Global Distribution of Annual Mean Wave Power

>50 KW/m

>20 KW/m
Differences and Advantages of AOE Technology

• **Enable storage of extracted wave energy**: No connection to the grid, no cables through the coastal areas, no dependance on demand in the grid

• **Installation offshore, as minimum 3 miles, but may be 100s miles from coastline**: Minimal regulatory control and approval; Limited or no intrusion on fishing/crabbing grounds; Outside of wave breaking zones and impacts from violent breaking wave forces

• **No moving parts and no direct contact with water column**: Increase durability, No corrosion due to salt water and no debris impact.

• **All installation is on a deck of regular barge**: No special and unique hall design; Proved to be appropriate for ocean conditions

• **Significant footprint of the barge**: Potential for high energy extraction; May not require multiple installations to produce commercially valuable energy

• **Other**
Wave Energy

Mechanical Energy of Wave Energy Converter (WEC)

Electricity

Electrolysis

2H₂O → 2H₂ + O₂

Hydrogen H₂

Oxygen O₂

Compression and Storage

Compression and Storage

50 KW/h Electrical Energy + 9 Liters of Water = 1 Kg of Hydrogen (H₂) + 8 Kg of Oxygen (O₂)
# Department of Energy Hydrogen Program Plan

<table>
<thead>
<tr>
<th>Transportation Applications</th>
<th>Chemicals and Industrial Applications</th>
<th>Stationary and Power Generation Applications</th>
<th>Integrated/Hybrid Energy Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing Growing Demands</strong></td>
<td><strong>Oil Refining</strong></td>
<td><strong>Distributed Generation: Primary and Backup Power</strong></td>
<td><strong>Renewable Grid Integration (with storage and other ancillary services)</strong></td>
</tr>
<tr>
<td>Material-Handling Equipment</td>
<td>Ammonia</td>
<td></td>
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<tr>
<td>Buses</td>
<td>Methanol</td>
<td></td>
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<tr>
<td>Light-Duty Vehicles</td>
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<tr>
<td><strong>Emerging Future Demands</strong></td>
<td><strong>Steel and Cement Manufacturing</strong></td>
<td><strong>Reversible Fuel Cells</strong></td>
<td><strong>Nuclear/Hydrogen Hybrids</strong></td>
</tr>
<tr>
<td>Medium-and Heavy-Duty Vehicles</td>
<td><strong>Industrial Heat</strong></td>
<td><strong>Hydrogen Combustion</strong></td>
<td><strong>Gas/Coal/Hydrogen Hybrids with CCUS</strong></td>
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<tr>
<td>Rail</td>
<td><strong>Bio/Synthetic Fuels</strong></td>
<td><strong>Long-Duration Energy Storage</strong></td>
<td><strong>Hydrogen Blending</strong></td>
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<tr>
<td>Maritime</td>
<td></td>
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<td></td>
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<tr>
<td>Aviation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contraction Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2015 Toyota

2017 Hyundai ix35 Fuel Cell

2017 Honda Clarity FCV
• More than 10 million metric tons of hydrogen are produced annually in the United States.
• There are 1,600 miles of hydrogen pipeline in the United States and large hydrogen production facilities in almost every state.
• Market for Hydrogen - $115 Billions/year at 6.5%/year growth
95% of hydrogen is produced from fossil fuels, such as coal, natural gas, and oil by separating methane (CH4) on hydrogen (H2) and carbon dioxide (carbon dioxide, CO2).
AOE Technology

Wave Energy of Wave Energy Converter (WEC) -> Electricity -> Electrolysis

2H₂O → 2H₂ + O₂

Hydrogen (H₂) + Oxygen (O₂)

Electrolysis

Compression and Storage

50 KW/h Electrical Energy + 9 Liters of Water = 1 Kg of Hydrogen (H₂) + 8 Kg of Oxygen (O₂)
AOE Technology

1. Floating Base
2. Wave Energy Converter
3. Electric Generator
4. Electrolyzer
5. Hydrogen and Oxygen Storage Facilities
Hydrogen- The World’s Cleanest Energy Production and Transportation - Conventional Technologies

2H₂O → 2H₂ + O₂.
Linear Electro-Mechanical Generator, UMBRA GROUP spa
WEC Type 2, Wave Energy Converter & Linear Electro Mechanical Generator
AOE Technology
Support for Demonstration Project

- Port of Grays Harbor
- Port of Willapa Harbor
- Port of Ilwaco
- Columbia River Crab Association
- Pacific County
- Cape Shoal Indian Reservation
- City of Raymond
- Quinault Indian Nation
(10) $593,000 of the state building construction account—state appropriation is provided solely to the port of Grays Harbor for an offshore ocean wave renewable energy demonstration project.
Demonstration Project Goals and Objectives

• Evaluate technical feasibility of AOE Technology for demonstration project at the offshore of Grays Harbor Estuary

• Prepare conceptual level design of the technology and protocol of the demonstration project (drawings, specifications, cost estimate)

• Identify all pertinent regulatory requirements for implementation of the demonstration project and obtain the required permits.
Grays Harbor Estuary

