U.S. Department of Energy
Advanced Research Projects Agency – Energy

Request for Information (RFI)
DE-FOA-0002142
on
Next Generation of Marine and Riverine Hydrokinetic Energy Systems

Objective

ARPA-E seeks input regarding the development of next-generation hydrokinetic energy converters, specifically tidal stream, riverine, and ocean current turbines, with significantly reduced operation and maintenance (O&M) costs, reduced installation costs, and optimized mass and efficiency. ARPA-E desires input from a broad range of disciplines and fields, including, but not limited to: developers of tidal, riverine, and/or ocean current energy systems, hydrodynamics, structural dynamics, controls engineering, design optimization, civil and environmental engineering, offshore and marine engineering, predictive maintenance, robotics, unmanned underwater vehicles, and others. Consistent with the agency's mission, ARPA-E is seeking information regarding clearly disruptive, novel technologies, early in the research and development (R&D) cycle, and not integration strategies for existing technologies.

Please carefully review the REQUEST FOR INFORMATION GUIDELINES below, and note in particular: the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME. Respondents shall not include any information in their response to this RFI that might be considered proprietary or confidential.**

Background

Marine and riverine hydrokinetic energy is a unique renewable energy source due to its proximity to major electric load centers, and its long-term predictability and near-term forecastability.[1] It is also vast. The amount of energy available in tidal streams, ocean currents, and river currents is estimated to be approximately 2,026 TWh/yr (6.91 Q/yr) combined (see Table 1).[2] It should be noted that the energy potential may very well be even greater still, once underwater surface/seabed floor topology is considered.

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[1] Iglesias, G., Sanchez, M., Carballo, R., Fernandez, H. The TSE index. A new tool for selecting tidal stream sites in depth-limited regions. Renewable Energy, Vol. 48, pp. 350-357, 2012.
[2] https://www.energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization

Table 1. U.S. Hydrokinetic Resource Potentials.[2]

Resource	Resource potential (TWh/yr)
Tidal streams	*Theoretical:* 445 TWh/year
	Technical: 222–334 TWh/year
Ocean currents	*Theoretical:* 200 TWh/year
	Technical: 45–163 TWh/year
River currents	*Theoretical:* 1,381 TWh/year
	Technical: 120 TWh/year

Despite the potential attractiveness and significant availability of hydrokinetic energy, it continues to be a largely untapped resource. This is primarily because the *Levelized Cost of Energy* (LCOE) of state-of-the-art of hydrokinetic converter technologies continues to be too high. Preliminary analyses[3,4,5] consistently show the LCOE of hydrokinetic energy systems as >$0.20/kWh, sometimes substantially so.

As a nascent industry, significant effort to-date has gone into design optimization that has focused on maximizing performance and lowering capital cost. These efforts have been largely successful, with industry now knowing how to achieve these design objectives quite well. The industry is now well-positioned to shift focus to reducing the operations and maintenance (O&M) costs, installation costs and system equivalent mass, which are prohibitively high in existing designs. The critical need for these cost reductions will be addressed in the next section of the RFI, which includes ARPA-E's techno-economic analysis of hydrokinetic energy systems.

O&M costs for hydrokinetic energy devices are high, at least in part, due to the harsh nature of the marine environment and the more difficult/limited access to the system. Several general strategies for O&M cost reductions can be envisioned, including, but not limited to:

- **Design for accessibility.** For example, the system could be designed to bring itself to the surface or even back to shore for maintenance.[6]
- **Design to minimize maintenance needed.**
- **Design for lower-cost remote access**. For example, robotic systems that allow for automated or remote-operated maintenance. Hydrokinetic energy systems might even be co-designed with such robotic O&M capabilities in mind.
- Incorporation of **predictive maintenance and/or low-cost remote diagnostics** to avoid time-based maintenance schedules.
- Application of **Control Co-Design methodologies** to design radically new hydrokinetic energy systems that significantly reduce the equivalent mass of the components (see

[3] Jenne, D. Scott, Yi-Hsiang Yu, and Vincent Neary. Levelized cost of energy analysis of marine and hydrokinetic reference models. No. NREL/CP-5000-64013. National Renewable Energy Lab. (NREL), Golden, CO, 2015.

[4] Neary, Vincent Sinclair, et al. Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies. No. SAND2014-3561C. Sandia National Lab.(SNL-NM), Albuquerque, NM (United States), 2014.

