efficiency of an Array of Tidal Turbines Blocking a Wide Channel. Journal of Fluid Mechanics, Vol.708, pp.596-606.

fact, applicants in that space will need to address OpEx to achieve the cost targets. The concept of designing for OpEx is also core to the philosophy of the program, both because of the need to reduce it in order to achieve cost competitiveness and the importance of reliability to systems deployed in remote areas.

Table 11. Tasks T0, including requirements (T0a) and recommendations (T0b)

	Tasks T0	Description
Requirements T0a	**T0a.1**	Minimum environmental impact: animals, sediments, noise, oil, blades
	T0a.2	Designs ready for micro-grid connection: voltage and frequency control
	T0a.3	Designs with a high level of resiliency/reliability
Recommendations T0b	**T0b.1**	Bio-fouling and corrosion resistance
	T0b.2	Low visible profile and flexibility in shared use waterways
	T0b.3	Designs that resist or avoids ice riverbed scouring
	T0b.4	Designs that resist or avoids solid debris
	T0b.5	Design for rapid deployment or removal/re-installation in water

Task T0

Besides the three tasks described above (T1, T2, T3), the SHARKS Program also includes some additional requirements and recommendations clustered as Task T0. Table 11 shows the requirements (T0a) and recommendations (T0b) under this Task T0.

Task T0a.1. This is a requirement. The new designs proposed to the SHARKS program must be environmentally friendly. Proposals have to show how the new systems take into account risks that involve the environment, reducing as much as possible the impact of the new HKTs on the water purity, local sediment transport patterns, acoustics and noise, marine life, mammals, and fish migration patterns. Aspects to consider are systems with no oil or biodegradable oil, arrays with configurations that do not alter the local sediments, turbines with no blades or that operate at a rotor velocity low enough to reduce the potential impact on fish and mammals, systems with low acoustic noise, fish-presence sensors and control systems to stop the turbines under the presence of fish or mammals, etc.

It is understood that not all of the environmental factors listed above will be considered by every applicant, and the nature of the proposed device and area it is designed for will determine the environmental impacts that are critical to examine. With that in mind, it is required that proposals consider the environmental impact of the system they put forward. This is especially true for systems deployed in remote areas where the waterways containing the energy resource may also be critical sources of food, transportation, and sites of cultural significance.

Task T0a.2. This is a requirement. The new designs proposed to the SHARKS program must be ready for micro-grid connection. Proposals have to include the power electronics systems to control the active and reactive power at the point of interconnection of the turbine to the micro-grid. This will allow control of, or help the operator to control, the frequency and the voltage of the micro-grid. These characteristics are especially relevant for HKTs in remote areas, with a very weak grid or no grid connection at all. It is important to note that even applicants proposing systems within the 'S3' and 'S4' case studies (Utility scale cases) must develop systems that are ready for connection to a micro-grid.

Task T0a.3. This is a requirement. The new designs proposed to the SHARKS program must show a high level of resiliency and reliability. This is especially important for remote areas, where it may be very expensive or otherwise impractical to transport a trained technician to perform routine/unplanned system repairs. In such remote areas the HKT could be the only electrical generator available for the community, increasing the need for dependability.

Task T0b.1. This is a recommendation. The new designs proposed to the SHARKS program can include bio-fouling and corrosion resistance solutions. These aspects will be considered of interest in the evaluation process.

Task T0b.2. This is a recommendation. New systems proposed to the SHARKS program can include designs that minimize the visible profile of the system and are flexible for use in waterways with multiple shared uses. This aspect will be considered of interest in the evaluation process.

Task T0b.3. This is a recommendation. The new systems proposed to the SHARKS program can include designs that resist or avoid ice riverbed scouring problems. These aspects will be considered of interest in the evaluation process.

Task T0b.4. This is a recommendation. The new systems proposed to the SHARKS program can include designs that resist or avoid solid debris problems. These aspects will be considered of interest in the evaluation process.

Task T0b.5. This is a recommendation. The new designs proposed to the SHARKS program can include solutions to speed up (1) the deployment of the system in the water, or (2) the removal and re-installation of the system in the water. These aspects will be considered of interest in the evaluation process.

D. APPROACH AND DESIGN PHILOSOPHY

The SHARKS Program seeks a multi-disciplinary team approach to design the new hydrokinetic turbine systems for tidal and/or riverine applications. Teams are encouraged to use Control Co-Design (CCD), Co-Design (CD) and Designing-For-OpEx (DFO) approaches to develop the new HKTs able to achieve the LCOE targets proposed in this Program. A brief introduction to these three concepts is presented next.

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.8.

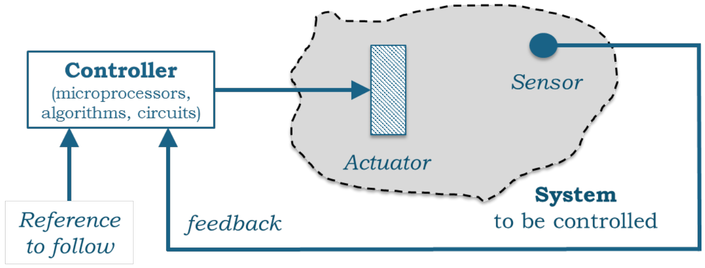

Fig. 8. Control system.

