Ocean Observing Prize Rules Workshop Notes

Now Open for Public Comment

The Ocean Observing Prize DEVELOP Competition will release a Final Rules Document that will provide participants with instructions and rules to participate in the DEVELOP Competition of the Ocean Observing Prize. Initial technical specifications and key questions were drafted by the prize team and then shared with attendees during the Rules Workshop on May 27 and 28, 2020. This document is a compilation of questions and notes from the Workshop. These Rules Workshop notes are posted on the Ocean Observing Prize HeroX website to solicit public comment and feedback.

DOE is collecting feedback on anything in the Rules Workshop Notes through July 10, 2020. Submissions should be sent to wptoprizes@ee.doe.gov with the subject "Ocean Observing Prize Rules Workshop". Please reference the relevant line numbers from this document that relate to your comment.

Table of Contents

Executive Summary

The Ocean Observing Prize is a DOE and NOAA-led prize meant to incentivize innovative systems that integrate marine renewable energy with ocean observing platforms. The DISCOVER Competition and DEVELOP Competition are two separate competitions that make up the Ocean Observing Prize. The Prize Administration team is currently scoping the rules for the DEVELOP Competition and hosted a Rules Workshop to solicit feedback from the public on preliminary ideas.

Over 60 participants joined a virtual Rules Workshop on May 27 and 28, 2020. These participants were divided into three of six breakout groups, each of which focused on different subsystems or components. During each 45 minute session participants provided feedback on the draft rules document and answered questions relating to that subsystem or topic. This feedback was recorded as notes.

Summaries for each breakout group are below, and detailed notes from each group can be found under that particular group's section.

- **Impact and Integration:** Participants assessed the real-world benefits and potential end-uses of systems that are likely to emerge from the prize and asked what are the integration issues that need to be considered when putting all of the subsystems together?
  Physical Characteristics: Participants provided feedback on physical aspects of systems to compete in the prize, such as: max overall size, weight, and volume, depth rating, and more.
- **Instruments and Payload**: Participants provided feedback on different sensors that should be hosted by the vehicle for data collection and ways to represent dummy payloads which are representative of real instruments in power draw and duty cycles.
- **Navigation, Control, and Communications:** Participants provided feedback on underwater vehicle navigation and control methods, bearing in mind that this is an energy prize and not an autonomy prize. Related to this topic is communications and how data will be relayed on and off the vehicle and through what medium.
- **Power and Energy:** Participants provided feedback on power generation abilities of vehicles in this size range using wave energy harvesting and their ability to recharge batteries while balancing other energy consumers on the vehicle.
- **Operations and Safety**: Participants provided feedback on various operational aspects of these systems such as safety requirements, launch and recovery of the vehicles, and required infrastructure for handling and transporting.

In addition to the six breakouts, the team collected information on testing during each breakout. No testing will take place during the Design Contest, but competitors need to know what they will eventually be assessed against in the subsequent Build Contest. Participants provided feedback on practical ways to assess performance of prototypes. This feedback is reflected in the notes section of each breakout.

Purpose

The Rules Workshop for the Ocean Observing Prize DEVELOP Competition - Design Contest was held to help the Prize Administration team inform the contest scope, reduce risk, ensure a level playing field, and generally address open questions. Workshop participants represent a variety of backgrounds and subject matter expertise in order to cover a diversity of perspectives; specifically, unanimous agreement or even consensus on any particular topic was not an objective. The feedback collected through the Rules Workshop will not dictate the official rules for the Design Contest, but will be considered by the Prize Administration team when writing the Official Rules Document.

The Ocean Observing Prize team is seeking any additional feedback on the breakout topics, missions, trials, or any other information contained in this document.

Introduction

The Workshop had six different topical areas on which the Prize Administration team requested feedback. In each of these topical areas, workshop participants were encouraged to provide feedback on the following:

- Ways to score or assess
- Ways contestants might game or cheat
- Integration issues with other systems
- Best practice in industry
- Safety and regulatory aspects

The following topical areas had dedicated breakout groups:

1. **Impact and Integration:** Participants assessed the real-world benefits and potential end-uses of systems that are likely to emerge from the prize and asked what are the integration issues that need to be considered when putting all of the subsystems together?

2. **Physical Characteristics**: Participants provided feedback on physical aspects of systems to compete in the prize, such as: max overall size, weight, and volume, depth rating, and more.

3. **Instruments and Payload**: Participants provided feedback on different sensors that should be hosted by the vehicle for data collection and ways to represent dummy payloads which are representative of real instruments in power draw and duty cycles.

4. **Navigation, Control, and Communications:** Participants provided feedback on underwater vehicle navigation and control methods, bearing in mind that this is an energy prize and not an autonomy prize. Related to this topic is communications and how data will be relayed on and off the vehicle and through what medium.

5. **Power and Energy:** Participants provided feedback on power generation abilities of vehicles in this size range using wave energy harvesting and their ability to recharge batteries while balancing other energy consumers on the vehicle.

6. **Operations and Safety**: Participants provided feedback on various operational aspects of these systems such as safety requirements, launch and recovery of the vehicles, and required infrastructure for handling and transporting.

In addition to the six breakouts, the team collected information on testing during each breakout. No testing will take place during the Design Contest, but competitors need to know what they will eventually be assessed against in the subsequent Build Contest. Participants provided feedback on practical and assessable ways to gauge the performance of the prototype systems. This feedback is reflected in the raw notes of each breakout.

Additionally, information was collected on potential missions, the suggested trials to test out systems, and the organizers collected feedback on the general structure and overall intent of the competition.

This document is structured to reflect the six breakouts and present summaries and raw notes from the participants for each breakout in addition to the testing and general feedback.

Participants

Approximately 62 participants were involved in the workshop, including facilitators, notetakers and webinar hosts. See Figure 1 for participant affiliation.

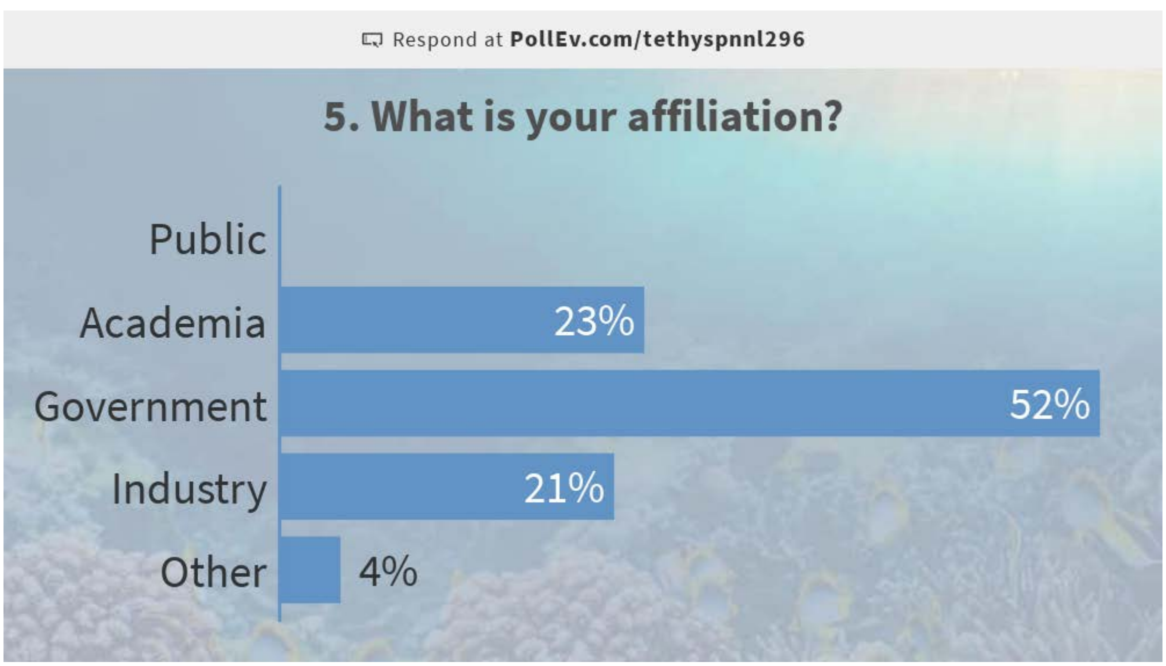

Figure 1 - Participant Poll: "What is your affilliation" N = 52

Rules Workshop Discussion Notes

The following subsections are the consolidated notes from the Workshop organized by breakout groups. Each section includes a summary of the information collected, drafted by the facilitators, and the consolidated notes responding to facilitator questions as recorded by notetakers during the workshop.

Impact and Integration

Summary

This group of about 20 subject-matter experts identified mission-specific issues around energy budgets and charging logistics, instrumentation needs and availability, and overall mission design and system integration. The group highlighted questions regarding the prize definitions and structure, the intent, and what was within scope - items that should be resolved and clarified going forward.

For Ice Sheet monitoring, the group noted that there is very little data available so any data would be useful; the distance between charging location and monitoring location may be a significant factor. Upward-looking echo sounder would be especially useful. There is some potential for overlap in missions with the Great Lakes being ice-bound at times.

For Great Lakes invasive species monitoring, participants noted that the wave resource may be limited or more challenging than for other missions; but at same time it was thought that the duty and charging cycle could be shorter - charging could be close to observation. eDNA was noted as a potentially significant dataset.

For Hurricane monitoring, the energy tradeoff between instrumentation and mobility was noted. A week-scale charging time and larger battery capacity to enable multi-day observation could be one concept. CTD profiler and ADCP (shear) and air-surface temperature instruments are all relevant; some sense that instrumentation for this mission would be more off-the-shelf available than for other missions.

Notes

- Is a recharge cycle for the AUV of a couple days to couple weeks, dependent upon battery capacity and vehicle performance, permissible for a resident AUV?
    - Applications-specific. Need to address each application separately to answer this question.
    - Not just about mission profile but also sensor payload and are where you're working. Tropical seas have shorter research times
    - Take what we can get in Arctic. So few observations, a couple of days or more would be good to get to those observations.
    - Arctic/Antarctic most $$ for power budgets, 2-day mission requires a lot of capacity comparison in comparison with Great Lakes, which only requires a few hours between charge cycles.

- If you can get multiple days of operation after charging for a couple of weeks, in a hurricane setting, for example, 2-3 days of operation, that can be useful. In another setting with same scenario, charging for a couple weeks, then going into an ice operations, maybe capture an event that we couldn't before with that kind of charge.

- What are likely sensors to be used on board the vehicle?
  - For Lakes application, predefined sensors: imagery, cameras, potentially acoustics for bottom classification.
  - To encourage people to think outside, eDNA for Great Lakes, in addition.
  - eDNA. With hurricane scenario, CTD system measures temp and depth. Arctic mission: Measuring amount of ice in monitoring glaciers moving in?
  - Big application for us is monitoring sea ice and subglacial ice. Upward looking/inverted Echo Sounder.
  - Great Lakes. Sensor suite, while out there, measuring water quality parameters, temperature.
  - Current regime is ongoing sample over time allows us to map ocean features and how they mix and don't mix with different storms coming by, so we can predict whether the storm will be stronger or weaker. We want to know more about intensity of storms.
  - They want to add to hurricane sensors. ADCP to measure shear.
  - Accelerometer is a low-power sensor that is still of use.
  - Also measure wave energy. Statistical measuring of waves for WEC would be useful information.

- What useful data would be collected by these vehicles?
  - Advantage of AUV over a glider, dissipation rates and so forth. Useful data to be collected while recharging.
  - Tradeoff between payload package and recharge time, tradeoff between payload package and mission time.
  - In light of that, are there nonpower-hungry observations that could be captured with less impact on charging? Accelerometer or wave observation, with just floating.
  - Leave CTD on is low data/transfer requirement, useful for deep salinity just before or just after the storm goes through. Also useful in Great Lakes environments as well.
  - Temperature is important to measure. Water temps.
  - Some measure of downward light irradiance.
  - What about measuring shape of the ice, the boundary.
  - Could measure the shape of the ice acoustically, usually we use a bottom tracker, side scan sonar, to look at the ice above.
  - For hurricanes, water (surface) and air temperature is important, affecting the weather.
  - And wind speed would be interesting, but don't know how to do that with AUV. Sonic wind speed could be done?