[5] International Levelised Cost of Energy for Ocean Energy Technologies. Ocean Energy Systems (OES). May 2015.

[6] https://arpa-e.energy.gov/?q=slick-sheet-project/marine-hydrokinetic-turbine

next section), including the cost of installation, manufacturing and materials needed, and improve the system efficiency. An introduction to the Control Co-Design concept and methodologies can be found in the FOA of the ARPA-E ATLANTIS Program.[7]

The purpose of this RFI is for ARPA-E to gather information from the relevant technical communities about the challenges and opportunities associated with next generation hydrokinetic energy systems. ARPA-E is specifically interested in:

- The most up-to-date cost breakdown for tidal, riverine, and ocean current systems.
- Feedback on the opportunities and challenges for O&M minimization, including if there are additional strategies beyond those proposed by ARPA-E.
- Feedback on the opportunities and challenges for cost reduction of installation, manufacturing and materials needed.
- Feedback on the opportunities and challenges for hydrodynamic, electrical and mechanical efficiency improvement.

Metric Space Definition and Technical Performance Targets

As mentioned above, in January 2019, ARPA-E announced the ATLANTIS Program to develop new technical pathways for the design of economically competitive Floating Offshore Wind Turbines (FOWT). The program proposed new Control Co-Design (CCD) methodologies and introduced a new *Metric Space* to guide the design of advanced wind energy systems.

Marine and riverine hydrokinetic turbines share many characteristics with wind energy systems. In particular, tidal energy converters, free-flowing river and stream turbines and ocean current turbines capture kinetic energy from the flowing water in a similar way as wind turbines capture energy from wind.

As a result, the new *Metric Space* proposed for ATLANTIS can easily be adapted to hydrokinetic energy systems as well. The following sections introduce briefly the *Metric Space*, apply it to a Tidal Energy Converter (TEC), and propose some technical performance targets for a new potential ARPA-E Program.

A. Metric space definition

The proposed *Metric Space* considers two metrics M1 and M2. The first metric (M1) represents the power generation efficiency of the turbine (or a farm of turbines), and the second metric (M2) the specific swept-rotor-area per unit of total-mass (m^2/kg) of the turbine (or the farm). Combining these two metrics in a two-dimension orthogonal space displays the LCOE standards as isolines.[8] This resulting *Metric Space* is particularly useful to evaluate new design concepts and to select research tasks needed to improve the technology while navigating across the LCOE isolines. The next paragraphs introduce the metrics and LCOE isolines. All the variables and parameters of this section are expressed in the metric system.

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[7] ARPA-E ATLANTIS Program. https://arpa-e.energy.gov/?q=arpa-e-programs/atlantis
[8] Garcia-Sanz, M. (2019). A metric space with LCOE isolines for research guidance in wind and hydrokinetic energy systems. Submitted to Wind Energy, Wiley.

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 output of the turbine – i.e., the electrical power generation at the point of interconnection of the turbine to the internal grid of the farm -- in Watts –see eq.(2). P_{w1} is the power of water in Watts –see eq.(3). Both powers, P_{e1} and P_{w1}, are calculated at the same below-rated water speed V_1 (e.g., V_1 = 1.5 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 farm, electrical losses L_e (substation and electrical lines, intra-farm and farm-to-shore), turbine availability A_v and other losses L_o, like water shear and others –see eq.(5). In summary, the main equations for M1 are:

$$M_1 = \frac{P_{e1}}{P_{w1}}\Big|_{at\ V_1} = C_p\ \mu \tag{1}$$

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

$$P_{w1} = \frac{1}{2}\ \rho\ A_r\ V_1^3 \tag{3}$$

$$C_p = C_{pmax} \tag{4}$$

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

where:
→ ρ = 1025 kg/m³ is the density of water,
→ $A_r = \pi R^2$ = swept area of the rotor (in m²) [9]
→ V_1 is the selected undisturbed upstream below-rated water velocity without any water shear effect (for example = 1.5 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 farm,
  - L_e: electrical losses (substation and electrical lines, intra-farm and farm-to-shore),
  - L_o: other losses, including water shear and others,
  - A_v: turbine availability.[10]

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

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[9] For both, Horizontal Axis Water Turbines (HAWT) and Vertical Axis Water Turbines (VAWT), A_r is the area of the cross-section of the rotor, perpendicular to the water direction. For submerged tethered turbines that move in the ocean, A_r is the area of the annular path described by the tethered system.