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, hydrodynamics, control, etc.) is an independent step in a sequential process –see Fig.9a, Control Co-Design (CCD) brings together various technical disciplines to work concurrently from the start –see Fig.9b.[17,18]

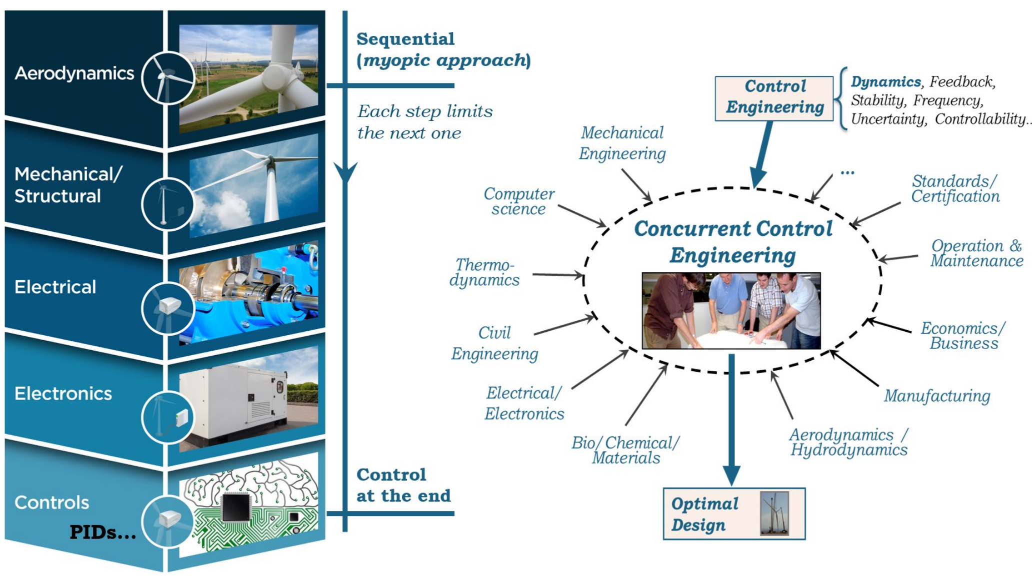

Fig. 9. (a) Classical sequential design process vs. (b) Control Co-Design.

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

[17] Garcia-Sanz M. (2019). Control Co-Design: an engineering game changer. Advanced Control for Applications, Wiley, Vol. 1, Num. 1.

[18] 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, Ocean Week).

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.

Several CCD techniques to design new optimal HKT solutions are considered in this program – see Fig.10, including: (a) Control-inspired paradigms, (b) Co-optimization techniques and (c) Co-simulation methods. Control-inspired paradigms incorporate basic control concepts and bio-inspired ideas in the design, including stability principles, resonance mode damping, bandwidth, non-minimum phase characteristics, multi-input multi-output coupling, observability, controllability and others.[19] 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.[20] Co-simulation methodologies deal with iterative multi-physics dynamic simulation processes.[21]