    - Important for device to anticipate storms, rather than coming from remote data? Some feedback would be interesting. Forecasters would enjoy the data.
    - Feed in mission parameters. If a storm is coming through, may want to measure ice more frequently if it's about to be hit by a storm.

- Are there industry standards that should be adopted or enforced for sensor integration, data collection, or communications?
    - Standard for sensors would be serial interface, but most common in oceanographic sensor world is RS232, but may not be obvious for how we want to describe this.
    - Several talking about adopting a robot system, ROS.org is one place to look. Larger companies like Google are looking at that.
    - A lot of folks are going to use 802.3 or ethernet for internet-facing things.
    - RS232. Iridium standards.
    - SAE has standards for control systems. Standard messaging set.
    - Standards should be open standards.
    - Given extreme environments in Hurricane, no docking station will be necessary.

- What issues need to be considered for integrating all of these subsystems together?
    - Power management should be a big part of the challenge. Some of that should be up to contestants.
        - Is it okay for rules to dictate various modes of operation? Minimal acceptable? Emergency Mode, Degraded mode, versus Full operational Mode.
        - How much reserve do we want? My expertise is making systems much more efficient by optimizing power and energy. Need to be smart about power. I want to compete that way.
    - You could see competitive choice there is around a stop and recharge, retract and move on, or a WEC component that is always sort of on in many ways. Not completely feathered. Innovations in those two areas are a tradeoff. Competitive advantage in one over the other. That's where the competition is focused on. Mistaken competitive advantage, though? But integration between WEC and AUV is likely to be that tradeoff of size and operational capabilities. Stop and charge or charge by moving.
    - Subsystems within the same AUV for this argument. Instrumentation and charging substations: how do we integrate multiple modes? Full performance, standby modes.
    - Integrating in one device.
    - Physical characteristic issue. Center of gravity, weight and balance issue.
    - This brings it back to the maneuverability issue. Integrating makes AUV larger and heavier, certain tasks not as easy to accomplish. Collecting data in a tighter spot might be challenging.
    - Distance between where you can charge and where you need to do observations is critical for ice shelf.

- Subsystems housed in same AUV, but power management, monitoring, communication are all different. Need multiple modes to manage power distribution for different activities.
- Keep safety systems completely separate. Navigation beacon transmitting should be separate from the WEC or anything else that could go wrong. Make sure we get the vehicle back.

- Are the intended missions good prototypical missions for a resident AUV?
  - Some depends on the purpose of WEC integration. Two types of missions: duration or allow AUV to carry a sensor payload with a higher power draw than conventionally feasible. What do we want the WEC to do?
  - Some missions are long duration, and they will all have specialized sensors.
  - Higher draw of energy for some sensors - need an energy profile. (e.g. salinity sensor)
  - Maybe that's the competition. Want the WEC to be an effective part of AUV. Cycles should be integrated with other components of AUV, not added. Low TRL at early stage, same components in advanced AUVs. These would converge because they are low tech.
  - Essentially, this is the WEC challenge encompassed in all of this. Fatigue of rigid components in particular. Recognizing that rigidly connected bodies almost fail in fatigue almost instantly. This is the design challenge.
  - Hurricane case, sitting in a huge part of the ocean waiting for a hurricane to show up. In ice scenario, it would be a much closer watch circle; don't want to run into ice or icebergs, on a scale of less than a km, likely.Great Lakes probably the same range, half km to a km, depending on specifics of the mission.
  - Arctic application most challenging for power budgets and most costly to deploy equipment. Hurricane application might be quickest payoff, Great Lakes might be easiest to do.
  - Doing some of the ice adaptability in Great Lakes and Arctic. Ice in both places. NOAA would volunteer to do that initial demo.
  - Is a recharge cycle for the AUV of a couple days to couple weeks, dependent upon battery capacity and vehicle performance, permissible for a resident AUV?
  - It depends and varies a lot. Obvious concern is how close can we get a tender ship, or does AUV need to go somewhere accessible for charging?
  - Hurricane scenario: needs to go 1,000 or more miles away. Arctic is perhaps similar. Big concern from plenary session that comes up here. In plenary session, for design/build competitions, type of batteries used came up. Not all batteries are created equal.
  - Resident AUV, need a whole different set of hotel needs/loads, whether those are for sensors or other monitoring. Can't truly go to sleep. Some sensor needs to tell it to go resident or out of residence. With hurricanes, it may have a massive watch circle, something as simple as gps may be included. Whereas if the AUV is hanging out at the surface for a period of time, may have a different set of controls.

- Are there industry standards that should be adopted or enforced for sensor integration, data collection, or communications?
    - My concern is that if we are tied to one type of batteries, it may not be feasible to meet some of these operational requirements. Safety needs to determine batteries, and contestants need to be able to choose their own batteries to optimize mission performance and wave generation.
    - The competition should try to avoid becoming a battery competition, hence the need to decide on a standard battery and reward the ability of the integrated AUV/wave power unit to charge quickly
    - Mission dependent. Time constraint of event is important (hurricane is quick or might be sequential but changing ice mass is slow). Loitering around waiting for a hurricane to pass by? That could be a matter of months. Ice changes a lot slower than that, so there's more time for charge. Is there a huge time constraint for something happening so fast that we can't get back out? Mussel migration might be a different story.
    - Batteries start to add a lot of weight and space for long duration. With 6- or 10-hour duty cycle, battery size might be less important.
    - Prototype versus deployable model is an issue.
    - Invasive species mission is a little bit delicate, finding those species.
    - WEC in the Great Lakes is more difficult than in the Atlantic.
    - Sensors for Hurricane are off the shelf, whereas Great Lakes and ice, are there sensors that work for those scenarios? Or do teams have to build them?

Physical Characteristics

Summary

Approximately 25 domain experts discussed the rules regarding physical characteristics in the competition over three separate sections. Interesting ideas from the sessions include stimulating creativity by allowing functional requirements to determine the physical characteristics of the device, rather than define hard constraints within the prize. A prize-defined use case would allow the definition of these functional requirements, providing guidance for the otherwise widely varying likely physical characteristics.

Where possible, the competition was encouraged to incentivize the desirable physical characteristics through a graduated scoring scale; leaving hard competition rules regarding physical characteristics to be determined by the limitations of the (well-chosen) test facilities and other realities of the test.

Participants voiced a desire to focus the competition on the energy harvesting portion of the challenge, expressing concern over the added complexity of co-developing autonomy. There was interest in potentially multiple-bodied solutions (e.g. surface docking stations), again with a strong primary focus on the energy harvesting portion of the design and development.

To ensure that competitors arrive with a level of readiness to compete at the desired level of complexity, the prize was encouraged to consider having applicants submit videos of the vehicle performing basic capabilities as a stage gate, potentially as a part of a critical design review.

Notes

- What are the logistical constraints that should be considered for these vehicles? Is a pallet the right volume constraint for shipping?
    - The pallet size described is not consistent with the length of the AUV. It will be difficult to make a UAV that fits on the pallet in one piece that has the required capabilities. Making a UAV in multiple parts to be joined together for the trials increases risks. To reduce risks and increase probability of a successful competition we would welcome a relaxing/removing of the requirement to use a standard pallet.
    - Reasonable, have to consider freight/airfare for transporting
    - Most oceanographic equipment is sent in containers, a pallet may be restrictive. A 20' shipping container is suggested alternative
    - NOAA uses a combination of deployment/storage containers. More space will be needed for additional equipment in most cases. Offshore distance necessary based on mission (small boat deployment vs. a ship) should be considered. Testing capability (pools, etc.) is also a factor.
    - If the length is 2.5 m, the shipping size should be enlarged to accommodate that. A 20' container seems too large. A double wide pallet would work. Does this size requirement include miscellaneous tools and equipment needed? (laptops, tools?) No - just the vehicle.
    - If we make a 2.5m long AUV we would like to ship it in one piece. Forcing teams to split their hull into 2 or 3 parts unnecessarily increases risks of water ingress and/or other problems. This unnecessarily decreases the number of successful entries that the competition will receive.
    - Wave Energy Prize: Submit drawings ahead of time with regard to volume/layout.
    - Suggest giving guidance rather than finite limits for portability, shipping, deployment.
    - Two-pallet dimension instead of one, perhaps a happy in-between the one-pallet restriction and a shipping container.
    - Statistically speaking the success rate in this trial will be adversely affected by the requirement to ship on a standard pallet. If we design and build a 2.5m long UAV then we would like to ship it in one piece and not split it into several pieces for shipping. Limiting the size of the uav to 1.2m long would likely result in difficulty meeting the power requirement.
- Should a shipping weight restriction be used?
    - A volume constraint is recommended - but there is a difference between deployment (2 person) and size restrictions.
    - Is the expectation that they will be manually deployed by two people? Or can they expect to have a mechanism to deploy them? (Use case dependent)
    - Pallet requirements and size help to standardize the AUV size with respect to the testing requirements (pool access, etc.). Don't try to limit innovation beyond testing/deployment requirements.
- What is the max size and weight for two-people to safely manage?

    - Two-person not realistic for real-world, use a crane typically, usually have cranes or davit that are more than capable, but lighter is generally better
    - Should we include bigger/heavier vehicles to test? Two-person deployable vehicle sounds reasonable.
    - A-frames are usually used for NOAA missions, but smaller vessels can do deployments (Gulf of Mexico for ex) and are a benefit for recovery/deployment.
    - Basis for 80 kg selection? Pulled from existing designs. OSHA safe lift limit for 2 people is 75 lbs. If you are using a crane this limitation is lifted.
    - Depth missions may require heavier platforms compared to shallow missions.
    - DOE is trying to demonstrate basic functionality with this Prize, but these systems aren't meant to be commercially ready by the end of this prize.
        - Question: Can it be a modified current system?
        - The DOE is considering that. They can modify a current platform as long as it meets the necessary requirements.
- Could an 80 kg vehicle accommodate a wave energy converter?
    - Yes, this could be a viable size, but it could pose some challenges. It also depends on how much power you need. Estimated ~50 watts may be necessary. Power requirement will drive this weight. Low wattage may be acceptable based on 'down time' allowed for recharging. Use case dependent. Great Lakes use case may be optimal for a more controlled environment with planned recharging.
    - Likely power output 0.5 to 25 watt. Consider battery pack for recharge time, especially if targeting fast recharge times if deployed for hurricane purposes.
    - Does an 80 kg with 30 kg for WEC sound reasonable for a WEC developer? It sounds reasonable, initially thought it would be larger. Commercial WECS may require a larger weight, and may not be completely scalable. (Generator and batteries do not scale). Geometry is something to be considered. AUV functionality/WEC functionality as a form factor.
- What are the minimum infrastructure requirements (if any) to safely deploy and recover the vehicles from a pool? From a coastal ocean environment in conditions up to sea state 4?
    - Discussion of using a crane vs small boat for deployment. In the Atlantic is may be easier to use a small boat.
    - Real world applications - you have to drop out of an airplane for hurricane season. You're limited to that deployment req. Alternatively; you can deploy beforehand and have them recharge until needed. (Build a 'fence' in hurricane alley).
    - Have to consider biofouling, vessel strike, or vandalism when surface charging.

- Should depth rating be an assessed metric? Does it matter for this stage of development? How deep underwater must they go for testing?
    - Depth requirement will drive weight. If it's not as deep, you will be able to hit the weight requirements. This is relevant to use case.
    - Concept of 'bonus points' rather than disqualification based on system requirements. Make them 'recommended' guidelines, rather than required. However, consider later potential issues such as testing capability (pool size, doorways, OSHA requirements for weights) Set disqualifications rather high, based on limitations (such as pool, etc). May deduct points based on larger gaps from recommendations, but not full disqualification.