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

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

to the electrical power per unit area of the rotor (W/m²) at the selected below rated water speed V_1: i.e., M1 = k (P_{e1} / A_r), with k = 1/(0.5 ρ V_1^3).

<u>Metric M2</u>

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

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

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

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

where f_t is the material factor, f_m the manufacturing factor, f_i the installation factor, m_c the mass of the component in kg, and z the number of components for the turbine.[11]

The equivalent mass M_{eq} includes all the main components (m_j, j = 1, 2…. z) of the turbine, from the water stream to the electrical output, all in kg. For the *Tidal Energy Converter* studied in the next section, this corresponds to: m_1 = rotor, m_2 = nacelle, m_3 = cross-arm structure, m_4 = tower, m_5 = foundation, m_6 = electrical system –with z = 6 in this case. 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 hydrokinetic energy systems is defined here as a high corrosion resistant austenitic stainless steel.

The actual mass of each component, made of its original material, is represented by m_c and is expressed in kg. The material factor f_t is non-dimensional, and represents the ratio between the cost of one kilogram of the original material ($/kg) divided by the cost of one kilogram of steel of reference ($/kg) –see Table 2. The manufacturing factor f_m is also non-dimensional, and represents the ratio between the cost per kilogram of the manufacturing of the component ($/kg) divided by the cost of one kilogram of the original material of the component ($/kg) –see Table 3. 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) –see Table 3. The equivalent mass M_{eq} can also be calculated by dividing the CapEx ($) by the cost of one kilogram of steel of reference ($/kg).

<u>LCOE Isolines</u>

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[11] In case of 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 turbine (see Table 3) and n the number of turbines.

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

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

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

Putting the two metrics M1 and M2 together in a two-dimension orthogonal space enables identification of LCOE contours of constant value or isolines for each case of study. Figure 1 shows the *Metric Space* with the M1 and M2 metrics and the LCOE isoline for the tidal energy converter (TEC) based on the Sandia National Labs Reference Model 1 (RM1), detailed in the next section.[12,13]

B. Example 1. A Tidal Energy Converter

The case corresponding to the circle in Fig.1 is presented here as an illustrative example to understand how to calculate the metrics. As mentioned above, this case is based on the tidal energy converter (TEC) defined by Sandia National Labs as the Reference Model 1 (RM1).

- *Metric M1*:

  Every turbine of this TEC has the following hydrodynamic coefficient and losses: C_{pmax} = 0.45, L_g = 0.10; L_{dt} = 0.08; L_w = 0; L_e = 0; L_o = 0 and A_v = 0.95. Applying eqs.(4) and (5) gives C_p = 0.45 and μ = 0.7866, which in eq.(1) results in M1 = $C_p\ \mu$ = 0.3540.

- *Metric M2*:

  The TEC of this example is a dual rotor machine, with two rotors of a 20 m diameter each, which gives a total swept area of A_r = 628 m^2. The masses and factors of the two rotors, two nacelles, cross-arm structure, tower and foundation are shown in Table 3. Applying eqs. (7) and (8) results in M_{eq} = 2105527 kg, which with the swept area A_r = 628 m^2 in eq.(6) gives a metric M2 = 0.0298×10^{-2} m^2/kg.

