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XCT System for Harvesting In-Current Hydrokinetic Energy from Low-Velocity Sites

Daniel Bateman and Kimbal Hall PE in the large flume at Alden Laboratory 12/20

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Project Overview

Project Summary

The kinetic energy in river, tidal and ocean currents is an abundant resource that could support a potential $20 billion global market. However, an estimated 80% or more of this potential is locked up in relatively slow-moving waters where currents flow at 2 m/s or less for most of the year.

The central idea of the LPS “cross-cutting” (XCT) current energy conversion devices is to efficiently convert modest velocity flows into electrical power. The XCT trades swept area for localized velocity, by moving small, inexpensive turbines through the water rapidly. It eliminates gearboxes. Intended to fun fully flooded, it is anticipated to reduce maintenance costs.

Intended Outcomes

The specific goals of the project are to validate, through physical subscale prototype tests, a current energy converter that can:

- Support LCOE < $0.10/kWh in a high-capacity-factor setting such as an ocean current;
- Cut in at 0.5 m/s, and maintain an essentially constant C_p in flows from 0.75 to 2.25 m/s;
- Be stopped immediately in an emergency;
- Eliminate gearboxes;
- Interact with aquatic species in a manner reasonably expected to allow them to move around and beyond the device in a safe, timely, and effective manner; and
- Operate fully flooded.

Project Information

Principal Investigator(s)

- **David Duquette** (LPS)
- **David Torrey, Ph.D.** (GE Research)

Project Partners/Subs

- **GE Global Research**
- **Turbo Solutions Engineering LLC**
- **Alden Research Laboratory**

Project Status

- **Ongoing**

Project Duration

- Project Start Date: **8/1/19**
- Project End Date: **12/31/22**

Total Costed (FY19–FY21)

$**2,417,315**

Project Objectives: Relevance and Approach

Relevance to Program Goals:

- In its Multi-Year Program Plan (MYPP) promulgated under the as directed under the Energy Act of 2020, WPTO identified ***"the fundamental challenges of generating power from dynamic, low-velocity, and high-density waves and currents, while surviving in corrosive marine environments."*** It has also focused on ***"Powering underserved communities and enhancing coastal resilience***" by ***"supporting the design, manufacture and validation industry-designed prototypes at multiple relevant scales,"*** specifically including ***"Improving methods for safe and cost-efficient installation, grid integration, operations, monitoring, maintenance, and decommissioning***"and "***Supporting the development and adoption of international standards for device performance and insurance certification***" and "***leveraging expertise, technology, data, methods, and lessons from the international marine energy community and other offshore scientific and industrial sectors.***" Relevant to these stated goals:
  - The XCT was specifically devised as a cost-effective way to prosecute common moderate-velocity hydrokinetic sites – both oceanic and riverine – with a reliable, inexpensive current energy converter (CEC) design. A key idea is the use of small off-the-shelf generators and to use the water itself to provide the desired gearing.
  - The XCT is based around a conjecture that sites with non-reversing currents but offering a high capacity factor may in some case be better hydrokinetic resource than tidal sites, which may offer high peak velocities but low capacity factors.
  - Unlocking this resource with an economically viable technology is an especially acute challenge in the U.S., since these modest speeds characterize most potential sites in or near the USA.
  - Deployment and maintenance are at the heart of the program. Although not addressed in this program, the XCT system was specifically conceived to work with known an emerging marine robotics techniques, for deployment and retrieval.
  - The XCT prototypes have been designed and fabricated with emerging international standards in mind, principally IEC TC 114.
    - E.g., early on in the project we had not given much thought to stopping the device. The IEC standards requires that a CEC incorporate primary and backup braking system. This turned out to be a very time-consuming part of the work: braking a device that intentionally omits a fulcrum to react torque is not trivial.

Approach:

- Cost components for past CEC installations were analyzed. Biggest contributors were (i) installation and (ii) O&M. LPS conjectured that if system net torque could be zeroed, and gearboxes could be eliminated, this would help greatly, cost-wise, with both issues.
- Our approach has been indirectly inspired by technology developers like Minesto: trade swept area for localized velocity. Optimize for LCOE, not device efficiency (i.e., C_p) per se.
- Focus on a system design that is easy to moor and requires only simple civil works.
- On the thesis that "the ocean always wins," the entire device was conceived from the outset to run flooded – i.e., without seals of any kind.

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

Validate through numerical simulation, laboratory tests, and tests of two consecutive fully integrated sub-scale prototypes that the XCT device demonstrates the capability to:

- Support LCOE <$0.10/kWh in a high-capacity-factor non-reversing current, in a farm installation;
- Operate at essentially constant efficiency in a moderate flow regime (velocities 0.75 to 2.25 m/s);
- Run small, inexpensive gensets in direct-drive mode;
- Be able to stop in an emergency;
- Interact with aquatic species in a manner reasonably expected to allow them to move around and beyond the device in a safe, timely, and effective manner; and
- Demonstrate ability to run the system fully flooded
- Rotary transformer efficiency >97%

Outcomes:

The expected outcome of the project is a CEC design that

- has been validated to meet the metrics listed to the left, and
- is mature enough to take the next step of open-water testing in a pilot site installation as evidenced by test data on a fully integrated sub-scale XCT system.