- Should the rules incentivize faster devices, or maneuverable devices, or both?
    - Steer away from the AUV aspects, focus more on the energy integration
    - There should be enough speed to drive against currents, and dive
    - Maneuverability may not be as essential (outside of avoiding ships, however this would change if the mission is in the Arctic).
    - The speed requirement of 0.5m/s effectively excludes gliders from the competition. Gliders provide inherently greater range and endurance per unit energy than propeller driven AUVs and are typically more capable in terms of controlling depth for making measurements. Would you consider one speed requirements for gliders and a different speed requirement for propeller driven craft?
    - Buoyancy requirements?
    - Positive buoyancy is necessary, high reserve buoyancy is helpful – in event of system failure, it can help it rise to the surface.
    - Should there be center of gravity considerations to force righting moments for stabilizing? Maybe beyond the scope of what to consider here.
- Are there shipping or transportation restrictions to consider? Shipping of Li--Ion batteries for instance
    - Lithium ion batteries do have shipping restraints (air), and it may be good to set safety precautions for storage, charging, discharging. Suggestion to prioritize safety.
    - Should we specify a standard/best practice for fire safety?
        - It may be good for all teams to use the same battery pack, or supply the battery pack at the testing facility so that they won't be shipped.
    - Is there a best-practice for battery fire mitigation to be used on a marine vehicle?
    - NDBC buoys employ a safety feature for discharge (controlled failure).
- Should waterproofness be demonstrated ahead of time, prior to arrival at the test tank? Perhaps through an online video submission? Is this a prequalification?
    - Suggestion to limit the number of teams in the progression by early testing/video submission (between kickoff and testing). An intermediate testing may be good. Idea of a design review (video submission for criteria - key performance parameters to be verified by video such as buoyancy, waterproofness, etc.). Past experience/performance may be helpful, but shouldn’t be the sole consideration.
    - Insert an intermediate step where a team submits a video to be scored based on vehicle success/capability? This would serve as a good check in for the teams who wish to participate in the pool testing.
    - Other competitions rely on virtual presence in some cases - RobotX competition
    - Need to ensure that competitors don’t cheat but swapping out parts during the video or submitting fraudulent videos
- Should vehicles design around vessel constraints such as available deck space, load limits for cranes or davits, etc.? If so which ones?
    - 200 lb davits (hand operated) are available at certain testing facilities. This might be a good limit to bear in mind.
- **Does the energy harvesting source have to be located within the vehicle?**
    - Conflicting resources management of the teams to either prioritize the design against requirements, mission specific goals, or the actual energy harvesting

component? Could the teams be given a standard AUV to start with to standardize payload, weight, dimensions, etc. This may allow more time to focus on the energy components necessary. The WEC could be deployed as part of the payload, for example.

- Additional thoughts
  - We spent some time discussing the physical requirement of the vehicle, mostly due to logistic and testing facility limitations. Most of those requirements are based on existing products in the market. In my opinion, such requirements will only limit innovations. By creating a ‘box’ (literally) based on commercial products in 2020 (which were developed in 2010s), I doubt we will be able to find any breakthroughs that truly deserves our investment for decades to come.

Instruments and Payload

Summary

Specify less in terms of instrumentation. Focus on defining the minimum mission for the testing. Taking the complexities of an AUV out of the equation might improve the outcomes for this prize. We need to decide if integration of the WEC and the AUV is a key part of this competition, and how much the AUV needs to be capable of doing. Funding will limit how much can be accomplished if we’re asking people to design an AUV, a WEC, integrate them, and add sensors. Support expressed for dummy payloads in terms of a generic mission. Recommending a standardized, modularized device with a CTD (provided, or specified) that can be used to validate energy conversion and quality of data collection. Energy conversion is the main focus.

Notes

- What is the minimum volume or weight required for a typical vehicle payload?
  - Current specs are fairly small (2 person carry). Expecting that effective (with respect to energy harvesting) devices will require larger size / wetted area.
  - Minimize specs for AUV design so that teams can focus on energy harvesting. Set basic requirements on volume, weight, power, and let the teams build around that. Several others agree that current specifications are too detailed. At most, give overarching performance goals. For the time-scales and cost considered here, some of these rules are too specific.
  - Consider not specifying if the energy conversion device needs to be integrated with the AUV, leave it open to the teams.
  - Teams need to choose those trade-offs between payload capability and size themselves.
  - Set a maximum volume or weight, but no reason to set a minimum. Need clarity here in rules.
  - Consider describing payload requirements in terms of power, not sensors or ports.
- What are the required instruments/systems for a vehicle? Which ones should be supplied to competitors and which should they source themselves?
  - Could a bare bones AUV be provided and let teams build a WEC to integrate into it? Providing a standard platform to all teams would allow teams to focus on energy conversion (buoyancy, location information, etc.).

    - One problem with this is the requirements of WEC designs, systems that people might design might not work with the provided platform. Don’t want to limit creativity.
    - Is there a reason this needs to be an AUV, as opposed to a buoy or drifter? Could be integrated later down the line. An AUV may be too complicated for this timeline.
- What sensors or instruments should comprise the payload package?
    - Depends on the mission - for invasive species monitoring, it would be needed to have a monitoring package on board. If the mission doesn’t matter for this stage of the competition, then instrumentation is not as important.
    - Recommended that there are metrics for each mission, let competitors determine the hardware/sensors they want to use in order to successfully complete the mission.
    - Having a camera on board does not provide evidence that a vehicle can complete a mission.
    - CTD should be involved. Video camera not necessary - many other sensors can get at the same information (acoustics, etc.). Consider both the test environment capabilities and at sea testing for sensing requirements.
    - Consider defining metrics (X payload, Y power, survivability) instead of requiring certain instrumentation.
    - Instrumentation is driven by the mission.
    - Payload could be a ‘spy’ to provide metrics for evaluation, instead of relying on participant data to evaluate efficiency of their device.
    - Payload vs. power consumption is affected by time between missions (charging). Describing the mission is key to define these other specifications. It’s not strictly a payload issue, but a time-sensitive issue.
    - Not all CTDs or installations of CTDs are created equal. It might be good to have a check for accuracy of data.
    - A minimum payload is ideal, with flexibility - if a device has capacity to swap out sensors to compete in all 3 missions, that should definitely be rewarded. Suggestion to have a competition with separate missions, and that a general device that can successfully compete in multiple missions would score higher.
    - Dummy power sinks help to understand power production capabilities of WECs. The WEC design is enough of an undertaking, without emphasizing all the integration / sensing aspects of instrumentation.
    - Still imagery is a critical component (especially thinking about Great Lakes mission).
    - Consider integrating something standard like a YSI sonde - but it might not be what you would use in all missions (inductive vs. conductive). A standard sensor suite helps with standard data and power requirements.
    - Consider a more standard oceanographic CTD, like Seabird.
    - Need to measure wave height as part of WEC operations and data collection.
    - ADCP would be required for hurricane mission. An integrated IMU (on a ping by ping basis) would also be needed. Power requirements depend on ping rate. Thinking about the hurricane mission, it would charge pre-storm, record as long

as possible, and dive to safety. Storm length ~3 days, so a series of AUVs might be required.

    - Recommended that operational guidelines at the national level be followed/ implemented for AUV requirements - don't need to reinvent the wheel.
    - Payload could be used for independent validation of energy conversion capabilities. Provide power needs of instrument.
- What instruments should be required for each vehicle?
    - CTD is the most basic instrument, should be required to collect mission information (for hurricane mission, temperature is necessary). Having a CTD makes a lot of sense, but specifying other instruments or types could lead to some gaming the systems.
    - Restricting requirements for payload will allow for focus on wave energy conversion.
    - The risk in adding requirements is adding other skill sets to the team. People will need to divide their time and talents - to enable integration of sensors, data processing, etc. Having a payload at all is just a demonstration that sensors could be powered on the vehicle. Propulsion is also a huge power draw.
    - What you do with a payload depends on the mission. Definitions shouldn't be so stringent to disqualify teams that might not have as much sensor/integration expertise.
- What instruments should be supplied by the prize administration team? Which ones should competitors be expected to acquire?
    - Think about it from a point-scoring perspective. If you can host X payload (or dummy payload) for Y time, you get Z points (or a fraction if you can't demonstrate mission completion)
    - Price is a consideration - are we going to buy CTDs for all companies?
    - Consider providing the AUV portion - the autonomy work + the energy conversion is a heavy lift.
    - Consider providing a CTD with a separate power source for collecting mission information.
    - If the intent is to have a single integrated WEC and AUV device, then we can't really provide a base AUV since the shape and other features would change with integration. A charging base WEC sounds like a completely different competition. We need to decide if we're focusing on autonomy, or energy conversion.
    - It's not realistic to design a WEC, integrate, and a custom AUV given the time and money available.
    - We cannot define the shape of the AUV - this is too limiting.
    - We don't want to limit ideas/creativity with a standard package, but we also want some control over standard payload (modular approach) to plan for future commercial developments (separating out vehicle and sensor package). Recommended a small instrument package for us to collect basic data on ocean obs.
    - Agreeing on a CTD package would help to establish a baseline. Should CTD package be required, but with the door left open for teams that want to do their own thing (with required specs).
    - Require proof of simple telemetry (e.g. line of sight RF)

    - Echosounder would be required for ice sheet - but not at all for hurricane. Are any acoustics required?
    - Need to decide: do we want flexible devices that can complete any of the 3 missions, or a general device that can handle dummy payloads and basic actions?
    - Recommended providing specifications instead of providing packages. Consider liability if instrument were to fail.
    - Avoid precluding something truly innovative (that we haven't even thought of yet).
    - CTD would be easy to pre-determine, but other sensors (like ADCP) would be harder to specify because they have a larger impact on the AUV shape/size.
- What are the integration issues with the required sensors?
    - Consider quality of data collection - such that measurements are not affected by device operations.
    - Could be validated by CTD measurements.
- What is the best way to wirelessly transmit the data back to shore?
    - Depends on where you are testing. Wireless/4G if nearshore, satellite if far away. Need to decide if you want real-time data transmission or if a logger on board is sufficient. Again, it comes back down to the missions described (hurricanes, ice shelf would definitely need satellite data).
    - Consider data processing onboard (general comment for AUVs).
    - Commercial solutions exist. Don't put too much thought into this.
    - Water quality data is essential in real time, but imagery could be recovered later.
- General Comments:
    - Think about focusing on wave energy converter design and a path to integration with AUVs on paper. Especially considering the funding available - we want to focus resources.
    - For basic autonomy, this is doable but for more advanced autonomy it could be more difficult.
    - Most competitors won't be starting completely from scratch.
    - Timeline and funding seem a little limiting, especially between the design - build phase if intermediate awards are small.
    - Money would be better spent with larger prizes
    - Using WEC portion of design as docking station (not integrated with AUV) doesn't work with the described missions. Focus on self-contained, single package. Those two routes aren't comparable for evaluation in the same competition, it can't be left open to the competitors.
    - If the goal is operational use (power generation), then standardization is necessary. If everything is custom, it is harder to modularize. Establish minimum baselines, but leave the rest to the teams.
    - The energy conversion capabilities are the most critical component of this - but there still has to be room for a useful payload (that can be demonstrated).
    - Need a way to measure efficiency of wave energy collection, collect data to assess wave/vehicle interactions and conversion rate. Health monitoring of the vehicle + environmental measurements. E.g. wave height, period (available energy), vehicle attitude, energy input and output.
    - Depth measurement (wave energy diminishes with depth)

- Having a CTD on board is recommended, providing a general baseline.
- Consider manufacturers other than Seabird in rules document
- Question: is the goal to be the most efficient wave energy converter, or to perform the best on the defined mission?
- Commercial industry is driving towards lower power needs, thus the focus is on conversion efficiency.
- Tracking wave environment on board device may be contradictory to mission goals. Perhaps some of this data should be provided ahead of time (wave spectral data) to every competitor, to level the playing field and understand ground truth for comparability/evaluative purposes.
- Current profile should also be provided
- Lots of agreement that wave data for a location does not need to be collected on board test device, especially if data already exists
- Consider collecting percent uptime (since instrumentation will likely vary by mission) to evaluate wave energy conversion efficiency, focusing on continuous data collection instead of mission length or time.
- If the focus of the contest is power generation, then we should focus on that. Adding instruments and payload requirements will only distract the objective and exponentially complicated the design.
- In the long term, we need to develop modular and standardized payload packages (WEC and/or instruments). We should be able to swap them on the fly for different application/vehicles.
- Instead of requiring a payload, we should require the competitors to demonstrate level of power output. Perhaps we should also provide the competitors with a standard instrument package to collect performance data that will be used for independent verification.