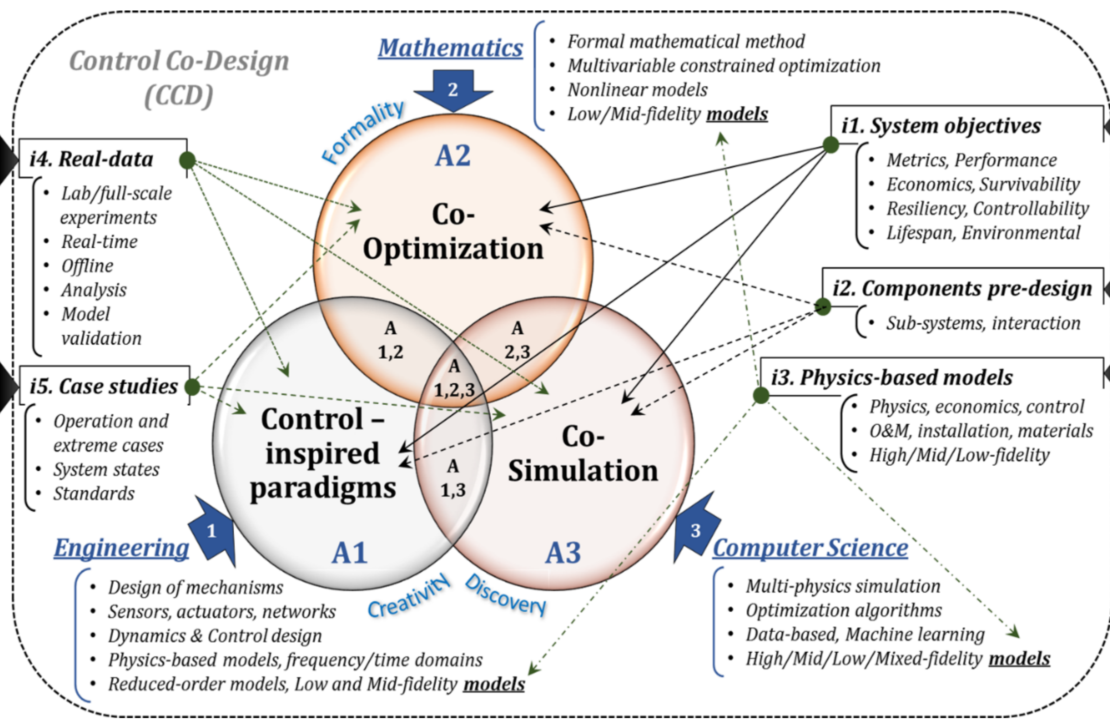

Fig. 10. Control Co-Design areas: Control-inspired paradigms, Co-optimization, Co-simulation[22]

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[19] 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.
[20] 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.
[21] 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.
[22] Garcia-Sanz M. (2019). Control Co-Design: an engineering game changer. Advanced Control for Applications, Wiley, Vol. 1, Num. 1.

The highly coupled dynamics involved in the design of HKTs make this problem an ideal candidate for the CCD approach. HKTs are composed of many sub-systems that interact dynamically among each other: rotor, drive-train, electrical generator, power electronics, substation, nacelle, structure, floaters, mooring system, hydrodynamics, grid and control systems. As a rule, the higher the sub-system dynamic interactions, the more effective and needed the control co-design methodology.

In a similar way, Co-Design (CD) is a general philosophy that applies a concurrent engineering methodology to design multi-disciplinary systems, with a particular emphasis on specific coupled spaces such as electro-mechanical systems, integrated hydro-structural systems, bio-hydro-mechanical systems, etc. This approach is especially important when the physics of the various different disciplines have disparate mathematical descriptions and require multiple areas of expertise to understand and optimize the system. The impact of Co-Design is highest when consideration of the coupled system dynamics, and concurrent work in those coupled disciplines allows engineers to arrive at designs that are fundamentally different than if a sequential approach was taken.

Finally, Designing-For-OpEx (DFO) is a methodology that put the emphasis on the operation and maintenance aspects of the system. As seen in the previous sections, current HKT designs have a high cost for operation and maintenance (OpEx), which significantly affects the LCOE. The DFO approach helps to reduce the LCOE to economically attractive levels by proposing HKT design solutions to optimize the OpEx. Of particular interest here are the impacts of bio-fouling and corrosion resistance.

As stated in Section I.C.4, the reduction of OpEx is critical to achieving the LCOE targets outlined in this FOA. This is most stark for utility scale tidal energy systems (case S4), as the case study shows that without a reduction in OpEx the target LCOE metric is not achievable. However, OpEx is a significant contributor to cost for any of the four case studies. Reducing operation and maintenance costs not only drives the LCOE towards the target values, it also opens up more potential markets to hydrokinetic devices. For a system deployed in remote or isolated areas, system reliability is paramount to success. This is why DFO is core to the philosophy of the SHARKS Program, and designs that utilize this process will be considered of interest in the evaluation process.

E. AREAS OF EXPERTISE & MULTIDISCIPLINARY TEAMS

In order to achieve the program targets (Section I.C.3), by means of the four defined Tasks T0-T3 (Section I.C.4), and while taking advantage of the CCD, CD and DFO methodologies described above (Section I.D), teams will benefit from a wide range of technical experience. The following list of technical areas can be used to guide the applicants throughout the potential team building process: (i) hydrodynamics; (ii) mechanical engineering; (iii) electrical generators, power electronics and grid connection; (iv) systems and control engineering; (v) materials and corrosion; (vi) anchoring and mooring systems; (vii) numerical simulation; (viii) experimental testing; (ix) techno-economic analysis; (x) environmental impact attenuation; (xi) rapid deployment in water; (xii) operation and maintenance; (xiii) control co-design.

Applicants may find that certain technical areas listed above are not relevant for the success of their project. Conversely, applicants may determine important technical areas that do not appear in the list above. ARPA–E strongly encourages outstanding scientists and engineers from different organizations, scientific disciplines and technology sectors to form new project teams. Interdisciplinary and cross-sector collaboration spanning organizational boundaries enables and accelerates the achievement of scientific and technological outcomes that were previously viewed as extremely difficult or impossible.

To assist in the formation of multi-disciplinary teams, ARPA-E developed a Teaming Partner List. The Teaming Partner List is available on ARPA–E eXCHANGE (http://ARPA–E-foa.energy.gov), ARPA–E's online application portal will be updated periodically, until the close of the Full Application period, to reflect the addition of new Teaming Partners who have provided their information.