Demonstration Project Approximate Location

~3 miles
## Ocean Engineering – Completed

<table>
<thead>
<tr>
<th>Month</th>
<th>Hs (ft)</th>
<th>Hmax (ft)</th>
<th>Period (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>5.30</td>
<td>9.54</td>
<td>6.2</td>
</tr>
<tr>
<td>June</td>
<td>4.56</td>
<td>8.21</td>
<td>6.3</td>
</tr>
<tr>
<td>July</td>
<td>4.15</td>
<td>7.47</td>
<td>5.9</td>
</tr>
<tr>
<td>August</td>
<td>4.43</td>
<td>7.97</td>
<td>6.1</td>
</tr>
<tr>
<td>September</td>
<td>5.95</td>
<td>10.71</td>
<td>6.5</td>
</tr>
<tr>
<td>October</td>
<td>7.37</td>
<td>13.27</td>
<td>7.7</td>
</tr>
</tbody>
</table>

![Graph showing significant wave height and return period](image1)

**Grays Harbor 2018 05 25 2133**

### Energy Density

![Energy density graph](image2)

**Average Occurrences in Height Category**

![Average occurrences graph](image3)

**Five-year Average**

May 2015-2019

For Hs Category

4.95 ft - 5.41 ft
**Naval Architect, Barge Motions Modeling**

**Completed**

<table>
<thead>
<tr>
<th>Particulars</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall</td>
<td>180</td>
<td>ft.</td>
</tr>
<tr>
<td>Width</td>
<td>54</td>
<td>ft.</td>
</tr>
<tr>
<td>Depth</td>
<td>12.5</td>
<td>ft.</td>
</tr>
<tr>
<td>Lightship</td>
<td>457</td>
<td>ST</td>
</tr>
</tbody>
</table>

![Diagram of barge motions with labels for surge, roll, yaw, heave, sway, portside, starboard, and positions at 0, 45, 90, and 180 degrees (following seas, quartering seas, beam seas, and head seas).](image-url)
WEC Design - Pneumatic Spring Alternative
WEC Design

WEC housing structure shown transparent

Barge
WEC Linear Electro –Mechanical Generator Design

Preliminary design proposal:

- Diameter: 1.97 inches
- Pitch: 3.15 inches
- Pole pairs: 8
- Speed Constant KE: \(181.0 \frac{V_{RMS} \cdot \text{ph} \cdot \text{ph}}{\text{krpm}}\)
- Torque Constant KT: \(2.9 \frac{Nm}{A_{RMS}}\)

Max OD 9.84 in (TBC)

Stroke 15ft (TBC extra stroke)
PRELIMINARY SELECTION OF PARTS

A market analysis was done on AC/DC and DC/DC inverter manufacturers to identify flexible and cost effective proposals.

OPEN POINTS:

- Output DC level of the electrolyzer;
- Output AC level of the electrolyzer (120 Vac 60 Hz);
<table>
<thead>
<tr>
<th>Task</th>
<th>Title</th>
<th>Timeline</th>
<th>Deliverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data Collection and Analysis</td>
<td>Q2 2020</td>
<td>Section of the Technical Report that summarizes the project data and major Requirements/Criteria for the Demonstration Project.</td>
</tr>
<tr>
<td>2</td>
<td>Marine and Naval Architecture Design</td>
<td>Q2 2020</td>
<td>Section of the Technical Report that summarizes the marine and naval architect study with recommendations for the demonstration project.</td>
</tr>
<tr>
<td>3</td>
<td>Mechanical and Structural Engineering Design</td>
<td>Q3 2020</td>
<td>Section of the Technical Report that summarizes the electrical engineering study and design, including recommendations for the electromechanical generator and estimates for PTO during the demonstration project.</td>
</tr>
<tr>
<td>4</td>
<td>Electrical Engineering and Design</td>
<td>Q3 2020</td>
<td>Section of the Technical Report that summarizes the electrical engineering study and design, including recommendations for the electromechanical generator and estimates for PTO during the demonstration project.</td>
</tr>
<tr>
<td>5</td>
<td>Chemical and Hydrogen Engineering Design</td>
<td>Q4 2020</td>
<td>Section of the Technical Report with specifications on the equipment on water electrolysis, compression and storage of hydrogen, and recommendations for handling of oxygen.</td>
</tr>
<tr>
<td>6</td>
<td>Environmental Permitting Requirements</td>
<td>Q4 2020</td>
<td>Section of the Technical Report that summarizes the requirements for obtaining environmental and operational permits and develop general guidance for obtaining these permits. Prepare draft environmental and operational permit applications (where appropriate).</td>
</tr>
<tr>
<td>7</td>
<td>Conceptual Design and Cost Estimates</td>
<td>Q1 2021</td>
<td>Preliminary drawings, specifications, and cost estimates.</td>
</tr>
<tr>
<td>8</td>
<td>Project Coordination, Meetings, Reporting</td>
<td>Q1 2021</td>
<td>Final report</td>
</tr>
</tbody>
</table>
Project Plan and Schedule

Phase 1 - Feasibility Engineering and Preliminary Design of the Demonstration Project, Completion April 2021

Phase 2 - Demonstration Project Final Design, Construction, and 6-months Open Ocean Testing (with objective to evaluate efficiency and economic validity of the AOE Technology), Start and Completion TBD

Phase 3 - Commercialization Plan and Implementation, Start and Completion TBD
Port of Grays Harbor, WA Renewable Ocean Wave Energy Demonstration Project

THANK YOU