Navigation and Communications

Summary

Apart from scientific or mission-specific instruments and sensors, this breakout session was focused on systems to support the navigation, control, and communications of the vehicle. We were interested in eliciting feedback from the participants as to the minimum or optimum hardware that should be required for the competitors to successfully complete the Challenge objectives and what hardware- if any- should be supplied due to cost or complication.

There were strong opinions from the participants regarding level of autonomy and overall simplification- favoring less emphasis on autonomy and simpler challenges for assessing the vehicle's navigational performance. However, the participants seemed to agree that autonomy and navigation could be a bonus points category. In addition, a common message we heard during the breakout sessions was to leave decisions about what hardware to use to the competitors and not mandate them in the official rules. Basically, spell out the challenge in the rules and allow the competitors figure out their own approaches.

Notes

- How to demonstrate basic autonomous navigation and control of a vehicle without overburdening competitors? This is an energy competition, not an autonomy prize?
    - for most of mission outlined - Pacific, Arctic; autonomy adds to technology challenge of designing the system. No requirements on autonomy, navigation; would have geo fence/station keeping requirements.
    - fully autonomous vs. remote control - min reqs/threshold for this challenge? Installing a GPS on a fake payload, acoustic ID system to monitor locations. To do this need Iridium link/cellphone device. 9600xx connection; if Iridium, can we afford telemetry?
    - Go low tech: surface expression and GPS track. Takes onus off autonomy. Balance - lim to time/budget/scope, emphasis needs to be on energy side of equation. How much time and effort should be spent on autonom. More you ask on autonom/nav, higher the risk the teams won't participate in the energy side.
    - Don't eliminate due to lack of autonomy. Could admins provide bare-bones AUV they could all work from, all start from same kind of vehicle? Wave energy production part of it may inform… if we provide something, may limit creativity?
    - Something more complicated, makes autonomy requirement more difficult. To keep autonomy simple, keep path planning simple. Execute waypoints, or series of station keeping functions. Doesn't have to be done dynamically. If dynamic way points, then need comms.
- What is the most realistic comms methods to be employed on a vehicle that would be used for the intended mission?
    - GPS obviously for when surfaced. Some GPS-deprived part, though. Acoustic positioning? Telling the vehicle designer what equip to use vs. what function it should perform. If purpose is to id location for safety vs. comms system on board so vehicle knows where it is in its environ. For energy harvest - former more important. A requirement could be that the vehicle location could be monitored every 30 min within x distance. Could satisfy safety, but not environmental awareness requirement. Where do we land on importance of fully autonomous, environmentally aware vehicle to id potential collisions, path planning. Energy optimized path planning…
    - it is appropriate to give designers widest latitude - want to describe the perf during test and conditions under which test conducted. Relevant to talk about specif comms protocol? Or stipulate they can have comms of a certain type - for safety or performance aspects. More important - prohibiting positioning info.
- Safety aspect: anything we should require at minimum? Knowing location? Radio kill switch?
    - Robo Sub - their safety was kill switch for motors. To find: positive buoyancy, if contestants fail integrity of hull test in the field, if GPS or other comms capabilities.
    - Initial issues - losing buoyancy would be addressed in pool test, would know before catastrophic failure. Positive buoyancy and simple GPS ping, even if inconsistent, is cheaper and easier way instead of additional comms system with implications for weight/design.

- What should be provided in way of comms for open water portion? Cellular or wi-fi an option given location? Acoustic?
    - This could inform location selection. Does Iridium make most sense? Rock block system - 50 bytes per packet, could have 1000 packets for $100. Or more wi-fi/cellular arrangement?
    - if competition supports sat comms - vehicle designer needs onboard receiver only. gives competition capability of providing uploaded info (dyn or periodic). If competitors want to focus on wave energy harvest, maybe competitors just have receiver onboard.
    - acoustic navigation aides - if we want them to have this ability but not spend time/money on infrastructure, then competition needs to not stipulate or needs to provide this. Provide transponders for acoustic nav system and they have transceiver. Do admin want to spend money on this infrastructure or not? External infrastructure off of vehicle - who provides?
    - Would optical methods for pool test be useful? If using optical for comms or nav, still need offboard infrastructure. Depends on where do you want developer to spend time and money in developing a working vehicle. How much info/what kind on vehicle vs. how much time vehicle developer expends in supporting those comms? If all sat/optical/acoustic/sensors - a lot of gear that needs to be powered.
- Should users be allowed to send commands or information to the vehicle during testing?
    - Full control: proxy for remote control. Should they be able to have full control over vehicle or only interact with vehicle for exceptional cases?
    - When competitors get to robo subcompetition - tether vehicle to check sensors, autonomy. Having ability to recover vehicle might have some advantage, if they could later untether and go autonomous could be a benefit. Might want to allow either or both.
    - Could vehicle be tethered in initial stages, and demonstrate autonomy later
- How to demonstrate basic autonomous navigation and control of a vehicle without overburdening competitors? This is an energy competition, not an autonomy prize
    - Navigation and comms tied in together, based on freq you want data from platform, should be allowed to talk to instrum/platform. Frequency is symmetrical. Should be up to designers.
    - These criteria should be determined by user functionality. As energy engineer - what is the load I'm going to have to meet and from there, make sure power and energy sys meet that load. Nav and comms, with AI involved, probably best to get requirements from users.
- If we leave comm thresholds to the end user should there be a limit to that? Remote control vs. autonomous control?
    - challenges in autonomous systems, trying to demonstrate systems powered through wave energy is the goal, too complicated to also ask for autonomy? How much do we require/help competitors in this area?
    - a lot of levels of autonomy. On basic level, mission planning (instead of auton), not all vehicles are truly autonomous. Ability to put out weigh points, GPS coords, where the vehicle can drive to, can set altitude or depth. Vehicle can drive to coords. With telemetry, know where vehicle is, give it flight mode command to

execute mission or stop and surface for retrieval. That is imp for control system like this.
    - how ties back to the power reqs - if competition about integration of wave energy for power requirements - imp of making it focus on that wave energy recharging rather than dev sensors/auton systems. Need associated power requirement...heart of competition, more wave power, more advanced actions. Don't turn into a sensor competition. Focus on wave energy.
- What are minimum required navigation instruments/systems for a vehicle? Which ones should be supplied to competitors and which should they source themselves?
    - can it meet the mission or not? Ice shelf vs. hurricane determines these reqs. Needs to be minimalist but more focused on the mission reqs so whole system can meet these reqs. Vs. one type of nav versus another.
    - why would we want to include a DVL? If an ice system - looking at pack ice, an obvious concern. Considering trial environment - as far as open water/pool scenario, does Dopplar/DVL make sense?
    - yes, in shallow water. They're super expensive, fairly short range, 12m or so depends on model, tracking range not high. Best navigation for shallow water. GPS lock on surface, bottom lock on DVL. positional error from DVL, 1% or less of your movement.
    - for short sprints under water - 10s of m range: sig advantage in DVL? From dead reckoning and INS, high speed, yes, underwater vehicles, move slowly. Like gyros on subs? INUs and INSs for drones - not accurate enough to dead reckon. I.e. bluefin sandshark - 2m vehicle, doesn't has DVL, just dead reckons - not accurate. Without a DVL, positional accuracy is not very good.
- What is the best wireless communication method for the vehicles at the two test environments?
    - Acoustic positioning? DVL? Dead reckoning? Depends on what the mission will be and how you employ capabilities. Depends on competition objective/theme.
    - In a pool scenario, submerged nav several meters, maneuver through gate and return home: acoustic posit could be impacted by type of tank you use. Sharp edges, corners - maybe acoustic is right way to go. It depends. Depends on characteristics of the tanks.
    - left open unless there's a specific user req that NOAA needs long term, or spec req for test facility.
    - want to realistically frame trials that will be scored. If req a spec device by proxy - DVL or otherwise and if expensive, base it into challenge and need to provide it (due to expense) or workaround so we don't need expensive piece of equip.
- Should we reward autonomy?
    - if autonomy and accurate nav are a function of power available, they should be rewarded, better you can recharge, more auton you can be for any particular mission. Want to reward to be able to charge higher to be more autonomous and accurate.
- What is the most realistic comms methods to be employed on a vehicle that would be used for the intended mission?
    - satellite comms. It may be req depending on mission. Also depending on mission, frequency you use will depend - for EHF prob won't work for hurricane mission,

but higher freq might work, point to point or satellites. Dep on mission. Affects transmitter, receiver size. Iridium is SHF - affects tran - not a lot of satellites at high latitudes for ice missions. Frequency det by mission and what's available. Will also determine size of transceiver.
    - Iridium in Arctic, blackout area at high latitudes, but for most parts, satellites orbited.
    - Tropical storm scenario - satellite comms blackouts? Maybe freq dependencies on cloud blockage. For trials: could have storm during trial, would need to let participants know they need to prep a contingency.
- Should users be allowed to send commands or information to the vehicle during testing?
    - minimal operator interface as goal - esp for hurricane, ice shelf applications/missions. Invasive species could have more operator interaction with the vehicle, still line of sight issues, weather issues that could impact.
    - set a bare minimum req of vehicle is untethered, other than that, if they want to use some RF direction/remote control, ok for competition. Awarded more points for more advanced autonomy. As bare min to entry, make as low as poss.
    - min level of autonomy - avoid some obstacle they don't know much about ahead of time, maybe in pool course. Could tie into safety Qs of AUV as well.
- Should the vehicle be tethered?
    - If energy harvesting is goal, min reqs for nav/comms. Allow them to tow antennae, or incorporate scoring mechanism that encourages less constant comms, great but point is energy harvest. Reducing these reqs is key. Ultimately goal is to demonstrate energy harvesting. Key concept - what is energy conversion metric? Key grading criteria.
    - What would generate public interest/engagement?
    - From admin side, renewable energy is hot topic, try to find existing capability - tethered buoy that operates via solar and show it could be powered by wave energy for example. Practical challenge. Sea buoy for mariners? Benchmark to show future utility.
    - What are minimum required navigation instruments/systems for a vehicle?
    - to what degree would you expect the vehicle to come to the surface and submerge? From an energy perspective - optimized to operate beneath the surface. Do you have access to GPS or not? And at what rate? Nav on an AUV is $50K-$125K. Cheaper options would cause drift, to go around buoy could use acoustic ping….
    - For the pool test: GPS deprived, underwater completely or surface indoors, you don't have access to GPS, nav from 10m - 90 deg. Turn, go through gates, vision?, returning back 10 m: could this be reasonably exp from an INS with … filtering and such? Reasonably priced, not aerospace apps.
    - Are we using pool test to verify systems work or as way to prep for open sea trials? Additional cost factors? Don't want to build twice, want what you build in pool to be applicable to other parts of competition. Think like a fish: if you were doing a pool test to verify before sea trial, need forward looking acoustic system for active avoidance of obstacles. Need to get initial fix from sea surface. What's surface/submerge rate, tied to comms plan, any time you resurface, you should

