Project Number: 901405

Project Start: Jan. 1, 2014[1] **Project Duration (in years): 3**[1]

Please indicate what type of project is being proposed (mark only one).

[ ]	[X]	[ ]	[ ]	[ ]
Feasibility/Scoping [Less than 100 days effort]	**Development**[2]	**Research**	**Infrastructure**[2]	**Education**
	[ ]	[ ]		
	Time Series	**Institute Initiative**		

Project Manager[3]: Andrew Hamilton

Principal Investigator: Andrew Hamilton

Lead Scientist: [Enter name here]

Lead Engineer: Francois Cazenave

Project Title: PowerBuoy

[1] This date and number should remain the same for the duration of the project. If your project start date for 2014 is not January 1, please indicate the start date in the first cell of the milestone chart.
[2] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[3] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.

1) ABSTRACT (new projects only)

Under DARPA funding the PowerBuoy project has developed and fielded a wave-energy conversion buoy that has the capability of producing average powers of about 300 Watts and that has a usable lifespan in the ocean of one to two months. The project has been a proof-of-concept effort justified by the idea that power is a limiting factor when considering long-term robotic exploration and monitoring of the ocean. As the DARPA funding ends there are two categories of issues to consider when evaluating if this project warrants MBARI funding, use-cases for the resulting system, and the severity of the technical challenges still to be addressed.

Under DARPA funding we've been working to ascertain what is possible in terms of power generation and survivability without detailed plans for how that power would be used. In general this work can be viewed as an investment in a technology that will enable a persistent presence in the ocean. All along, there has been a vision of using such a system to recharge a fleet of AUV's and this probably remains the primary use of such a system. However this must be seen as a long-term goal and requires the investment in other technologies in parallel with the power generator itself, in particular AUV docking. There are other potential applications as well, including the powering of buoy based instrumentation and communication equipment. All of these use-cases are fairly ill-defined at the moment and if MBARI funding is to be considered for this effort, it is important that specific and viable use-cases for the technology are identified.

The development of this system has been very challenging and there are a number of technical issues left to tackle before this system is routinely usable for science applications. In particular the immediate stumbling block is longevity; the system was designed for two-week long deployments in non-storm conditions. When we've attempted to push the deployment durations to longer time periods we've run into a number of failures that have been caused by material choices that weren't intended for extended deployments, and by the fact that the current design does not include a strategy to deal with extreme loads during storm events. We feel that both of these issues are solvable through engineering, but often this sort of refinement takes a lot of extended deployments before a truly reliable system is realized.

Another limitation of the current system is that it does not have a station-keeping capability. The Liquid Robotics "flapping foil" concept is very attractive for this system and we expect it would work nicely at our larger scale. To date we've been unable to partner with that group and proceed with development, but such an arrangement would probably be a key element of realizing a system capable of supporting at-sea instrumentation for extended periods without being moored.

At this time it is also worth considering other incarnations of wave-energy harvesting for the purposes of oceanographic research. Before the DARPA project started there was a feasibility study at MBARI to investigate the possibility of a wave-powered vertical profiler that captured electrical energy on board a profiler in addition to using the waves to motivate the profiler up and down. This project remains compelling and it may be more straightforward to identify nearer-term science applications for this sort of device since they presumably wouldn't depend upon an entire ecosystem of technology developments. The DARPA project has allowed us to develop very specific tools for analyzing wave-energy extraction concepts, and given us significant experience with the power conversion elements required. Because of these efforts we are in a strong position to revisit this sort of project.

The proposal to be submitted will contain the following elements

1) An outline of possible use-cases for this system in the mid to long-term timeframe. Near-term deployments of a next generation system would likely continue to be engineering based.
2) An analysis of the technical challenges that must be met to realize the above use-case goals, approaches for each, and a recommended order of tackling these.
3) A discussion of station-keeping options and limitations.
4) An outline of other energy harvesting technologies worth exploring with the expertise we've gained through the DARPA project.