F. PROOF OF CONCEPT EXPERIMENTS

Projects in this program are required to propose some form of experimentation during their period of performance to provide proof-of-concept validation of the device's underlying hypotheses. The 'underlying hypotheses' are fundamental technical innovations that result in significant changes in the LCOE or deployability of the HKT under Tasks T0 to T3.

It is understood that the nature of these experiments may differ depending on the device being proposed and the sub-systems that need to be tested. Physical experiments could take place in either laboratory facilities, tanks, or real world environments. However, they must be designed to test the underlying assumptions teams make when estimating the LCOE of their novel devices.

For instance, if a team proposes a novel turbine design that allows for higher tip speeds before cavitation is induced, they may test a scaled model of that turbine in a water channel facility. Similarly, if a project develops a generator with significant reductions in losses, they may also propose an experiment to test that generator to demonstrate the benefit it provides their device. Projects are expected to highlight what they see as the fundamental hypotheses of their device and propose experiments to validate the performance of those components.

Water Power Technology Office (DOE-WPTO) TEAMER Program

For the experimental validation mentioned above, and as part of the process of identifying test facilities, teams may want to look into the program U.S. Testing Expertise and Access for Marine Energy Research (TEAMER), recently announced by the Department of Energy's Water Power Technologies Office (WPTO). The objective of TEAMER, sponsored by the U.S. Department of Energy (DOE) and directed by the Pacific Ocean Energy Trust (POET), is to accelerate the viability of marine renewables by providing access to the nation's best facilities and expertise in order to solve challenges, build knowledge, and foster innovation. TEAMER is envisioned to include a wide array of U.S. Marine Renewable Energy (MRE) and MRE-relevant testing facilities including lab and bench-scale facilities; wave tanks, basins, and flumes; and open ocean/field-based testing sites. TEAMER will also support requests for technical expertise to assist with numerical modeling, data collection, and analysis.

TEAMER may offer a series of open Requests for Technical Support (RFTS's) starting in mid-2020. In order to better align with the timeframes needed by various stakeholders, the RFTS calls are currently planned to occur 2-3 times per year (roughly every 4-6 months) with an emphasis on rapid implementation and results. The program is currently in the process of qualifying potential test facilities to be included in the TEAMER network and it is anticipated that the TEAMER facility network will expand over time. The TEAMER Network Director, POET, will be continuously reviewing and qualifying new facilities based on clearly defined facility network criteria, as well as routinely evaluating existing facilities for compliance with the TEAMER criteria. Applicants to the ARPA-E SHARKS Program are encouraged to look at the WPTO TEAMER Program to better identify potential facilities for testing the new systems and potentially accelerate the experimental validation. More information about the facilities and application process can be found on the TEAMER website (https://teamer-us.org).

G. SHARKS PROGRAM STRUCTURE

Projects under the SHARKS Program will develop radically new designs of hydrokinetic turbines for at least one of the following applications:

- S1 (Riverine energy converters for remote areas without grid, ready for micro-grids),
- S2 (Tidal energy converters for remote areas without grid, ready for micro-grids),
- S3 (Riverine energy converters for large utility scale application, with grid connection),
- S4 (Tidal energy converters for large utility scale application, with grid connection).

While it is required that projects identify at least one application (S1 to S4) for their proposed design, they may show how it achieves the cost targets across multiple applications. If a project chooses to do this, they should include justifications of the achieved LCOE for each application.

Submissions to the SHARKS Program must, at a minimum, include the following:

(a) A new HKT design that achieves at least one of the program target metrics described in Section I.C.3: the point M1, M2 of the new HKT must be above the LCOE isoline target in the Metric Space, being 0.085 $/kWh for S1, 0.105 $/kWh for S2, 0.065 $/kWh for S3, and 0.040 $/kWh for S4 –see Table 9.

(b) An analysis of the aspects to be validated experimentally to reduce the risk and improve the final system, and the design of scale prototypes following the appropriate scale methodology (Reynolds number, Froude number, or others).

(c) The experimental validation plan, test execution and conclusions to prove the main concepts and scale prototypes of the new technology.

(d) A techno-economic analysis, risk analysis, and sensitivity analysis of the new HKT.

(e) A multi-disciplinary team composed of all the critical areas of expertise necessary to design and test the new HKTs.

H. MULTIDISCIPLINARY RESEARCH AND COLLABORATION

The success of the SHARKS 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, co-design, operation and maintenance, installation, hydrodynamics, electrical and mechanical systems, power electronics, electrical generators, structural engineering, naval engineering, materials, modeling, optimization, economics, multi-scale and multi-physics computer algorithms, distributed sensors, intelligent signal processing and actuator networks.

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.[23,24,25]

[23] Cummings, J., Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. Social Studies of Science, vol. 35, no. 5, pp. 703-722.
[24] Adams, J. (2012). The rise of research networks. Nature, vol. 490, pp. 335-336.
[25] 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.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $38 million available for new awards, to be shared between FOAs DE-FOA-0002334 and DE-FOA-0002335, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 8-12 awards under FOAs DE-FOA-0002334 and DE-FOA-0002335, combined. ARPA-E may, at its discretion, issue one, multiple, or no awards.