Success would make marine hydrokinetic energy more accessible to coastal and riverine communities near places where water is moving at modest velocities.

Project Timeline

FY 2019

- project start August 2019
- 3Q19: visited Juneau & had discussions about AK pilot site
- conducted a risk assessment that led to the decision to test a 2 meter integrated test article in the lab

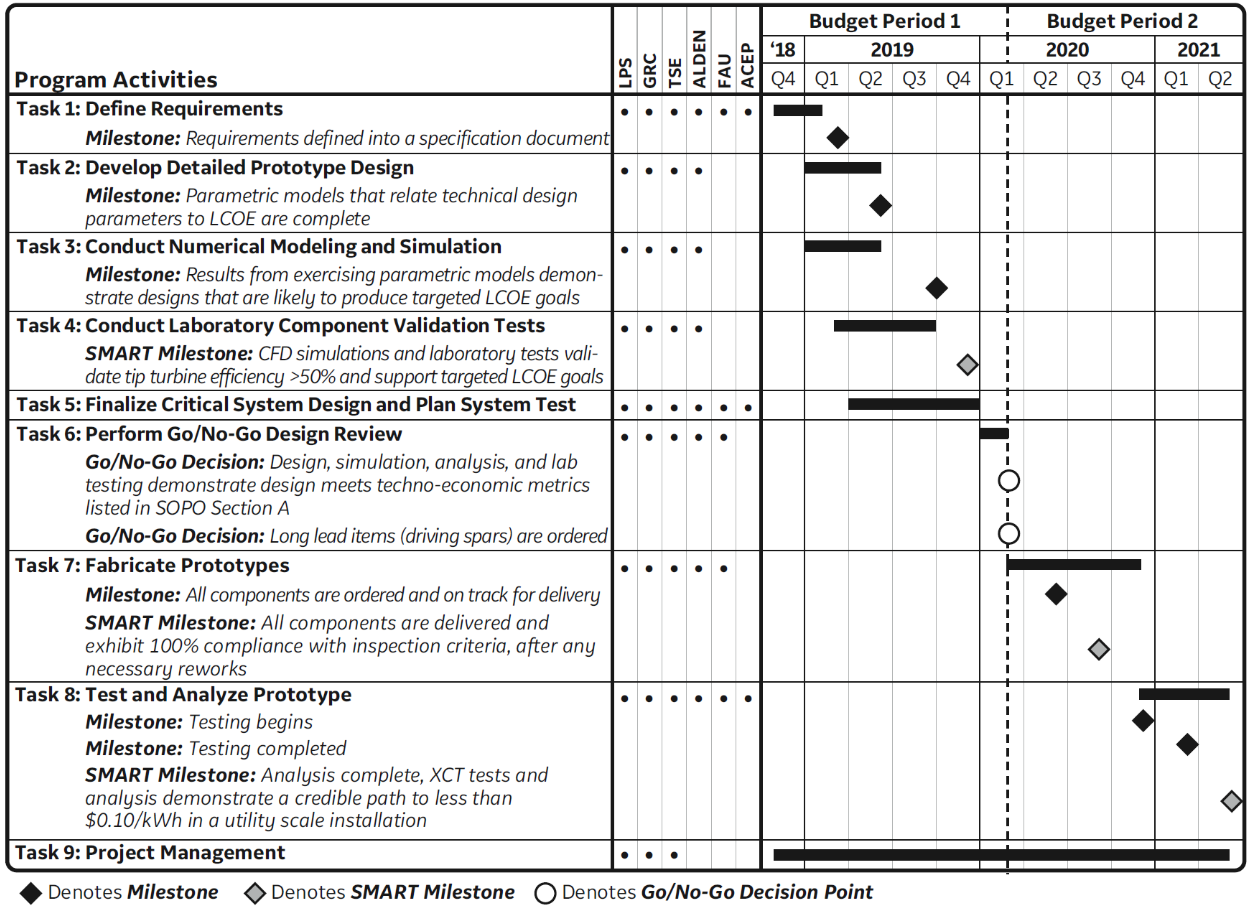
FY 2020

- laboratory-scale test article (LSTA) designed & fabricated
- LSTA tested in Alden large flumeu
- validations from lab testing:
  - vortex effect;
  - rotary transformer;
  - ability to run flooded;
- patent application published in 2Q20

FY 2021

- passed GNG
- added FMEA to document failures & component wear in testing
- aligned LCOE analysis with the NREL System Advisor Model (SAM)
- notable change: project plan changed post-GNG for FMEA, aligning LCOE w/SAM; detailed data gathering; document failures and component wear
- compliance w/emerging ICE standards, e.g. 2x braking
- open water subscale prototype (XCT-1) design commenced, taking into account 2020 flume test results