2) PROPOSAL

a) New Projects

Statement of the problem, why it is important

A limiting factor for robotic exploration and monitoring of the ocean is the amount of power that can be brought along in batteries. For extended deployments of instrumentation and vehicles some energy harvesting is necessary, solar and wind sources are mature technologies but are limited in the quantity of power they can provide. Wave energy can provide larger amounts of power, which in turn expands the capabilities of the vehicles and instrumentation that can be fielded.

The ultimate vision is for a system that can survive for extended periods in the ocean (6 months minimum) and supply power to both on-board instrumentation and mobile vehicles through periodic docking of underwater vehicles. Ideally the system would have a station-keeping capability that would allow it to stay roughly in one location. Moored and freely drifting systems also have applications. In particular drifting applications far from shore in which it is desired that the instrumentation track the underlying water mass can benefit from this technology by limiting the wind exposure of the surface expression. Solar and wind harvesting typically requires a surface expression and tower, but a wave-energy powered device needs to be little more than awash, dramatically reducing wind forcing that typically causes drifting surface buoys to move through the water rather than with it.

The recently completed DARPA funded project has allowed us to develop a proof of concept wave-energy conversion device that generates approximately 5 times the amount of power generated by a similarly sized solar/wind buoy. This is a technical achievement but only at the proof of concept stage. There are several technical issues to be addressed before the device can be routinely used for science experiments. These include issues of reliability, power-system optimization, station keeping, and AUV docking. This three-year project addresses all of these issue but in 2014 intends to concentrate entirely on the reliability issues that plagued the extended deployments that were attempted at the end of the DARPA project. Only with the reliability issues solved can the remaining challenges be sensibly attacked.

How does it relate/contribute to MBARI's mission and strategic plan?
This project is aimed squarely at extending the time and space scales at which oceanographic measurements can be made in the ocean, which is in line with the "development of better instruments, systems, and methods for scientific research" clause in the mission statement. This project is very much a technology exploration to make a significant change in the amount of power available for long-term oceanographic measurements, which relates to objective number one of the strategic plan directly, "Foster technological innovation". The technical roadmap being developed to meet this objective specifically names "Advancing a persistent presence" as an engineering challenge and opportunity to pursue.

How does it relate/contribute to the Packard Foundation's Ocean Visions Grantmaking policies?
(See http://mww.mbari.org/oed/OED_Documents3.htm#Packard for documents.)
This project aims to develop technology that provides capabilities to enhance our scientific understanding of the functioning of marine ecosystems, which is one of three objectives called out in the Grantmaking policy document.

Approach to the problem
In order to achieve the system described above, there are a number of technical challenges that need to be addressed; Survivability, Improved Power Electronics, Station Keeping, and AUV Docking.

Survivability/Longevity
The existing system was designed for very short deployments (<2 weeks in summer conditions) to demonstrate that energy can be captured and converted to electricity. In the latter phases of the DARPA funded project the deployment durations were extended to periods greater than two months. This invariably led to failure of the system due to it operating outside of its design envelope. In addition to a variety of small non-fatal issues that came up due to the extended deployments, there were two catastrophic failures of the main tether in the system. In each of these cases there were failures of small items that led to the failure of the main tether. In one case it appears that a recovery line wrapped up in the tether and may have caused fatigue, in the other an electrical connector failure caused the gas spring to deflate which introduced significant shock loading into the system that caused very high peak tensions even in mild summer conditions. <u>Because of these circumstances it is not yet clear if the catastrophic failures that have occurred represent a fundamental weakness of the system concept, or if solving the smaller contributing factors will result in a robust system. Resolving this is the most important first activity to pursue and will be the focus of year one of this project.</u> The specific developments that will be pursued to make the system robust are described in the "Engineering/Technology Development" section below.