    - have ability to take a fix for where you are, nav system should be able to hold on to it and move it. Active pingers to bounce between things.
    - Would it be possible for test facility for pool and at sea to have surface platform that AUV could comm with? And it could give it things to help navigate, making pool and sea similar? Could also take care of data relay to satellite sys, power requirements get high with more data. If instead AUV relays data to single float, float does data transmission, this standardizes a bit among AUVs. Mission objective data to be sent back to add to realism in open ocean trial.
- How should station keeping be demonstrated, if at all?
    - Given limited resources - instead of demonstrating, have teams describe how proposed tech wouldn't hinder/would reduce drift in nav. Describe benefits to nav and comms. To do a demonstration of this would be extremely expensive and would spend no money on energy harvesting as a result. Describing might be more useful than demo.
    - what should we provide/prescribe as competition administrator? Set GPS coords to that point and provide acoustic pinger to home in on the acoustics, beacon, GPS coord.
    - balance power generation by power expended. Incentivize low drag systems, don't impede vehicles locomotion.
- How can the Prize Administration team assist with vehicle navigation (make it easier for contestants)?
    - Spectrum from full autonomy to remote control: how much autonomy should we expect, should we reward extra autonomy? Either deploying data bubble or come up and do same thing from vehicle. What is tank test supposed to represent? If goal is to show navig. From point to the next, in tank, can do this optically with a laser.
    - Goal with trial is to submerge, do a simple maneuver and return to base. Given resources and times - have team write what they would do in the future and focus on what matters: energy harvesting. In tank testing is very expensive, and could spend purse on just this.
    - Lean toward min nav and comms reqs on the vehicle. Can be solved by AUV designers, not intent of competition. Minimize this. INS or optical track follower for pool test. Doesn't translate to open ocean test. Minimal is better.
- Appears to be interest in the idea that the contest should focus on AUVs capabilities to harvest energy. What could you have as a min system? Should we standardize equip we provide to competitors? What are the key questions to minimize challenge of comms and nav?
    - For open ocean test: focus more on station keeping req; award points for distance traveled away from that point. Rather than a nav req, traveling from point A to point B; leave point A and come back to point A.
- Point 1 regarding using RS-232 is not clear. What purpose should it be used for? What physical interfaces?
- Point 4 regarding underwater navigation appears to be adding onerous competition requirements that are not related to the core innovations of the teams or to the goals of the competition. If the rules require teams to duplicate or integrate available navigation technology then this reduces effort that can be made on innovations in energy generation.

Realistically if we make a new energy generation system then the commercialization of this will be done by marrying it with an existing AUV manufacturer that already has navigation solutions available. If teams are forced to integrate navigation now it reduces the quality of the energy generation (the main point of the competition) and so reduces the changes of commercialization of the energy generation technology. We strongly feel that integrating a navigation requirement in the DEVELOP competition is a major deviation from the project goals. Adding navigation will reduce the effort that we can invest in the energy generation aspect of the competition, this in turn diminishes the impact on the goals of "Generate sufficient power from co-located marine resources" and "Accelerate commercialization of marine energy systems".

Power and Energy

Summary

Focusing on wave energy likely makes sense for being able to judge and test devices, though this constraint may limit creativity. Choosing a precise battery to provide contestants seems unnecessary, though benchmarking the onboard battery capacity is necessary. The method of judging the power output was discussed alongside the battery restrictions. Participants questioned the usefulness, fairness, costs, and safety risks of at sea tests and emphasized the capabilities present at wave tanks.

Notes

- Is wave energy the right resource to use here?
    - TAKE-AWAY: There was no true convergence on a “yes” or “no”. Some thought that limiting the resource limits creativity, but makes metrics much harder (though there were some thoughts on how to measure success in a resource-agnostic way). Some thought that because wave is the most energy-dense resource (is it?) that it should just be wave. Some thought that the focus should only be on the wave energy conversion piece - so competitors would only apply their WEC to an AUV theoretically.
    - Specifying resource can limit creativity, suggested a “do not use” list instead of a “use-only list” of resources
        - But: if the resource is not specified, can we choose a test site?
        - Would need to monitor the test sites as the test is running so we know what the resources are
    - Workaround might be devices that can harvest multiple resource (e.g. both wave and current)
    - Consider using efficiency metrics to score contestants
    - Consider having different testing sites if we allow multiple resources
    - No existing solutions for AUV power generation from the environment - except solar-powered wave gliders
        - Focus on highest energy density - which would lead to waves - but: might need high surface area to actually harness that wave energy
            - Suggestion: focus on wave energy and then tailor that to the size of the system, which would depend on the intended purpose

            - Leave design space open and then let engineers make tradeoffs during the building process
            - Focus on novel methods to pull energy from the ocean, and then ask participants to think about how this would transfer to practice
            - Metric: could benchmark generation by comparing the same surface area to what solar or wind would be able to generate
    - Need to determine which resources are available at the test site: including other renewable energy sources. Particular missions being targeted are not likely to have other renewable energy sources available.
        - There are tradeoffs - but within existing AUVs: how can wave energy be integrated into these existing geometries? Rather than coming up with a brand new AUV
    - Wave energy is the novel opportunity here - start with that, and then determine if they are applicable to AUVs
    - Unrealistic to only look at WECs - will only operate within certain parameters. Issue: only a small fraction of the power generated can be integrated into the system.
        - Solution: allow competitors to make up for smaller amounts of generated power (in theory)
        - Metric: how much charge can be put into a battery
    - Metrics: can be tied to battery charging and discharging, or can be tied to the mission
        - Useful to baseline how much energy is theoretically available in the environment - so you can determine how much of the energy was actually harvested, and what are the losses - what's the % of the wave that makes it into the battery
        - Tying it to the mission brings in a bunch of other variables - some of which are already being optimized by commercial sector
            - Required total energy of a mission is the driver or metric to focus on
    - Also: suggestion to tie it to the mission
        - This is the end goal anyway
        - This could encourage cheaper systems that can do the job a little more effectively - even if the power generation isn't at the highest efficiency
            - Metrics focused only on power generation doesn't tell us anything about what missions could be completed
            - Need to at least ask competitors to describe the mission they would be able to fulfill to get at this - but might be too expensive to actually test
        - Theoretical energy in a wave - is not tied to being at the surface
    - If the intent is to make a general AUV/WEC rather than a mission specific one, then it makes sense to to have multiple sea trials in very different environments. Perhaps the contestants could be allowed to swap out certain components in between these trials to better suit the trial at hand.

    - In case you aren't familiar - the Navy also has a very exquisite wave generation tank capability at NSWC Carderock in Maryland. This would be a very useful test environment as you can generate your own prescribed environment.
- Should a standard battery pack be required or should competitors be allowed to choose their own?
    - TAKEAWAY: no clear answer. One participant mentioned they had luck allowing competitors to choose their own. Many suggested metrics and agreed that baselining the battery would be necessary.
    - A better metric is power delivered to payload instead of monitoring battery
    - Vehicle design matters since it will affect energy use, maybe we can look into other metrics such as mission time
    - Another goal is how long the device keeps recording data
    - Compare the differences of uses and related power usage
    - There should be a baseline
    - Low-end car battery range: 1 -5 kWh
    - There have been successes in allowing competitors to choose their own batteries - need to think of some safety questions
        - Factors: capacity and duty cycle - these are dependent on the mission (trickle charge vs full recharge)
        - Also need to define the payload - in addition to the suite of basic sensors, defining the mission-specific payload would be very helpful from the competitors' point of view
    - if a standard battery is decided then some other variables should also be specified to focus innovations on the desired outcome e.g. define the payload, speed, duration and you'll get the best use of size & weight to harvest wave energy
    - Different batteries work at different voltages. Different batteries handle energy and power/current differently. Therefore it is very easy to generate power that is at a bad voltage/current. This bad voltage/current will require extra power electronics to effectively harvest
- What is the standard battery capacity to be provided to competitors?
    - TAKEAWAY: no clear answer. Could have a metric about time to full charge rather than specifying the capacity.
    - Depends on vehicle size, speed, payload, weight, and duration
    - 1- 50 W charging for battery
        - Seems to be too small
    - Could provide small batteries and allow contestants to use multiple
        - There has to be a threshold
        - Influenced by instruments on the device
    - Metric to consider: how long does it take for the vehicle to charge the battery
- What type/chemistry of battery (Li-Ion, Lead acid, etc.) should be used?
    - TAKEAWAY: Lithium presents safety concerns but are more standard.
    - Lead acid have a better temperature range, lithium are more standard
    - If different batteries allowed it will be hard to assess
    - Taking into account environmental safety perspective
        - Lead acid batteries in the water are bad, some other batteries can overheat and leak

    - Recommend staying away from Li-polymer for safety, there were fires from shorts or overdrawn currents
- Should exact battery make/model/capacity be specified, or just specify the max capacity and let competitors source the battery themselves
    - TAKEAWAY: no clear answer. Arguments made for each option.
    - Specifying batteries gives standardization- but it limits the scope of the design
    - Depends on the mission profile, duty cycles
    - The specific missions identified should have an associated "power budget" and "recharge intervals" that the wave energy components integrated with the AUV are required to address. Then other missions with similarly high power budgets can be addressed as part of a larger scale commercial roll out.
- What is a realistic expectation for continuous power output from a wave energy converter of this size? Is 80 kg weight limit too restrictive?
    - TAKEAWAY: 80 kg seems okay - but no real convergence. Semi unrelated, but there is a piece in the rules doc about a 1 W continuous power outage, and someone noted that this should either be average instead of continuous or removed completely, as the power output would be different with different charging scenarios
    - Minimum mass required for 10-50 W capacity (regardless of vehicle shape):
        - 30 kg seems realistic (within an order of magnitude) for 50 W
        - 15-20 kg seems realistic for a smaller wattage
    - Also need to define what piece of the device will count towards the weight
        - 80 kg may be too aggressive (light) for higher power range
    - 80kg displacement, 2.5m length and 1W power are compatible and consistent requirements, meaning that a 2.5m long 80kg AUV can be made to generate >1W.
    - Specify dry mass
    - It can be set to weight limit for the crane
    - While harvesting, it is assumed that the devices will be on the surface
    - 50 W for 30 kg seems doable
    - Needs a reference to react against
    - If we require continuous power - 1 W was used as an example - this might be unrealistic
        - But: average power continuous would be more appropriate
- What is a realistic test length? What would demonstrate that there is viability in the prototypes? 3 days? One week? One month? A fixed number of charge/discharge cycles?
    - TAKEAWAY: most people agreed that having a tank test first is the best route to take. It might be useful to split up metrics between tank and open water - from our brief conversation, this seems like it was echoed across breakout groups. Some thought that an at-sea test wouldn't be necessary.
    - It will come down to cost, it will have to be in the order of days
    - Depending on the duty cycle
    - Wave resource changes over time - everyone needs to be in the water at the same time
        - Or factor in this change in metrics
    - Logistic footprint will go up depending on the number of competitors
    - Stage testings:

    - First stage in a wave tank for standard testing (power and vehicle viability)
    - Second is open water
  - Use cases were all longer duration - but cost will be the limiting factor
    - Likely to be in the “days” range due to funding
  - Option: downscale a realistic test scenario to fit in a shorter amount of time
  - Consider: wave conditions - which change from day to day - will require that all contestants test concurrently
    - Or need to factor that into the scoring
    - Or could use a wave test tank for consistent conditions
      - This could be the first test of two (the second being an at-sea deployment)
      - Score different so stage one focuses on power generation and other metrics that need to be compared side-by-side
      - Use the second stage to score other metrics that don’t require a side-by-side
        - Could use for con-ops testing and fit to NOAA mission rather than mapping performance over different sea states, but focusing on the applicability of the device to scientific missions
      - Initial test at Carderock - would test waterproofness, but also ensure that devices don’t break during the in-water testing
        - Participant noted that Carderock would be an ideal testing site because the wave conditions are controllable and multiple competitors could test simultaneously
      - Could argue that at-sea test isn’t really useful - may not be able to build the WEC and integrate it into the AUV within a reasonable amount of time and money
      - Tank testing reduces complexity and allows the focus to be on the wave energy conversion piece - can also be better baselined in a tank where conditions are more controllable
        - Also reduces the risk of losing the hardware at sea because a tank can be shut down as soon as something starts to fail - reduces cost and loss of work
  - Consider: logistic footprint increases with number of contestants and time at sea - need to define realistic boundaries
  - Metric: could consider how much energy is going into the environment (propulsion) and use that as a denominator
    - Test facility - ideal if it can demonstrate a variety of sea states
- What is the minimum ocean energy resource (likely wave) required? What is the least efficient and most efficient design archetype at small scales? Assume worst efficiency for sake of site selection for testing
  - TAKEAWAY: need to be accessible by boat and extreme sea survivability should not be the focus
  - Any place we test should be accessible by small boat - safety and practicality
    - Survivability in extreme seas shouldn't be the focus

    - There has been some testing in Lake Washington - where waves were ephemeral (balance between accessibility and wave resource)
    - Test sites should be accessible by boats for practicality
    - <30 m deep
    - Weigh the access to site and presence of wave energy
- What is the temporal variability in the ocean energy resource at suitable test locations (somewhat sheltered, coastal shallow-water sites near infrastructure) and does that agree with the deployment duration? For example, if sufficient wave resource is only available one day a week, can we realistically expect the vehicle to survive six days?
    - TAKEAWAY: find a location that is unlikely to have surprise rough sea states
    - Rather than looking for a location with the waves you do want - look for a place that doesn't have wave you don't want
    - Need to pick a place that isn't likely to have a surprise wave that damages the device before survivability has been fully tested
- Does the energy harvesting source have to be located within the vehicle?
    - TAKEAWAY: lots of thoughts here - no convergence. Arguments for both sides.
    - Functionally - is there a difference? From a mission capability standpoint, it might not matter
    - Is there utility in inventing an entirely new vehicle class? Instead - focus on two technologies that already exist and make them work together (i.e. keep them decoupled)
        - If the recharge station is nearby then it doesn't matter
    - Example: mission under an ice shelf - integration of the power harvesting onboard, you get longer range at faster speeds that what a thermal glider would provide.
        - Con: power device might be unwieldy and affect vehicle performance
    - Vehicle could also tow a WEC
    - This is important so it has to be declared to be included within the vehicle
    - Does the mission require that the device be incorporated?
    - Will depend on type of mission
- How to measure power output/charging? What about sensor drift and recalibration? Redundancy in measurement
    - TAKEAWAY: should have a standards assessment package
    - Recommend: standard assessment package - some IO channels that are attached to device before testing
    - It should measure time to charge
    - Mechanical vs electrical: it would be difficult to measure mechanical power - kinematics (tension in the line?) - would be difficult to measure in a standardized way, and could potentially be limiting in that it depends on the geometry of the WEC
        - Device may be small enough for a rig to built to assess onshore to give baseline measurements - that is, providing power on shore from a controlled source and monitoring battery charge
    - Sensor drift/recalibration: if the devices were small enough, you could build a rig to calibrate on shore to measure electrical signals on board

    - Power emulator on shore to plug into battery on shore - should at least provide a baseline
    - Some national labs have measurement platforms provide a standardized assessment package
    - How quick to charge the battery
- How to ensure equal playing field (i.e., prevent cheating) on battery capacity? Is a battery pre-test or verification necessary?
    - TAKEAWAY: yes, and administrators could “look under the hood” to ensure there aren’t additional hidden batteries.
    - Yes, this should be tested
    - Open question: does it matter if the battery is provided or not?
    - Should there be a phase where the contest admin “look under the hood” of the device before it goes out to sea?
    - Competitors can also self-regulate this - folks will notice if there is a device with unusual capacity
    - Suggestion: decouple the metrics for battery and power production
        - Also could benchmark it with admin there (recharge cycles) and then put it out - so there is not time to game the system
    - Let administrators to look under the hood for hidden batteries
    - Battery sniffing dogs- sniff lithium
    - Limiting the battery capacity is to encourage multiple repetitions of charge and discharge cycles
    - What about having a system to record the amount of power generated?
    - At a certain load, measure charge and discharge rate
- What is the lowest state of charge competitors would be comfortable draining down to?
    - TAKEAWAY: this differs depending on competitor strategy and type of battery. May not be worth defining. One participant mentioned that focusing on the battery too much will draw attention from the goal (wave energy) to the battery. There are scenarios where a less “good” battery is worth the cost savings and still enables a mission.
    - Power to load - different WECs may perform better/worse with different energy storage systems. Thus they cannot be divorced.
        - Standardization of battery packs are important
        - Depends on type of battery/capacitor for SOC
    - May not matter - this could be part of the competitor’s strategy
    - Also dependant on type of battery - chemistry will dictate the degradation rate and could actually lead competitors to use a battery that would be best during the prize, but wouldn’t be appropriate for commercial use
    - Situation-dependant: focusing on the battery too much might draw attention away from the actual goal -which is the harvesting system and it’s capability to generate energy
    - Battery might have rate of discharge/charging that isn’t conducive to the energy harvesting strategy
        - Battery should be secondary and only looked at as a piece of the design
    - Would not specify battery pack

        - But could specify state of recharging - is it shut down? Are there hotel loads? Does it need to be able to maintain its location? Etc
        - Not necessary to standardize but should ensure the test conditions match operational requirements.
    - Depends on battery storage
- Safety restrictions on amperage and voltage?
    - TAKEAWAY: this is a major concern - use off the shelf. Need to keep safety of operators and divers at forefront.
    - Context: anything over 50 V requires special training at PNNL
        - 48 V is a common nominal voltage, but depending upon how it is done, this may float a little bit above 50V. Agree on COTS AUV safety specs.
        - A standard battery / power management systems would be needed to be able to identify the best solution for integrating wave energy conversion systems - to avoid a battery competition
    - Use commercial off the shelf systems for safety
    - Key battery safety standards: UN Transportation testing, DOT shipping requirements
        - Look at safety requirements for current AUVS with divers in the water
    - Needs to be grounded - especially if divers are going to come in contact with them
        - For a device that is floating without touching ground, grounding is technically impossible.
        - Rather than ground: minimize transient currents and static buildup (when out of water)

- Other safety considerations for the competitors or support divers?
    - TAKEAWAY: reduce diver interactions as much as possible
    - Make sure there is a boat ramp nearby!
    - Reduce diver interactions as much as possible - suggest towing instead
        - Would also reduce costs!
    - We may want a remove lock/unlock for launch/recover/divers

Operations and Safety

Summary

There were different opinions on the degree to which operations and safety should be used as metrics and stand alone goals within the prize--some participants felt strongly that safety and operations are half the battle for ocean observing and should be scored metrics, others argued that the prize should remain focused on technology innovation. All participants agreed that contestants do need to demonstrate in the design phase that they understand safety concerns and have a plan to mitigate issues. All participants agreed that operational safety was of paramount importance to prize activities--our test venue and testing crew need to ensure a safe process.

Most participants agreed that we should be less prescriptive in our rules document on specific design strategies, and instead simply state the outcome we want to achieve and let contestants design to meet that standard. Participants discussed that ideally we'd test basic operational strategies in a controlled test site or venue, before going out to sea. Some tests could be done in a pool, but others, such as deployment and retrieval, might be better completed in a controlled field site, with access to vessels, etc.

Notes

Initial Thoughts

- Anything about the first rule that you would like to comment on, disagree with, etc.?
    - The lift point would have to be above the surface of the water. Clearly visible.
    - Rather than calling it a "lift point", call it a "lift mechanism". One of the biggest challenges is at the launch and recovery phase, so this is a really important consideration.
    - In terms of launch and recovery, another important point is people's exposure to risks. Shouldn't require someone to hang over the boat, expose them to additional hazards, etc.
    - Even if something is handleable, it may not have a desirable recovery method. Might not be a device element, but more for the team working on the testing side.
    - Safety shouldn't be afterthought. Should be part of success.

Discussion Questions

- What types of lift points must be specified for the vehicles for at-sea recovery using deck machinery (a-frame, davit, etc.)?
    - Regarding the first rule, it depends on the size of the technology.
    - Is there any reason not to have a lift point? We don't have to be so specific for the trim rule, for example, but is there anything that makes this a hassle for developers?
        - If a vessel is under a certain weight, a lift point may be unnecessary from the safety side.
        - Smaller vehicles all have a handle, so maybe the wording ("lifting point") needs to be spelled out better.
    - There should be a way to grab the vehicle and support the weight...but why does it need to be in a neutrally trimmed orientation? Doesn't seem like a safety issue.
        - Wouldn't want to put someone at a disadvantage if…
        - Vehicle must incorporate at least one lifting point, etc. depending on the size, etc. "Neutrally trimmed" issues may not be necessary or depend on the design of the vehicle.
        - 80 kg may not be enough (e.g., OE Buoy)
    - Are the dimensions and weight appropriate? If it was any bigger ,would we be able to safely deploy and retrieve? Could it be built within the confines of this prize?
        - You could...but if you're trying to support all entered vehicles with a common vessel, that'll dictate what you can facilitate or safely handle.
        - Size, weight, and dimensions seems somewhat inappropriate

    - A lot of the things being asked for involve programming and autonomy that are already common to existing systems. So are you asking people to rebuild those? This prize needs to figure out what areas you want people to innovate on. Build a system with autonomy or one with energy efficiency?
    - Lift points v max length v etc… How is the max weight estimated? Has this all been estimated so the requirements are all consistent?
    - Is there a max size and shape that we think we can safely operate in a small scale social setting (e.g., two people with small A-frame)?
        - Yes. Remus 600 = 320 kg -> not possible for individual to lift; Iver = 38 kg -> possible.
- What restrictions should be placed on vehicle displacement or buoyancy?
    - Vehicles should be positively buoyant to ensure that the system fails the vehicle will at least resurface,
        - RoboSub requires vehicles be positively buoyant by at least one half of one percent (0.5%) of their mass
    - Is what we have a sufficient way of capturing the buoyancy question?
        - The requirement you're after is that someone is able to come and pick up the device? That's a pretty generic technique. Whether 0.5 kg drop weight is sufficient is up to the vehicle designer. Maybe leave the specifics to the designer. Consider a more generic criteria in the rules document.
        - If you state the requirement as the function rather than the mechanism, then you've got every vehicle designer covered.
    - Should we be more specific or open about this?
        - Agreed on open.
    - Are there any reasons we wouldn't want positive buoyancy?
        - May induce greater risk if working under ice.
        - If we go with an arctic use case, we may need to reconsider our recovery practices.
        - For the Great Lakes, it may be better for it to just go to the bottom if you have a location. Can go get it during summer.
    - Should we design the safety and recovery features for the contest or as core elements of the use case?
        - Maybe both. Operate differently during the demo phase than if it were to be put under ice.
        - Safety should not be part of the contest. Could compromise safety.
        - If you can't show operational safety, you're essentially disqualified from the prize.
        - Safety is important but on the technology side, it shouldn't be an important part of the competition since it's all about the technology. Safety features shouldn't be the core part.
        - We could design the prize with a core goal, with a number of subgoals around that that could be scored and weighted. Could allow people to optimize designs of one part or another.
        - One suggestion could be to get rid of the safety element.
        - How do you define safety here? For operators and individuals, that can't be compromised. Different from safety of technology.

        - Maybe recovery features shouldn't be one of the requirements.
        - Summary: Have to balance safety requirements to make sure we have a safe contest but not overweight safety at the detriment of the ability to explore some of the other elements of the prize.