- *Associated parameters for LCOE calculation*:
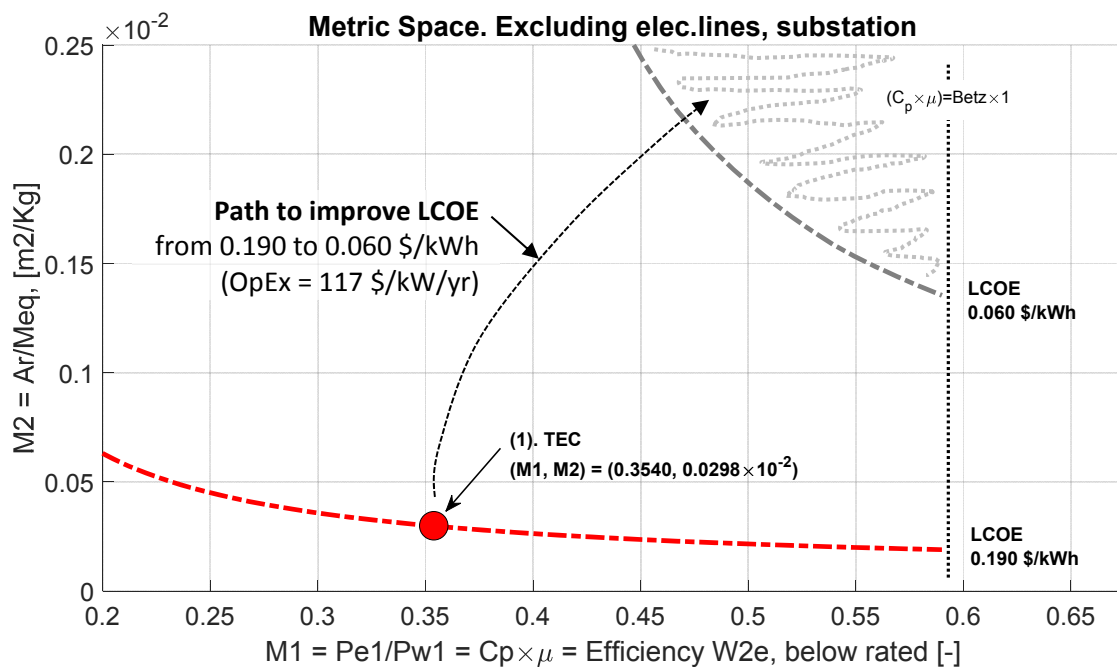
  Additional parameters for this tidal energy example are the following:
  — Water: site with average speed of V = 1.16 m/s at hub height, Weibull probability distribution with shape = 1.9 and scale = 1.31, V_{cutIn} = 0.5 m/s, V_{cutOut} = 3 m/s, and w_{shear} = 1, with P_e = 0.5 $\rho\ A_r\ C_p\ \mu\ (V\ w_{shear})^3$
  — Density of water, ρ = 1025 kg/m^3
  — Sea conditions: North Atlantic
  — Rated electrical power per turbine (two rotors per turbine), P_{er} = 1.2 MW
  — Hub height = 45 m

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[12] Neary V, Previsic M, Jepsen R et al. Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies. Sandia National Laboratories. Technical Report SAND2014-9040, March 2014.
[13] Segura E, Morales R, Somolinos JA. Cost Assessment Methodology and Economic Viability of Tidal Energy Projects. Energies, MDPI. 2017; 10, 1806: 1-27.

— Water depth = 60 m
— OpEx = 117 $/kW/yr
— Number of turbines in farm = 100
— Rated electrical power of farm = 120 MW
— Area farm = 7600 m x 1300 m = 9.88 km^2
— Farm power density = 12.15 MW/km^2
— Fixed charge rate, FCR = 8.2%
— Project number of years = 20 years
— Cost Steel Ref., C_{Sref} = $2.0/kg (high corrosion resistant austenitic stainless steel)

Metric Space. Excluding elec.lines, substation

$(C_p \times \mu) = Betz \times 1$

Path to improve LCOE
from 0.190 to 0.060 $/kWh
(OpEx = 117 $/kW/yr)

LCOE
0.060 $/kWh

(1). TEC
(M1, M2) = (0.3540, 0.0298 $\times 10^{-2}$)

LCOE
0.190 $/kWh

M2 = Ar/Meq, [m2/Kg]

M1 = Pe1/Pw1 = Cp$\times\mu$ = Efficiency W2e, below rated [-]

Fig. 1. Metric space definition. Example 1, TEC.

Table 2. Material factors (raw materials).
f_t = cost original material ($/kg) / cost steel of reference ($/kg).

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

(*) Steel of reference = high corrosion resistant austenitic stainless steel,
like grade 304 or 316, with a cost of $2 per kg.

Table 3. Information for M_{eq}, Example 1, TEC.

j	Component	m_j	f_{tj}	f_{mj}	f_{ij}	m_{cj}
1	Rotors (blades, pitch, bearings)	28126	4.0	1.41	0.28	2618
2	Nacelles (generator, drive-train, yaw…)	616088	1.0	4.13	0.60	107564
3	Cross-arm	410726	1.0	8.07	1.05	40582
4	Tower (pile)	959067	1.0	4.08	0.94	159491
5	Foundation	91520	0.3	1.18	0.25	125455
6	Electrical system (substation, lines…)	--	--	--	--	excluded

Using these parameters, and excluding the substation and the electrical line costs, the associated CapEx is 3509 $/kW, which with the rest of parameters above gives an LCOE of $0.190/kWh –see corresponding LCOE isoline in Fig.1.