Project Timeline



BP2 extended through 12/31/22

Project Budget

Total Project Budget – Award Information		
DOE	**Cost-share**	**Total**
$3,489,586	$872,362	$4,361,948

FY19	FY20	FY21	Total Actual Costs FY19–FY21
$40,754	$812,523	$1,564,038	$**2,417,315**
variance to budget: ($31,681)	variance to budget: ($110,274)	variance to budget: $135,438	variance to budget: ($157,211)

Other funding sources: project partners and MA Clean Energy Center

The project has faced some budgetary challenges – principally cost share timing – and they are being mitigated successfully.

End-User Engagement and Dissemination

- **Stakeholder/end-user engagement strategy:**
  - As with all of its product development activities, LPS has conducted extensive customer discovery w/r/t the XCT. In particular, in setting out the design brief for the XCT, we have spoken with several native American communities and the AK Energy Authority,
  - Specifically, looking @ villages along Yukon for post-project site
  - XCT-1 is scheduled to be loaned to VPI Technology Group (UT) for use in a pilot test of its river pollution cleanup device on the Delaware River
  - LPS has had discussions with WHOI and private marine robotics developers regarding the use of the XCT device at subsurface AUV recharging stations.
  - As the project continues, and as test results from the XCT-1 prototype become available, LPS will accelerate discussions with end-users
- **Rationale:**
  - The core idea of the XCT project is to see if current energy can be economically brought to a broader swath of end-users than existing technologies make possible.
  - One reason for engaging native American communities is to better understand exactly what they can realistically handle in terms of deployment, retrieval, and O&M. The primary reason for engaging AEA is to be able to cover most of the likely candidates.
  - The ultimate goal of the XCT initiative is to work with ocean currents, but based on discussions with utilities and private developers to date, before the considerable expense of transmission assets are justified, it is clear that it must be shown to work in riverine environments where transmission requirements are far simpler.
- **Project results/ information dissemination plans; commercialization plans:**
  - One patent (U.S. 11,371,481, invs. Duquette/Hall) has been granted related to the XCT technology; another is still in the works related to this tech; as the project continues, more applications may be made
  - Updated LPS website
  - Shows and conferences
  - Once the project is finished, with will prepare a final technical report that will be posted to OSTI.gov
  - LPS has a robust commercialization structure in place. Most likely, we will introduce the XCT to existing customers in the form of pilot tests, before proceeding to general sales efforts.

Performance: Accomplishments and Progress

- **Technical accomplishments to date:**
  - Cut-in speed 0.35 m/s, per flume tests – to be confirmed in open water
  - Unforeseen hydrodynamic effects:
    - optimal tip turbine blade shape not as expected
    - recapture of shed tip vortices makes a measurable difference (~17% in flume test)
  - Stability
  - Test results match digital twin predictions
  - Achieved smooth start/stop
  - extract power
  - Achieved adjustable operating point
  - Achieved fully flooded operation
  - Zero net torque
- **Significance:**
  - On track to meet LCOE goal
- **Economic and/or technical metrics & assumptions:**
  - LCOE is our main economic and technical metric

Performance: Accomplishments and Progress (cont.)

- **Benchmark the accomplishments against the original technical targets (if applicable).**
  - Compared LPS's LCOE analysis to LCOE predictions from NREL's System Advisor Model (SAM): closely matched value predicted by LPS's internal model. Using Froude scaling, LSTA observed performance suggests that 8.8m tip-to-tip unit would output 72.7 kW in a 2.1 m/s current. In a non-reversing flow this would imply 636 MWh/unit per year. Price $68,350 or less per turbine for 200 units.
  - These estimates will be refined as the XCT-1 is built and tested.
- **Important recognition.**
  - Patent applied for prior to award; US patent granted 6/22
  - Two additional CIP patent applications filed
  - Led indirectly to $3.2 million ARPA-E SHARKS program award
  - Seeking pilot site opportunities to demo product through multiple seasons
  - Small grant from Alaska Energy Authority targeting pilot site in AK

Future Work; Challenges

- Build final prototype XCT-1: 3-meter fully integrated subscale device
  - anticipated improvements over LSTA:
    - enhance hydraulic efficiency
    - reduce drag
    - increase power extraction
    - enhance generator performance
    - make lighter weight and more durable: incorporate composites
    - refine bearing strategy
    - incorporate closed-loop controls; MPPT power electronics
    - improve rotary power transfer
  - anticipated challenges:
    - mooring strategy
    - braking strategy
    - access for maintenance
    - tight supply chain
- Schedule delays, material supply
  - to mitigate fabrication delays for the project's final protoype, we are
    - changing fabrication vendors,
    - seeking state support for manufacturing, and
    - expanding partner involvement

Q&A