Power Conversion and Optimization
The electrical power system that was developed as part of the DARPA project is rudimentary and only provides the minimum features necessary for the test deployments. This system has two main purposes, the first is to control the electrical loading of the generator to optimally extract energy from the waves, the second is to convert the electricity generated from raw generator voltages (0-500V) to a voltage suitable for charging batteries and powering instrumentation (24V). The capacity of the existing system that converts electricity from raw high voltage to voltages suitable for charging the batteries is less than what is needed to convert all of the power captured. Instead the current system converts only enough to supply about the 60 Watt power draw of the control computers and radios. Additionally, the present system is uni-directional in that it only can absorb power from the piston between the buoy and submerged plate, and can't drive the piston motion by using stored electricity. A bi-directional capability is desirable for two reasons; The ability to position the submerged elements of the system relative to the buoy would allow stabilization of the submerged drag plate and any attached AUV dock or instrumentation. This could be a requirement for successful AUV docking to the PowerBuoy device. Secondly, there are control strategies that may increase the amount of power captured by a device of a given size that operate by feeding some power back into the system at certain parts of the wave cycle, this is challenging to do correctly but a doubling or more of the net captured power has been shown to be theoretically possible. Assuming sufficient robustness can be demonstrated in year one of the

project, the development of an application specific power system would occur during the second year of the proposed three year project.

Station Keeping

The original DARPA effort envisioned a station-keeping capability for this system. The system concept was driven early on by the hope that a collaboration with Liquid Robotics would allow us to integrate a larger version of the wave-glider propulsion device to enable station-keeping. Preliminary engineering work found this concept to be very attractive in that it simultaneously provides propulsion and increases the electrical generating capacity of the system. Additionally, analysis indicates it to be realizable from a structural point of view. Unfortunately, it was impossible to come to a collaborative agreement with Liquid Robotics due to our DARPA funding, so this approach was dropped and our subsequent deployments were either drifting or moored to the seafloor. With the DARPA funding completed it may be possible to revisit collaborative work with Liquid Robotics to realize this capability that would be unique and extremely powerful. Much has changed at that company since we ended our previous discussions so we do not know how the suggestion of collaboration would be received at this point. Ideally we'd go into that discussion after we've proven the reliability of the system as described above. If the Liquid Robotics concept can not be implemented, there are thruster-based approaches to station keeping that could be employed, but these would likely result in more limited station keeping performance.

AUV Docking

AUV docking is a critical part of the final vision for the PowerBuoy system. The DARPA project of the past few years recognized this and had a docking element which developed and built a prototype dock (but did not deploy or test it), and integrated a directional sonar system into the LRAUV. The sonar system was eventually made to work after overcoming quite a few integration issues. The resulting system is reasonably close to being usable for LRAUV docking in the case that the dock is mounted on the seafloor, fed by power from a moored buoy. The more challenging task of docking the AUV directly to the PowerBuoy system is largely unexplored at this point.

This proposal does not include an AUV docking effort, but instead concentrates on providing the infrastructure that would be needed to realize the final goal of docking the LRAUV to the PowerBuoy. In particular, these capabilities include dock stabilization capabilities and delivery of the power to the sub-surface element where a dock could be located. To dock the AUV to a drifting PowerBuoy the dock stabilization capability would likely be necessary due to the limited maneuverability of the LRAUV. Additionally, in the current design the electrical system is confined to the buoy and no power is delivered to the sub-surface element of the system. As part of the DARPA project, a plan and preliminary design to route the power through the power take-off device and down the tether was developed, but this work was never implemented or tested. Because the first year of the project is dedicated to addressing the reliability of the tether, it is sensible to include the needed copper elements in any new design work so the reliability testing does not need to be repeated for a new tether, even if no power is passed through that route at this time.

Overall Schedule

The proposed project is intended to be a three year effort that ideally results in a PowerBuoy that can operate for up to six months, generates, converts and stores sufficient energy to provide 200 Watts average power at battery bus voltages, has the capability to support an AUV dock, and is suitable to be integrated into the Liquid Robotics flapping foil concept for station keeping. It is not necessary to do significant work on the power system, station keeping, or docking before survivability has been proven. For this reason the first year effort is largely dedicated to re-design of some elements and at-sea testing that will improve the longevity of the system and uncover the fundamental limitations of the design. Presuming success in year one with that effort, improvements to the power electronics to enable new features (docking and optimal control) and exploration of station keeping will be pursued in year two. Positive results from year two testing would set MBARI up to bring the AUV docking efforts out of mothballs for integration into the system, this would best be done as a companion proposal at that time.

An overview of the three year schedule is described here, a detailed work-breakdown for the year one tasks is contained in section (c) below.