- What is the industry standard for AUV navigational lights? Is a simple white-light visible from 360 degrees acceptable? Need to specify brightness or distance visible? Would the light have to be running during the entire at-sea test?
    - The Coast Guard (CG) would probably like the light on continuously and at the surface, rather than just during recovery.
    - 1 km is a problematic specification due to visibility conditions. Would be good if there were CG requirements.
    - Do you plan on running missions in darkness or would all trials be done during the day? Any longer endurance runs? Can also be difficult to see lights during daylight…
    - Has anything else been used other than a light? Maybe a flag?
        - Sometimes a low frequency signal.
    - Perhaps we can avoid making specific measures… Could just say that the vehicle needs to float to surface if it fails. Don't need to include lights, just make it identifiable during the day. Maybe better measures for visibility at night?
    - Arcodrifter doesn't currently have a lighting/reflector requirement. So does an object like this actually legally require anything?
        - CG Best Practices in drift? They'll want it to be yellow. They'll want the nav stuff in and ability to detect oncoming vessels. Having yellow color may be enough given there are no CG requirements yet.
    - Are there any methods that work better than others?
        - Different colors?
        - You'd want some sort of reflective material, though biofouling may diminish this…
    - Is this based on a Coast Guard standard?
        - CG has been conducting interagency comments for a notice of best practices related to autonomous maritime systems. They are looking at lighting, collision avoidance, and mandating AIS.
        - Their only regulations right now are to let them know where and when you're operating.

- Should safer designs be rewarded in scoring? How?
    - This is a really short list in general. All geared toward vehicle safety, but nothing towards operator or human safety. Perhaps you could say that you've got enough redundant systems if something goes wrong.
    - May end up with additional comments from lawyers, etc.
    - A lot of this is designed around deployment recovery. Some parts of safety are more boxes to be checked (e.g., not going to expose electrical equipment). As far as scoring safety, you could award having clearly thought through mission dependencies, redundancies, etc.
    - Good to hear that we can be creative here…

    - Think about how difficult installation or assembly (e.g., time, # of components, # of specialty tools) will be. Prize looking at disaster response looked at some WHO requirements and allowables. Can imagine that many of these devices will be deployed on or near a beach. Could lose parts in the sand. Maybe other things to consider if deploying from a vessel (e.g., conditions, platform stability).
    - The Coast Guard will want it to be colored yellow if operating in coastal waters.
    - Not just a single hole attachment point. Could have another point to attach a guide line.
    - Could be an interesting metric. Testing the safety of lifting and retrieving.
    - One of the key metrics in the energy industry is exposure hours for personnel. How long does it take you on deck with a suspended load or trying to hook it. Could be a straightforward metric that gives a sense of efficiency.
    - Safe/maximum sea states for operations. What sea states can you handle? May be up to designer. May be up to boat and crew.
    - We don't need to reinvent the wheel with these safety and operation standards/guidelines/etc. For proposal, it could be as simple as the operation plan referencing that they meet government standards/best practices instead of dictating what they should/shouldn't do. Could be a scoring element.
    - Is there a safety reason/considerations relevant to transport of devices?
        - Do you think different sized devices could have different safety challenges?
        - Do we want to encourage having a device/platform that builds in some of these safety parameters?
        - Encouraging different safety metrics with points may be helpful. IF we can start normalizing some of these requirements (e.g., power per mission hour), we could incentivize smaller and more inherently safer devices.
    - Are you going to have the ability to offer certain bonuses for including certain design parameters? Could have some sort of bonus prize for the most compact and easy to handle device/platform
        - Waves to Water Prize do have some of these
    - What could some of these metrics look like?
    - Definitely think ease of use should be incorporated in the metrics as if it isn't easy to use, it won't become commercial at the end of the process. This includes ease of handling, ease of setting it up, ease of data download, powering/repowering and servicing. I was really pleased to hear that mentioned. Also, safety should be incorporated right from the design stage.
- Should leak sensors be required? Should particular models of sensors be specified?
    - Any real-world experience?
    - Best practice may be to not have your device leak and to know if its happening
    - From a safety standpoint, you need to know that leaks won't cause safety hazards (e.g., danger of electric shock).
- Should vehicles have an external kill-switch (clearly labeled on the vehicle) to stop vehicle propulsion or deactivate electronics? What should the switch deactivate?
    - By the time you identify that somethings gone wrong, wouldn't the battery have drained by the point a kill switch would be considered? By the time we can deploy someone out there to hit the switch, this could be useless.

        - Agreed. If you put a kill switch at the side of an AUV and its speeding along, the job you want is someone to turn it off and you're putting them in a risky environment. Design is prompting risk there.
        - Someone out there could find and press the kill switch without authorization.
        - You want the test to go well, but for this type of platform, it's small enough that you probably won't get into a safety issue.
        - Kill switch is actually your process. If you have a good procedure in place, that's your kill switch.
        - How do you turn these on and off without a kill switch?
            - Probably remotely. No physical switch.
            - Most have redundant systems. Some have internal fail safe mechanisms that identify when they're in trouble and cause them to adjust their ballast and return to the surface. Designers are very familiar with this.
        - Being able to deploy and operate the device safely should be the uncompromised priority of this competition. Safety should be a core value instead of competing factors. There are government and industry safety guidelines and best practice that the competitors can follow.
            - With that said, the detail requirements should once again be loosen up and allow for competitor's interpretation. For example, I think we should leave it to the designer to determine if it is necessary for features like kill-switches or lifting points. Adding a kill-switch because it is required may add unexpected consequence and operation challenges to the overall design (water-seal, electronic, flow dynamic, safety concern, etc).
        - The lack of this should maybe be disqualifying. Is this a value you want to communicate or a primary goal?
        - Maybe phrase this as a functional requirement rather than requiring that they have a big red button
- What are the minimum infrastructure requirements (if any) to safely deploy and recover the vehicles:
    - From a pool?
    - From a coastal ocean environment in conditions up to <u>sea state 4</u>?
    - Very important issue but typically dependent on sea state.
    - Experience of the crew is very important too.
    - I think whatever we decide will guide the dry weight requirement.
    - If you're looking at 80 kg as your dry weight spec, then in a pool or coastal environment, you wouldn't need something the size of an a-frame, but something to lift it. Ability to hoist is necessary but it doesn't need to be big or fancy.
    - Who are the people doing it? Competitors? Is there a rule around this?
        - Should this be written into the competition?
        - For the Waves to Water prize, which will culminate in a live test, we plan to have certified divers.
        - So the safer way may be to have a dedicated crew so a competitor isn't going out there to do this for the first time.

        - Could be a minimum req for the venue.
        - This matches what the Navy does when they host their annual technology demo exercise. The Navy uses its own personnel to handle equipment.
        - Need to consider ADA considerations
        - Having a device that is generically deployable may be better than having a competitor be the only people knowing how to deploy.
        - If we made it easier to deploy, should it score higher?
- What are the emergency communication systems for a vehicle? Should these be required?
    - Putting aside emergencies, what kind of communication requirements do we have?
        - Might have acoustic pingers for locating devices
    - Most commercial vessels require some sort of automatic signaler. The challenge is that you'd still have to have enough reserve power on board to run that emergency locator until someone comes to pick it up.
        - We weren't thinking about this in the power group
        - Unless it's got its own power
    - How do we manage risk so we don't go overboard with safety requirements?
        - Teams should at least be rated on how they communicate the needs for safety in their vehicle, and what steps they've taken in their safety plan, and what of those they've implemented if selected. Should be thinking about it in initial design phases.
- Are there shipping or transportation restrictions to consider?
    - Shipping of LiIon batteries for instance
    - Are there any DOT restrictions to consider?
- Other commonly used containers/crates used in industry for transport?
    - In most cases, when these things are shipped, they're shipped in plywood crates with packing. For example, custom cut foam and crate used. Will need a facility that can receive things of large size and move those around. Batteries generally shipped separately.
    - Packaging and storage requirements (long-term and short-term) may differ
    - Is a standard container size for shipping a useful requirement?
        - Could use ISO standard containers. Cradle is customized.
        - Problem with trying to specify a size is that there are a lot of different ways to configure the platform even within the 80 kg weight requirement. If you restrict size, may introduce additional costs and engineering challenges with splitting platform parts.
- What are important aspects to keep in mind when selecting test sites?
    - For any of the test sites, access for receipt and storage and handling of shipping containers is going to be important. Ease of maneuvering these things is also important - different access questions.
- Do you suggest any particular test site locations?
    - NOAA has a fairly large tank in La Jolla
    - Thoughts on a one-size-fits-all site versus several?
        - What's the test plan? Only testing the end system or interim tests? Tests in more controlled environments first?

        - If a one-size isn't available, I'm in favor of a more phased approach. Start in a pool, then protected ocean, then open ocean?
    - San Clemente Island, Wilson Cove is where all the Navy's AUVs are tested.
    - The Navy also has a testing range in Mississippi Sound. No tank capabilities though.
    - If you're adding several subsystems together, you're adding complexity
        - Some existing frameworks for complex frameworks analysis
        - Need to think about how we grade teams on adding these complexities
    - Hope we give thought to losing vehicles, but the human safety and risk first. There's a hierarchy.

Other Thoughts?

- Intrinsically, a lot of the elements of the application, vehicle sizing, propulsion, etc. are inextricably linked. In order to get a good handle on the system you want people to build, some of these things need to be more fully flushed out. If you have a common battery, how do you go about sizing and loads? If you have a solution that's periodic in its energy generation, then you may want to run for a longer period. There's a lot of technology and application-specific questions that will strongly impact specification-level rules.
- Any thoughts on the site itself? And ensuring safety there? Should we be looking for open ocean environments or more sheltered sites?
    - Depends on the sites, particularly with pools and tanks. Some will have very strict safety considerations you'll need to adhere to. If you pick the tank venue, you'll want to double check the rules. In terms of going out to see, one potential problem is that you're looking for a wave environment. You have to get them out in a safe way so it might be good to have the testing in two different phases. A calm nearshore environment or bay, and then use your acoustic navigation for example, versus a wave environment.
    - Agreed. Venue will dictate rules. If you're using a tank, who's tank you're using will dictate the rules.
- Look into Robonation resources for other ideas and existing standards…
- A good framework to consider for teams to use in communicating how they think about safety for their design is STPA: Systems-Theoretic Process Analysis. There is some work already done on using STPA for maritime industries: "Towards maritime traffic coordination in the era of intelligent ships: a systems theoretic study" (https://doi.org/10.2478/9788395669606-020) and "A systems approach to risk analysis of maritime operations" (https://doi.org10.1177/1748006X16682606).

Crosscutting Feedback

During the workshop, the organizers also collected feedback on the intended mission that would frame the competition, and encouraged general feedback. For the intended missions, this included a vote and general feedback.

Intended Missions

During the workshop, the organizers asked specifically for a vote on intended mission of the first DEVELOP Competition. The mission is intended to help shape and contextualize the Competition.