C. Envisioned program performance target

The proposed LCOE target for the envisioned ARPA-E program is: LCOE ≤ $0.060/kWh. Figure 1 shows the $0.060/kWh isoline at the upper-right area. A TEC system with a (M1, M2) point above that isoline, or inside the shaded area, meets the proposed target LCOE ≤ $0.060/kWh.

Figure 1 also shows a potential path to follow in the *Metric Space* to achieve this target, from the current (M1, M2) = (0.3540, 0.0298×10^{-2}) and LCOE = 0.190 $/kWh, to the target area with LCOE ≤ $0.060/kWh. Note that the figure has been calculated for the same list of associated parameters defined above.

Figure 2 shows again the original isoline of the proposed LCOE target for the TEC, LCOE = $0.060/kWh, and describes a multi-step strategy that tries to achieve that target. Beginning at the starting point (1), with (M1, M2) = (0.3540, 0.0298×10^{-2}) and LCOE = 0.190 $/kWh, we have identified two tasks (T_i, i = 1,2) as follows –see also Fig.2 and Table 4:

— Task T_1: from point (1) to (2). Increase the system efficiency, (C_p × μ) × 1.30. This moves the metric M1 to the right.
— Task T_2: from point (2) to (3). Reduce the equivalent mass of the system, M_{eq} × 0.38. This moves the metric M2 up.

These two tasks largely improve the efficiency and reduce the equivalent mass of the system. However, this is not enough to reach the LCOE target of 0.060 $/kWh. As seen in Figure 2, point (3) in the (M1, M2) Metric Space has a LCOE = 0.088 $/kWh, still far from the desired target. The proposed target cannot be achieved by only moving the (M1, M2) point right and up, improving the efficiency (M1 to the right) and increasing the swept area or reducing the equivalent mass (M2 up). It is mandatory to get additional improvements on some of the associated parameters as well. This will move the 0.060 $/kWh isoline down, as shown in Fig.3.
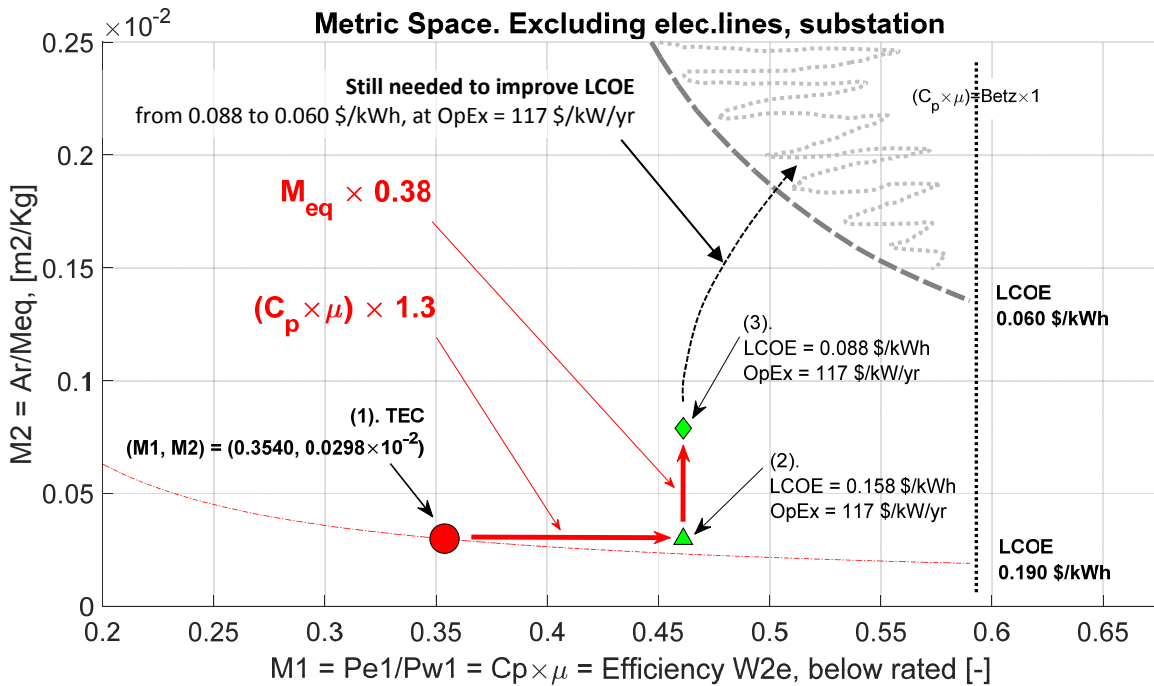
Fig. 2. Moving M1 and M2 to improve TEC design. Starting point (1), with (M1, M2) = (0.3540, 0.0298×10⁻²), LCOE = 0.190 $/kWh. Final point (3), with LCOE = 0.088 $/kWh.