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

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be February 2021, or as negotiated.

ARPA-E encourages submissions 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 is described in sufficient technical detail to allow reviewers to meaningfully 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 submissions with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

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

ARPA-E plans to fully fund your negotiated budget 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, extending the period of performance of the initial award, or issuing new 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."[26] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.C below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[27]

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 http://arpa-e.energy.gov/arpa-e-site-page/award-guidance.

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

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

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

"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 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 technical 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[28] 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.

[28] The term "nonprofit organization" or "nonprofit" is defined in Section IX.

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,[29] as the lead for a Project Team,[30] 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[31], and nonprofits[32] 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

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or

[29] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[30] A Project Team consists of the Prime Recipient, Subrecipients, and others performing any of the research and development work under an ARPA-E funding agreement, whether or not costs of performing the research and development work are being reimbursed under any agreement.
[31] The term "Institutions of Higher Education" or "educational institution" is defined in Section IX.
[32] 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.

otherwise formed or to be formed) under the laws of a State or territory of the United States to receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. All work under the ARPA-E award must be performed in the United States. The Applicant 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/. 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[33]

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

[33] 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[34] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[35]

2. *Increased Cost Share Requirement*

Large businesses[36] 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 cost share requirement, as appropriate.

3. *Reduced Cost Share Requirement*

ARPA-E has reduced the base 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 – may provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[37] 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.
- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are entitled to the same cost

[34] 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.
[35] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988(c)
[36] The term "For-Profit Organizations (Other than Small Businesses)" or "large business" is defined in Section IX.
[37]The term "small business" is defined in Section IX.

share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.

- 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 base 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, or ensuring payment of 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 of the FOA.

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[38] 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.

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.

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

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 V.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 currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to 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 will be deemed nonresponsive and will not be merit reviewed or considered:

- Incremental improvements to existing HKT designs.
- Efforts that do not consider a control co-design, or co-design or design-for-OpEx 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 components but do not include the design of a new HKT system and show the program performance target (metrics).
- Devices that are only designed for harnessing energy in ocean current streams are not of interest. However, systems that can be deployed in ocean currents as well as one of the four applications (S1 to S4) described in the FOA are of interest.
- Devices that only produce electrical energy from wave energy (i.e., PTO devices) are not of interest. However, systems that leverage wave energy in combination with tidal and/or riverine energy are of interest.

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 User 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 are allowed an Appendix with maximum length equal to 1 page per case study (S1 to S4) for which the design meets the LCOE targets. Each page of the Appendix may contain a plot of the Metric Space for the new design, and the descriptions and justifications for the parameters used to calculate the M1 and M2 metrics and LCOE isoline for the particular case study.
- 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 Calibri 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 Categories (S1 to S4), Proposed Funding Requested (Federal and Cost Share), and Project Duration.
- The Concept Paper must be submitted in Adobe PDF format.
- As part of the Concept Paper, applicants must submit a Metric Space Workbook for each case study (S1 to S4) that the device meets the LCOE target for, in a Microsoft Excel Spreadsheet, with the details of the new design that shows the calculations of M1 and M2 metrics and the LCOE isoline. Applicants are strongly encouraged to use the SHARKS Metric Space Workbook templates, named *S1_SHARKS_MetricSpaceWorkbook.xlsx*, *S2_SHARKS_MetricSpaceWorkbook.xlsx*, *S3_SHARKS_MetricSpaceWorkbook.xlsx*, and

S4_SHARKS_MetricSpaceWorkbook.xlsx that are 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. 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.C.3 of the FOA. For each application (S1 to S4) the project is claiming they meet the LCOE target for, include the metrics M1 and M2 and the OpEx that are expected to be most significantly affected via the new design, an estimate of how much they 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.
- Identify the items under Task T0 the device is addressing and provide a description of how those items are addressed.

c. Proposed Work

- Describe the final 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 the components of the system that are critical to the hypotheses laid out in the Metric Space Workbooks and include *brief* descriptions of how these components will be tested in physical environments. Note that in the Concept Paper it is not expected to have determined exact test facilities/sites or developed a test plan for the experiments.
- 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

- Plot of Metric Space from Tab: "2b. Proposed Design Plot" for each application (S1 to S4) that the project is claiming the new device meets the LCOE targets for.
- Description and Justification for the parameters used to calculate the M1 and M2 metrics and the LCOE isoline from Tab: "2c. Summary of Changes" for each application (S1 to S4) that the project is claiming the new device meets the LCOE targets for.