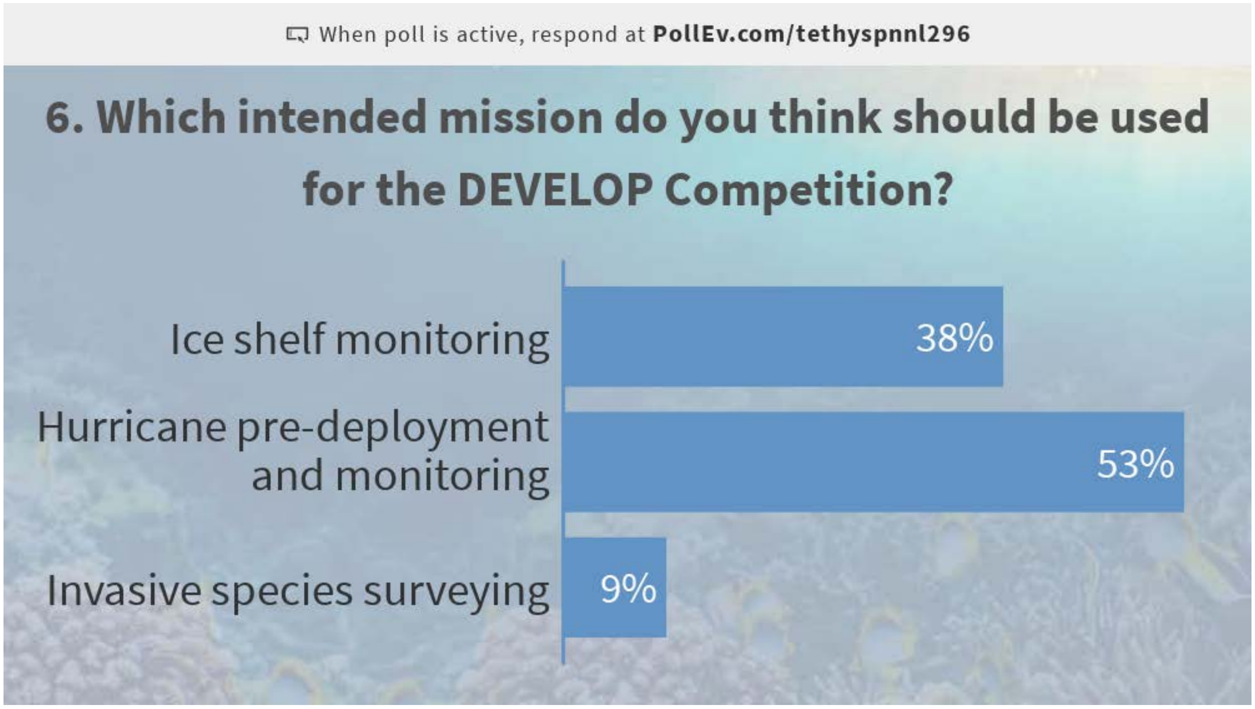

Figure 2 - Participant poll: "Which intended mission do you think should be used for the DEVELOP Competition?" N= 45

- Mission specific notes:
  - Ice Shelf Monitoring
    - How far must an AUV transit to go from the edge of the ice to reach the grounding line? How much time will the AUV spend under the ice? Is this captured by the 100km distance parameter? What is the expected sensor and data processing load? These questions will drive the energy requirements for the AUV.
    - How much time will the AUV have between sorties? What are typical wave conditions near the edge of the ice? This information will inform requirements for energy harvesting.
    - Under ice navigation over a 100km transit will be challenging. What is the requirement for navigation accuracy?
    - Satellite coverage is more challenging at high latitudes.
    - The AUV will probably require sufficient autonomy to determine when conditions (heavy seas, diamond dust, etc) are unsuitable for energy harvesting and/or other surface functions (e.g. comms)
  - Hurricane Monitoring
    - What drives the 20 km per sortie requirement? Is this the intended distance for an AUV sprint at 5 m/s?
    - A sustained speed of 5 m/s (10 knots) is very high for an AUV. While this is achievable, it requires a substantial increase in power. Consider that an

increase in speed from 2.5 kts to 5 kts reflects an 8x increase in power; likewise, an increase from 5 kts to 10 kts reflects another 8x increase in power.

        - When on the surface, an AUV's propulsive efficiency is greatly reduced (even in very clam water); as such, a transit at 10 kts on the surface will require even more power
        - If the AUV is to follow the hurricane while submerged, how will it determine its location relative to the eye of the hurricane?
        - Some USVs can travel at high speed and are quite robust to intermittent submersion; if 10 kts is a hard requirement, this may be a better alternative (with a sensor that can be dipped)
    - Invasive Species Surveying
        - Under ice navigation could pose a challenge--how will the AUV determine its location and a viable route to open surface (ice free)?
        - The requirement references a 5 km range per sortie; this requirement may be ill-posed... how can we guarantee the center of the watch circle will remain ice free? Presumably, the AUV will be near ice, given the requirement for "under ice survey"

Responses to the Suggested Trials

In addition to considerations during breakout groups, the organizers collected information about potential trials - or tests - that could be conducted in order to test systems before an open water test.

- 9.1.1 Trial 1 - Waterproofness
    - Statistically speaking the success rate in this trial will be adversely affected by the requirement to ship on a standard pallet. If we design and build a 2.5m long UAV then we would like to ship it in one piece and not split it into several pieces for shipping. Limiting the size of the uav to 1.2m long would likely result in difficulty meeting the power requirement.
- 9.1.2 Trial 2 - Speed
    - Gliders have many advantages including longer endurance and lower average power consumption per distance traveled. Gliders cannot meet this speed requirement. Would you consider a different speed requirement for gliders and propeller driven UAVs?
- 9.1.3 Trial 3 - Underwater Acoustic Navigation
    - We strongly feel that this trial does not support the goals of the competition and actually reduces the overall impact that the competition will have on its own goals. This requirement forces teams to divert effort from energy generation to navigation. However navigation is an available technology (no innovation required). Diverting team effort from innovation on core energy generation tasks to integration of navigation solutions reduces innovation in the teams reduces the overall impact of the competition. In addition, this trial specifies a method of navigation that is different to the method used in the station keeping trial (GPS/compass). Would you consider substituting a second round of energy generation trials instead of the navigation trial? For example it would be

        - beneficial to have a first round of energy harvesting trials in a controlled wave test tank environment before the already planned open sea energy harvesting trial.
- 9.1.4 Trial 4 - Energy Harvesting and Recharge
    - The requirement that "GPS/WiFi/Cellular antennae has an unobstructed view of the sky at all times" is onerous. Waves will naturally wash over the device. A low freeboard design is fundamental to survivability so this requirement undermines the device survivability. Would it be possible to adapt this requirement to say that "GPS/WiFi/Cellular antennae has an unobstructed view of the sky at least 25% of the time?"
    - The test duration is relatively long. This long duration means that the trial is a reliability test as well as an energy harvesting test. There is a conflict between innovation and reliability, more innovative designs will take more time/resources to achieve reliability while low innovation designs will achieve reliability relatively quickly and cheaply. If the focus of the competition is on innovation then the energy harvesting trial might be restructured to be less demanding in terms of reliability. A single 7 day trial favors conservative non-innovative designs as these are more likely to make it to 7 days. Alternatively 7 repeated 8 hour trials with an opportunity to repair/tweak/recalibrate between tests would favor innovative but less mature designs.
- 9.1.5 Trial 5 - Station Keeping
    - See above re "unobstructed view of the sky at all times".
- 9.2 TEST ENVIRONMENTS
    - As mentioned above doing the energy harvesting trial in a wave test tank instead of the open sea would favor more innovative designs. The time scales of the competition are short so that achieving both genuine innovation and also reliability will be difficult in the allowed time.

Workshop Specific Feedback

In addition to the summary and notes provided for each breakout, participants provided feedback on the general flow and overall workshop, as well as final thoughts about the overall scope of the competition. The feedback in its raw form is presented below:

- Logistics
    - Good effort in making the meeting telework compatible. Breakout sessions seemed to work in getting the feedback needed. Moderators were able to keep the discussion moving.
    - I found the format and the size of the groups to be a great way to facilitate discussions. I am sure I am not alone in having taken part in many technical competitions, so your group may also benefit from a session on competition logistics.
    - First, kudos on a really well organized and efficient workshop. Discussions were focused and productive, and the content seemed cleanly segmented.
    - The discussions were good. All the organizers have done wonderful work in preparing and facilitating the discussions.
    - Everybody seems to talk about charging the AUVs with wave energy? Are we allowed to use other types of energy like current and thermal, or is it restricted to wave?

- How will the mission of interest be decided?
- Scope
  - In order to facilitate emphasizing the energy harvesting aspect of vehicle development, I propose that the requirements stipulate everything you DON'T want the vehicle developer to spend their time on.
  - My concern is that this competition is being steered to a direction outside of DOE's mission. It is not "powering the blue economy" any more. Instead, the role of "powering" is minimal. Then it will be similar as DAPRA and Navy's underwater vehicle competitions. Please clarify it. Thanks!
  - Overall, I think this is productive. The "difficulty" I think is the possible number of combinations involved, e.g. 3 possible mission scenarios dictate different CONOPS, work in a tank, work at sea, so hard to make clear choices / recommendations on some things.
  - There were detailed discussions. They could have been a little bit longer. Unfortunately, not knowing which of the 3 missions to eventually design for left many questions unanswerable. Time would have been better spent, had this answer been known yet.
  - I think there was quite a bit of confusion on what the competition goal was based on the theme. I heard multiple times (including my own understanding) that we thought the DEVELOP competition was based on the winning designs presented in the DISCOVER prize. These had a wide range of use cases. This AUV with internal WEC competition really limits who can compete.
  - Given the limited resources and time scale of this effort, I'd focus almost entirely on the energy harvesting technologies and have performers provide a "path forward" in words to how these could eventually be integrated into a AUV or other maritime system (like a glider). The energy harvesting is the hard part here - we should focus the effort there. Also given the physics of wave energy, some of these harvesting systems are likely to be large in size (or rather surface area) - so expecting they can be integrated into a relatively small vehicle (2.5m, 80kg) is probably an unreasonable constraint. Focusing on candidate harvesting technologies, conversion ratios (of wave energy to useful on-board power) with a mind to eventual system integration (they can specify a path, identify size classes technologies will work with, etc) would be the best use of funds here as I understand the challenge.
  - I think there should be more work done determining the metrics for success that span across these different breakout topics. These types of Figures of Merit (FOMs) could really highlight the difference between solutions. For instance, to highlight smaller, more efficient vehicles: "AUV weight/mission hours." Or to highlight vehicles with more efficient energy capturing methods These types of Figures of Merit (FOMs) could really highlight the difference between solutions could be "AUV mission hours/AUV charging hours." I'd be happy to help discuss and develop these further if that's helpful -
  - Just a general comment, I think the rules document should stay as agnostic to system architecture as possible and focus instead keep rules focused on vehicle's functions.

- In terms of requirements, I think it’s really important to keep the requirements of the design as agnostic to systems architecture as possible, and instead focus on requirements from the perspectives of:
    - functional (what functions need to be done to accomplish prize objectives),
    - performance (how well the system needs to perform those functions),
    - interface (how the vehicle will need to interface for instance with a lifting winch/rig),
    - environment (what sea states and environmental conditions will it need to operate it?), and
    - constraints (what are the limitations on size, weight, power, etc.).
- I'd ask the organizers to clarify what new functionality we're hoping to develop in the contest that CANNOT be already had by commercially mature AUV (and/or ASV or ROV) technologies that can simply stay out longer with less human interaction. Pure energy harvesting/recharging stations are a simpler (more realistic) engineering goal for this competition, especially given the core competencies of most DISCOVER stage entrants. Simpler recharge stations would avoid a lot of integration and testing burden compared with AUVs, for instance high precision IMUs for subsea navigation or cameras and machine vision for obstacle avoidance. Those also translate into higher cost for eventual commercial systems. In most cases the only interface between the AUV functionality and the WEC functionality is power transfer, and perhaps communications, so those seem like logical places to draw the line between the two systems. There may be some redundancy is systems (eg two controllers, two battery monitors, two IMUs), but in the case of the WEC these are actually relatively simple compared with an AUV, and shouldn't distract from the large challenge of PTO/generator/battery integration, which seems to be the current industry challenge. The counterpoint here would be if we caught the interest of established AUV developers who have already solved and operationalized some of the navigation challenges I described. These would probably be the best commercialization partners, too, as they could just merge wave harvesting components with AUV components into commercial products.
- Keep the requirement minimal to encourage out of the box thinking. Rules and requirements will limit creativity.
- Avoid creating a long wish list of features. The mission should be simple with only a single purpose.
- Consider using a dummy SUV for this phase, again, the focus should be how to convert wave energy. You do not want to throw in 10 other variables into the equation