Year 1: The main effort in year one is to harden the system and demonstrate that a six month deployment is possible in non-winter conditions. This effort will consist of two test deployments, a two month test of the system as it is now to establish the current fatigue factors that may be impacting the tether, and a longer six-month deployment incorporating design changes to the surface buoy and submerged plate elements of the system. Little to no changes to the electrical and software elements of the system will be required for these tests. Background work on the power-electronics and station keeping elements of the overall plan will also take place, including power system concept design and modeling and lab-testing of high-risk elements. If the system has proven to be robust at the end of 2014, this would be an appropriate time to re-approach Liquid Robotics and explore a collaboration.

Year 2: Presuming success in year one, the second year of the project will include upgrading the power electronics to a system that is capable of converting and storing a larger fraction of the electricity generated, incorporating systems to deliver that power to the sub-surface element, and pursuing station keeping technologies. The preferred solution to station keeping remains a collaboration with Liquid Robotics, not only is this the most appealing technical approach, but working with them could also provide additional outlets for technology transfer beyond application in MBARI science experiments. Should it not be possible to make these arrangements, we will explore a thruster approach, but this is likely to be less effective, resulting in degraded station keeping capabilities.

Year 3: The third year will be oriented towards engineering deployments to demonstrate capabilities to support as-yet undetermined science experiments. In particular the stabilization techniques and the delivery of power and communications to the sub-surface elements that are needed for AUV docking will be developed and demonstrated in an extended deployment. If results from year one and two are promising, MBARI could consider funding a project in 2015-2016 to complete the AUV docking efforts and dock to the system during the third year of this project.

b) Continuing Projects

c) New and Continuing Projects: Plans for 2014

Described here is the work to be done in 2014 aimed only at refinements and deployments to demonstrate reliability of the system.

Engineering/technology development
The main effort for 2014 is to make modifications to the existing PowerBuoy system to increase its longevity and to demonstrate that at least a six month deployment is possible with this design concept. Storm survivability will be addressed in the design changes but will not be tested in 2014 due to the risks of losing the system that storm testing entails. Should a six month deployment be successful, it is more valuable to recover the system and analyze its condition and residual strength than risk losing that accumulated data (and the hardware) by leaving it out in storm conditions. Depending the data collected in 2014 and the appetite for risk in 2015, storm testing could be done in Jan-Feb 2015.

The issues that need to be addressed fall into three categories;

1) Changes that specifically address the current weak point in the tether connection between the buoy and the submerged plate. This element is likely to fail either due to fatigue after long periods of use, or due to large storm-wave events. In fact this tether has failed in two previous deployments, but in each case there were extenuating circumstances so the actual lifespan of the existing system in the absence of other failures is currently unknown.

   Several approaches are planned to address this problem. The first technique is to simply increase the size and strength of the tether itself. Up to a point there is a little penalty for making this stronger and this will help with fatigue issues and some peak loading events. A larger cable has already been acquired for the existing system so the first iteration of this testing can simply be achieved by re-deploying the existing system.

   It is unlikely that severe storm survivability can be achieved by simply making the tether stronger because two elements of the design currently have little compliance in the event of large waves. The buoy has significant reserve buoyancy so is always on the sea surface, and the submerged plate is rigid so the force imparted to the tether goes up as the square of the plates velocity through the water. The combination of these characteristics means that larger waves always means larger forces. Even in moderate storms there is a non-zero chance that a very large wave will come along and damage the system. For this reason some upper limit on the force that can be exerted on the tether (and other components) needs to be engineered into the system to limit the peak forces regardless of wave size.

   Two complementary approaches are proposed here to introduce compliance. The first is to redesign the surface buoy to have limited reserve buoyancy. In this design the buoy would become completely submerged when faced with large waves (much like a crab-pot buoy). This will limit the buoyancy force exerted on the system, the tether forces will still increase in larger waves due to the inertia of the buoy itself, and the hydrodynamic drag forces on the buoy, but some compliance will be introduced. In the extreme design the surface buoy will have a large water-plane area (which translates to large power production in smaller waves) but little reserve buoyancy to limit peak forces in larger waves. The nearly awash buoy will become a bit of a navigation hazard so a mast that is sufficient for lights, radar reflectors, and radio antennas will still be present. This approach follows an emerging trend in buoy design (the OOI moorings in particular) that uses submersible buoys to limit peak loads. In the drifting PowerBuoy application, such a low-profile buoy will not be subject to significant wind forcing and will hence track the underlying water mass better than buoys with large above water windage.