2. *Second Component: Metric Space Workbook*

In addition to the Concept Paper, Applicants must fill out and submit a Metric Space Workbook for each application (S1 to S4) that the project is claiming the new device meets the LCOE targets for. Applicants are strongly encouraged to use the SHARKS Metric Space Workbooks named *S1_SHARKS_MetricSpaceWorkbook.xlsx*, *S2_SHARKS_MetricSpaceWorkbook.xlsx*, *S3_SHARKS_MetricSpaceWorkbook.xlsx*, and *S4_SHARKS_MetricSpaceWorkbook.xlsx* that are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov). These files include two tabs ("1a. Original Design" and "1b. Original Design Plot") that characterize the original design presented in Section I.C.2 (see Case studies S1 to S4), and three additional tabs for the new HKT proposed design ("2a. Proposed Design", "2b. Proposed Design Plot" and "2c. Summary of Changes") –see example in Figures 11 to 15 for Case study S1. 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.13 for Case study S1, Section I.C.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 <u>every</u> such adjustment as a separate row/item in the "2c. Summary of Changes" tab –see Fig.15 for Case study S1, Section I.C.2. This tab includes four 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 <u>what</u> 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 requires 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.11) and "1b. Original Design Plot" (Fig.12) shows the State-Of-the-Art for Case study S1, Section I.C.2. This Metric Space Workbook will be used during ARPA-E's evaluation of Concept Papers.

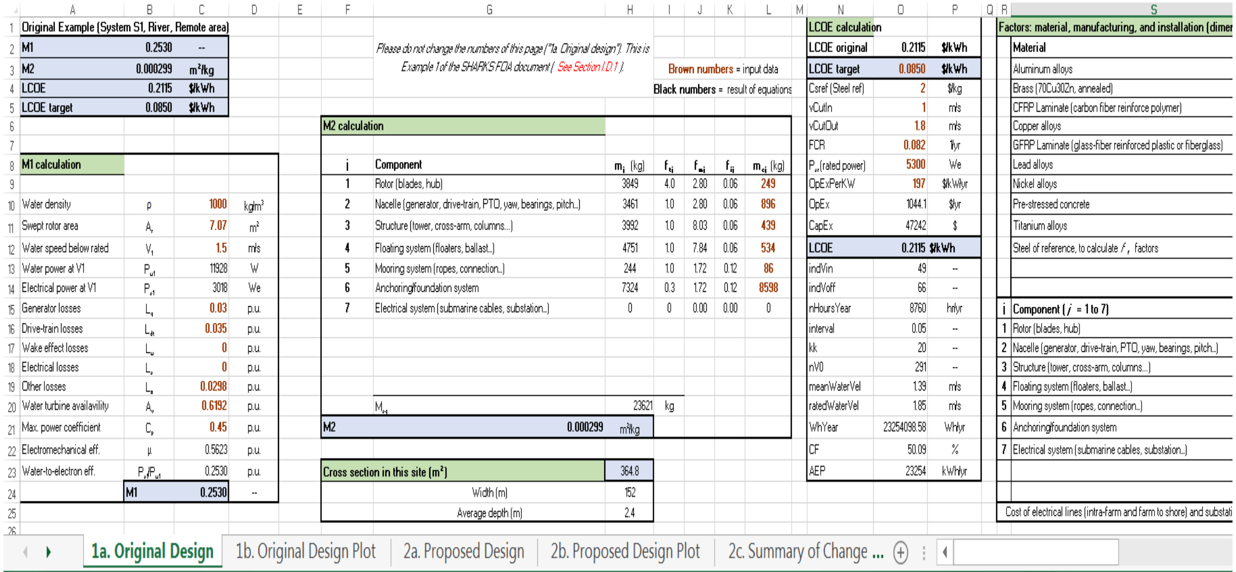

Fig. 11. Tab "1a. Original Design" in document *S1_SHARKS_MetricSpaceWorkbook.xlsx*. This is for Case study S1, Section I.C.2.