For this final step, a third task is proposed –see also Fig.3 and Table 4:

— Task T_3: from point (3) to (4). Reduce operation and maintenance expenditures, OpEx × 0.38. This moves the 0.060 $/kWh LCOE isoline down, and keeps the same (M1, M2) point.

The final point (4) satisfies the objective LCOE ≤ 0.060 $/kWh for the new TEC. The metrics M1 and M2, the three identified tasks and four points of Fig.3 are shown in Table 4.

Table 4. Design path for TEC. See Fig. 3.

Point	M1 (--)	M2 (m²/kg)	OpEx ($/kW/yr)	LCOE ($/kWh)
1	0.3540	0.0298×10⁻²	117	0.190
2	0.4612	0.0298×10⁻²	117	0.158
3	0.4612	0.0789×10⁻²	117	0.088
4	0.4612	0.0789×10⁻²	45	0.060
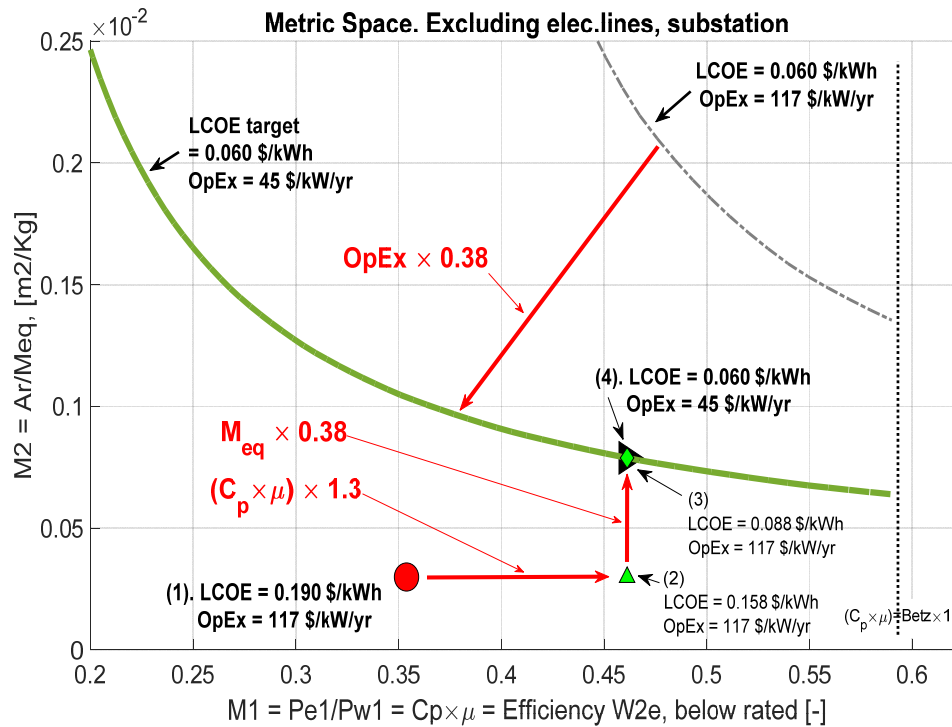
Fig. 3. Tasks to improve TEC design. Starting point (1), with (M1, M2) = (0.3540, 0.0298×10^{-2}), LCOE = 0.190 \$/kWh. Final point (4), with LCOE = 0.060 \$/kWh.

In summary, this example has shown some tasks needed to satisfy the proposed target LCOE ≤ 0.060 \$/kWh for the new TEC. Breakthroughs for new designs that achieve a better efficiency (T_1), less equivalent mass (T_2), and a much cheaper OpEx (T_3) are needed.