The second approach is to redesign the submerged plate to have “vents” that open when the plate is pulled quickly enough through the water. This will be a passive spring-loaded system of flaps that will naturally shed power when heavily forced. There are a number of options of how to implement this, an additional but related design goal of this work will be to increase the stability of the submerged element in heave, currently it swings around quite a bit which not only increases the bending loads on the tether but also makes AUV docking more challenging. A design that is more stable in the downward heave direction (i.e. descends less like a falling leaf) could prove beneficial.

The power-generating capability of the current design is currently limited by both the size of the surface expression and the size of the submerged plate. Both of these dimensions are limited by peak load considerations and therefore the systems capability to generate significant power in the common low-wave conditions is limited by the need to survive the rare large-wave conditions. The two suggested changes to the design could therefore increase the utility of the system in addition to providing storm condition survivability.

2) The longevity of the hydraulic system (motor and seals). This is a system that degrades slowly, but will degrade eventually. Throughout the past deployments we’ve improved some aspects of this system and have yet to see measureable wear in any of the components and anaylsis of the hydraulic fluid after deployments have indicated clean oil, with only traces of water and metal in the fluid. Nevertheless, longer deployments will certainly start to show performance degradation. There aren’t a lot of engineering changes the system requires at this point, but successful longer term deployments will help characterize the life-time of these elements. We have done all our deployments with the same hydraulic motor, so it already has more than 5 months of use on it with little degradation. The rod seals in the system have been replaced for each deployment (for various reasons). In planning for a six month deployment we would likely use a new hydraulic motor (which we have in stock).

3) System hardening. There have been failures due to insufficient electronics housings and the large number of connectors and penetrations in the system. The current design was intended for short term deployments and as such the housings on the buoy are simple fiberglass NEMA boxes. These have proven problematic and although it’s never ended a deployment, water intrusion into these boxes has caused considerable damage and required quite a few field-service trips. Additionally, the prototype nature of the development so far has resulted in a large number of housings and connectors and this could be streamlined. In conjunction with the submersible buoy concept described above it’s attractive to consider a sealed hull buoy in which all electronics and batteries are inside the hull, and thus don’t require separate housings and waterproof connections. The risk of this approach is that a single leak could cause the system to sink. Previously, a hybrid concept design was developed as part of the DARPA effort that includes positive foam floatation around a single dry housing with all the electronics inside. The trade-offs in the buoy design will be re-examined as part of this project.

Field programs (detail ship requirements/deployments/diver requirements)
Two deployments of the system are planned, a shorter 2 month deployment of the system as-is to perform tether fatigue testing that we have been unable to achieve due to previous tether failures, and a longer 6 month deployment of the system that incorporates the design changes outlined above. The reason to split the effort this way is to maximize the return on the refurbishment of the system that was performed at the end of the DARPA funding to address the failures that ended the previous deployment.

Note: The system is currently ready to go out again for a non-storm condition deployment for up to two months. Notwithstanding the MBARI funding cycle, the ideal course of action would be deploy this system in August of 2013, but no funding remains in the DARPA project. If this were possible it would allow us to gather the needed tether fatigue data in the current configuration and allow the maximum amount of time to incorporate that data into the redesigned elements. If MBARI funding was available for this deployment in 2013 the effort would be advanced significantly. Approximately $9450 would be required and 216 hours of engineering time (ME = 152 hrs, EE/SE = 64 hrs) and 76 hours of technician time (ME = 68 hrs, EE = 8 hrs). The time commitments could be reduced some if the post-deployment data analysis and residual-strength tests waited until January 2014.