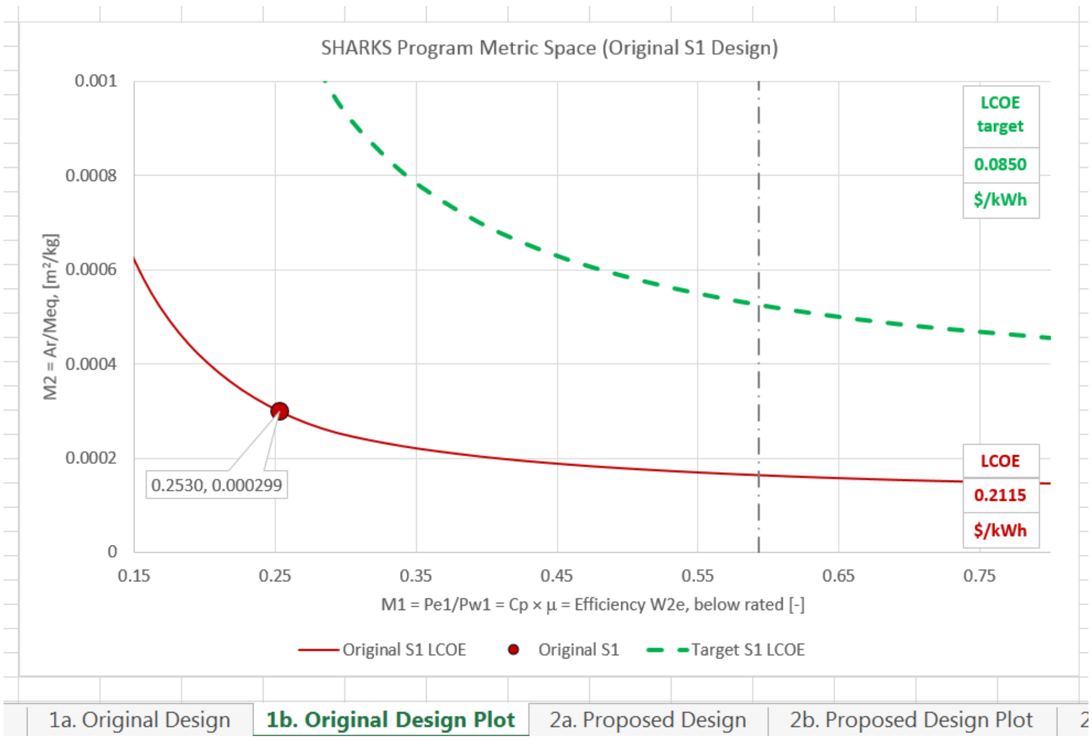

Fig. 12. Tab "1b. Original Design Plot" in document *S1_SHARKS_MetricSpaceWorkbook.xlsx*. This is for Case study S1, Section I.C.2.

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).

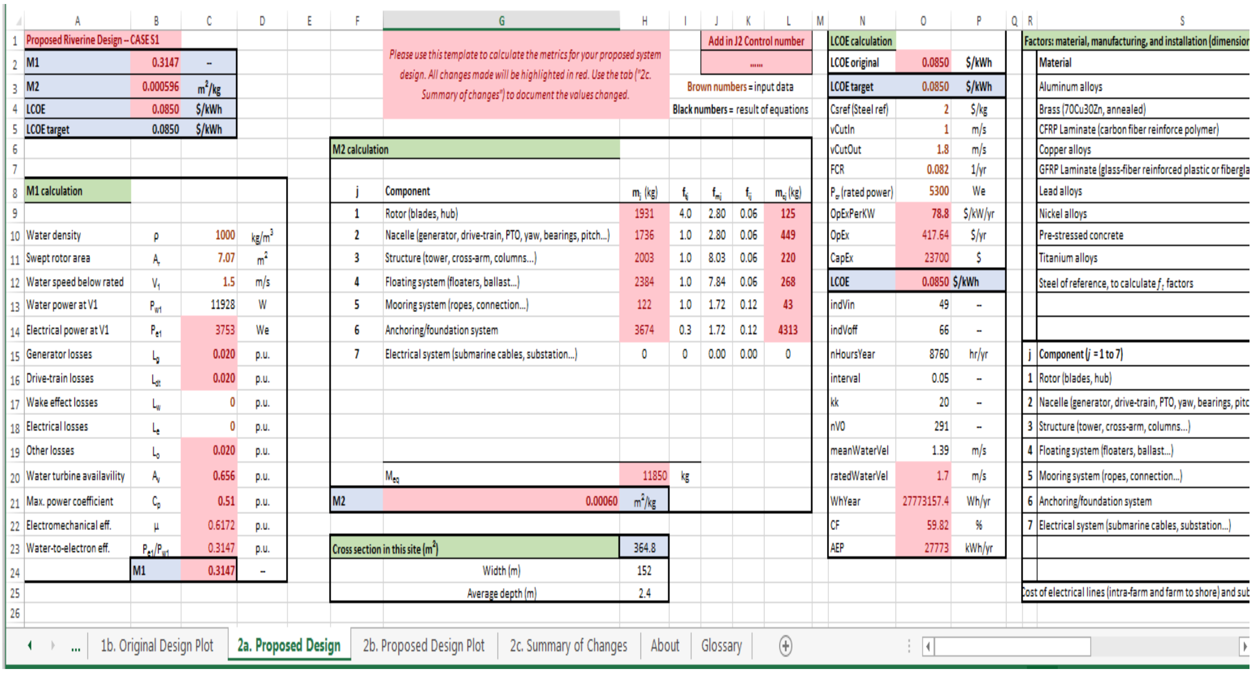

Fig. 13. Tab “2a. Proposed Design” in document *S1_SHARKS_MetricSpaceWorkbook.xlsx*. This is for Case study S1, Section I.C.2.