Purpose and Need for Information

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future programs intended to help create transformative hydrokinetic energy systems. ARPA-E will not pay for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI on a non-attribution basis. This RFI provides the broad research community with an opportunity to contribute views and opinions regarding the hydrokinetic energy system development path. Based on the input provided in response to this RFI and other considerations, ARPA-E may decide to issue a FOA. If a FOA is published, it will be issued under a new FOA number. No FOA exists at this time. ARPA-E reserves the right to not issue a FOA in this area.

REQUEST FOR INFORMATION GUIDELINES

ARPA-E is not accepting applications for financial assistance or financial incentives under this RFI. Responses to this RFI will not be viewed as any commitment by the respondent to develop or pursue the project or ideas discussed. ARPA-E may decide at a later date to issue a FOA based on consideration of the input received from this RFI. No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any

submitted material. ARPA-E reserves the right to contact a respondent to request clarification or other information relevant to this RFI. All responses provided will be taken into consideration, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that might be considered proprietary or confidential.**

Responses to this RFI should be submitted in PDF format to the email address ARPA-E-RFI@hq.doe.gov by **5:00 PM Eastern Time on July 19th** 2019. ARPA-E will not review or consider comments submitted by other means. Emails should conform to the following guidelines:

- Please insert "Responses for RFI DE-FOA-0002142" in the subject line of your email, and include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center (FFRDC), government-owned/government-operated (GOGO), etc.), email address, telephone number, and area of expertise in the body of your email.
- Responses to this RFI are limited to no more than 5 pages in length (12 point font size, single or double spaced).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential methodologies.

- **Questions:** ARPA-E encourages responses that address any subset of the following questions of relevance to the respondent and encourages the inclusion of references to important supplementary information.

  1) Is the proposed 0.060 $/kWh LCOE target (excluding substation and intra-farm/farm-to-shore electrical lines) an appropriate objective for the envisioned ARPA-E Program on hydrokinetic energy converters, including tidal/riverine/ocean systems?
  2) What comprises the OPEX costs for existing tidal/riverine/ocean systems? Which of these costs are "fixed", and which can we actually improve?
  3) The data used in the metric space was from the Sandia National Lab study cited above,[14] which is somewhat dated and may no longer represent state of the art. Are there more recent case studies with similarly detailed cost / performance data that ARPA-E could use for the baseline case in the metric space?
  4) What are state of the art costs for tidal installation?
  5) What are the controls challenge(s) and/or design optimization priorities today?
  6) What are ideas for designing radically new hydrokinetic energy systems that significantly reduce the equivalent mass of the components, including the cost of installation, manufacturing and materials needed, and improve the system efficiency?
  7) Noting that the designs would likely be different for systems at various depths, how do we prioritize the depth to focus on? What are the tradeoffs? Is there an ideal range?
  8) What are approaches to lower O&M costs? For example:

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[14] Neary V, Previsic M, Jepsen R et al. Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies. Sandia National Laboratories. Technical Report SAND2014-9040, March 2014.

- Ability for the system to bring itself to the surface for maintenance
- Designed to need very minimal maintenance
- Robotic maintenance (and perhaps co-design of system and its maintenance system)
- What other approaches are we missing?
- What are the challenges and opportunities with each of these approaches?

9) This RFI used a tidal energy system in the metric space analysis as an illustrative example of that class of hydrokinetic device (i.e., assumed that current/riverine systems would have similar characteristics/considerations, and would need to follow a similar trajectory). Is that assumption valid? If not, why? What's different?

10) Would advanced hydrokinetic research benefit from the development of new computer tools to design and simulate the hydrokinetic energy converters?
    o In that case, should these new computer tools incorporate some particular hydrodynamic equations, submerged body representation, modular capabilities (libraries), control co-design optimization techniques, electrical systems, economic analysis, and perhaps parallel algorithm implementation capabilities?

11) Would advanced hydrokinetic research benefit from gathering or generating new experimental data accessible to research and engineering teams to validate computer tools and improve new designs?

12) Are there analyses that characterize the available resource while going beyond satellite-based data to consider topology/velocity data?

13) Radical redesign will also need to incorporate potential environmental impact/regulatory/permitting considerations early in the co-design process. What capabilities exist to do such an analysis?

14) Any other relevant comment or suggestion for a potential new ARPA-E program on hydrokinetic energy systems?