Traditionally this system has been deployed and recovered by the Shana Rae. This has proven very cost effective due to the fact that the system was designed for that ship from the beginning. The ship costs outlined in the budget reflect the continual use of this boat. Deployments can be done from the Rachael Carson if it is available but some effort will be required to re-engineer our systems. In order to expand the ship options for deploying this system, we will consider features in the new designs to facilitate deployment and recovery from ships aside from the Shana Rae.

During deployments we typically dive on the system once every 2-3 weeks to inspect various aspects of the underwater systems. This and other inspection trips have been effectively performed with the Paragon and we would like to plan for one Paragon trip for each 2 weeks of the 2 month deployment, and one Paragon trip for each 4 weeks of the 6 month deployment. Typically these are two-three hour trips as the deployment site is nearby and the Paragon is fast. In the budget and ship request it is assumed that each service trip requires ½ of a Paragon day.

Specific deliverables
- Results from short term deployment designed to test issues related to tether fatigue characteristics in the existing design concept. This is a critical parameter relative to the long-term deployments of this design.
- New buoy design. Design reviews, design documentation, and fabricated item.
- New plate design. Design reviews, design documentation, and fabricated item.
- Numerical modeling analysis of expected power generating performance of refined system.
- Results from long term deployment including longevity results, outstanding wear issues, power production, and lessons learned from deployment/recovery.

Milestones (see personnel classification list)

2014 Project Start Date: 1/1/2014	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	Total Resources[4] for each resource category for all milestones listed here
Milestone Date	5/1/2014	2/1/2014	6/1/2014	6/1/2014	12/1/2014	
Milestone Description	Complete 2- Month Tether Test	Complete PTO Improvements	Complete Buoy Redesign	Complete Plate Redesign	Complete 6 Month Deployment	
EE	24	8	48	0	96	176
SE	40	16	16	0	124	196
ME	152	88	844	720	320	2124
EE Tech	8	16	32	0	48	104
SE Tech	0	0	0	0	0	0
ME Tech	68	56	182	328	84	718
Machine Shop	0	0	320	120	0	440
Divers	28	0	0	0	40	68

Milestone 1: Complete 2-Month Tether Test. The goal of this task is to deploy the system as is to ascertain the fatigue mechanisms that may be going on with the existing tether configuration. This data will be very helpful in determining how much the loads in a new design need to be reduced, and comes at little cost since the system was appropriately refurbished at the end of the DARPA project and is currently ready to be redeployed. *As noted above, it would fit the overall schedule best if this task could be done in 2013, which would require an estimated $9450 in expenditures in addition to the labor specified in the table above for milestone 1.*

Milestone 2: Complete PTO Improvements. This task and milestone refers to a number of material upgrades to the existing PTO hardware to increase its lifetime. Most of this is upgrading from plain steel components that were originally specified for cost reasons when the deployment plans were much shorter. In the most recent two month deployment none of these items showed significant corrosion or signs of impending failure, so probably don't need to be replaced before the proposed 2 month deployment.

[4] This number should be the same number you entered on the resource requests for this particular resource.

Milestone3: Complete Buoy Redesign. This task and milestone refers to the buoy redesign that is intended to harden the protection of the electrical components, and provide some compliance and storm condition survivability to the design.

Milestone 4: Complete Plate Redesign. This task and milestone refers to the plate redesign that is intended to add some force/power shedding characteristics to the submerged plate, providing some compliance and storm condition survivability to the design.

Milestone 5: Complete 6-Month Deployment. If successful, this task and milestone will provide evidence that this design concept can last for extended deployments, more work will be required to prove storm survivability and further extend the deployment lengths, but an understanding of the long term wear characteristics of the hydraulic elements of the system will be achieved.