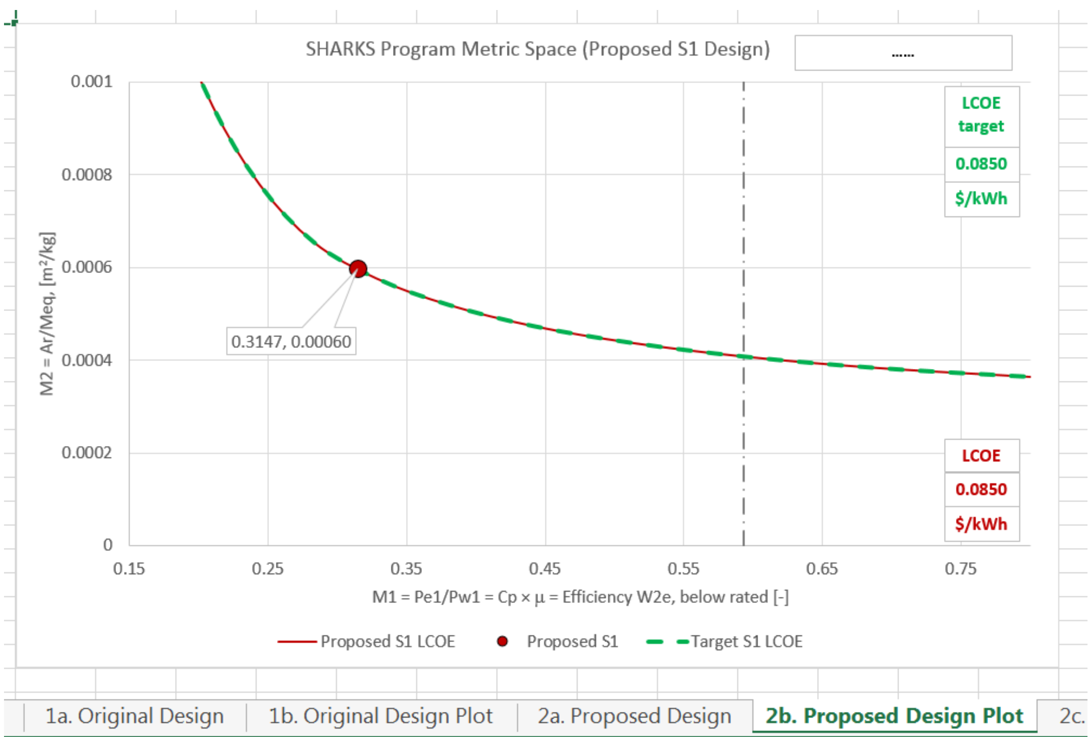

Fig. 14. Tab “2b. Proposed Design Plot” in document *S1_SHARKS_MetricSpaceWorkbook.xlsx*. This is for Case study S1, Section I.C.2.

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**
H9 (EXAMPLE ONLY)	*Mass of Rotor Blades*	*New value is 1/3 of previous value*	*We propose a new blade design that ...*
F16 - L16 (EXAMPLE ONLY)	XYZ (NEW)	Added a new required component, XYZ, and included its mass (##), ft (##), fm (##), and fi (##)	XYZ is required for this design, but it will enable reduction in mass elsewhere in the system...

Fig. 15. Tab "2c. Summary of Changes" in document *S1_SHARKS_MetricSpaceWorkbook.xlsx*. This is for Case study S1, Section I.C.2.

From the case shown in Figures 11 and 12, Figures 13 and 14 show improvements of about ×1.25 in M1 (Task T1), ×2.0 in M2 (Task T2), and ×0.4 in OpEx (Task T3) to achieve the LCOE target for S1 of 0.0850 $/kWh.

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 JULY 2020]

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 Concept Papers and 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.C 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 JULY 2020]

3. *Criteria for Replies to Reviewer Comments*

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 U.S. 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.**

VII. **Qualified Opportunity Zone (QOZ).** Whether the entity is located in an urban and economically distressed area including a Qualified Opportunity Zone (QOZ) or the proposed project will occur in a QOZ or otherwise advance the goals of QOZ. The goals include spurring economic development and job creation in distressed communities throughout the United States. For a list or map of QOZs go to: https://www.cdfifund.gov/Pages/Opportunity-Zones.aspx.

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 JULY 2020]

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 of the FOA for guidance on pre-award costs.

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 Prime Recipients/Subrecipients elect to retain title, they must file a patent application in a timely fashion, generally one year from election of title, though: a) extensions can be granted, and b) earlier filing is required for certain situations ("statutory bars," governed by 35 U.S.C. § 102) involving publication, sale, or public use of the subject invention.
- 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 and VI.B 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 should 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 of the U.S. Department of Energy.

Cost Sharing: is the portion of project costs not paid by Federal funds (unless otherwise authorized by Federal statue). Refer to 2 C.F.R. § 200.29.

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.

For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.

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

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

Institutions of Higher Education (or *educational institutions*): Has the meaning set forth at 20 U.S.C. 1001.

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

Nonprofit Organizations (or *nonprofits*): Has the meaning set forth at 2 C.F.R. § 200.70.

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 any of the research and development work under an ARPA-E funding agreement, whether or not costs of performing the research and development work are being reimbursed under any agreement.

Small Business: Small businesses are 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).

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).