Budget justification

The table at the end of this proposal contains a work breakdown for all the tasks and sub-tasks that make up the total requested labor, ship-time, and expense. The labor and ship-time estimates are based on our experience with this project and the effort required to make engineering changes and field-test the results. The expense budget is based upon component quotes where possible and estimates where the items are not well enough defined at this point for quotes. In particular:

- Shana Rae time is estimated at $2000/day, compared with the $1950/day he has been billing us in recent history.
- Stainless Steel fittings, manifolds, tubing and flanges for PTO upgrades: These costs are well established based upon verbal quotes received from the vendors.
- Residual Strength Testing. These costs are based upon the cost of similar tests previously done at Tension Member Technologies, plus a margin for inflation.
- Buoy Hull, Housing, and Mast materials. These are rough estimates based on experience and can not be refined until further design work is completed. The connector budget is estimated to be fairly low because we expect considerable re-use of connectors that are part of the existing system. This will require disabling the existing buoy system.
- Material cost for submerged plate re-design. These are rough estimates based upon the build of the previous iteration of this element. Further design work is required to refine these costs.

Project team

The bulk of the tasks required to implement the longevity changes and testing are mechanical engineering oriented. Francois Cazenave, John Ferreira and Andy Hamilton are the key personnel that can not be easily replaced. Jon Erickson could also contribute to many tasks identified for Francois. Little software and electrical changes to the design are planned, but support from the original software engineer (Wayne) is generally needed during testing and deployments.

Project lab space
Project lab space is a significant issue for this project. The test equipment needed is large, noisy, and difficult to store between uses. DMO has graciously allowed us to use significant space in building D, we moved in there three years ago with the intention of staying for a single test and we're still there. Patience may be wearing thin, if we are to stay in that location the space allocations should be made more official within MBARI. Unfortunately there aren't a lot of other on-site options, but we are willing to be creative as needed. Aside from the noise we periodically make, we are in the way in building D with regards to the storage and retrieval of ROV tool sleds and associated equipment. Moving this material to the new expedition staging building would free the space for our exclusive use, but of course this isn't an immediate solution. The other issue is the noise our test equipment makes, although we run it infrequently, it effectively limits the ability for anyone else to work in building D. One possible solution to this problem would be to move the hydraulic power unit outside, which would require a wall penetration and a weatherproofing shed of some sort. If we did this it could then be a significant noise issue for Phil's Fish Market, which could have interesting repercussions.

Data availability outside project team, uniqueness
We typically publish live performance data of the system on the web-site in the form of graphs. Detailed numerical data is not available without us providing it. We have shared considerable performance data with our collaborators at IDMEC in Lisbon for the purposes of collaborating on an upcoming paper.

Export Regulation
Does the project team anticipate any foreign collaborations or international travel? If so, please identify collaborators by name, institution, and country.

> As part of the DARPA project we had a very successful collaboration with IDMEC in Lisbon, Portugal. The group there are experts at modeling this type of wave-energy converter and associated advanced control techniques. We have plans to collaborate on a paper in 2013 summarizing the work we did together. Our project has gotten them interested in small-scale wave energy converters and they currently have a student analyzing a small wave-energy converter based on an oscillating water column technology. They are tentatively claiming >1000W production from a buoy of similar size to ours, and we've informally discussed collaborating on a test of such a system "in the future". This could provide an alternative technology if we are unsuccessful at hardening out piston-based design (which is more suitable to oceanographic work at the expense of robustness). We do not have specific plans to work together in 2014 but will maintain this connection as appropriate.

Does the project team plan or anticipate export controlled purchases, shipments, or transfers of items (e.g., research instruments, proprietary data, hand-carried tools or samples) outside the U.S. temporarily or permanently? If yes, please identify country or countries and indicate whether these items will remain under MBARI control while abroad or controlled by others. Will the items be exported to more than one country? Please include foreign collaborator information as described above.

> No.

Monterey Bay National Marine Sanctuary SESAs (General map)
Projects will need to indicate whether or not work will be conducted within one of the Monterey Bay National Marine Sanctuary's Ecologically Significant Areas (SESAs). An interactive map can be found on the Sanctuary's SIMoN webpages at http://sanctuarysimon.org/maps/sesa/. (*Note: It may take a moment for the page to load, so please be patient.*) To determine if your work will occur in a SESA, specific coordinates can be entered using the locator function (click on the red "target" button in the toolbar at the top of the map). If your work will be conducted in one of these areas, please indicate which area, by number.

> None, deployments are typically in the Sanctuary (7 miles from MBARI) but are not in the SESAs.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High	X		X	
Medium				X
Low		X		