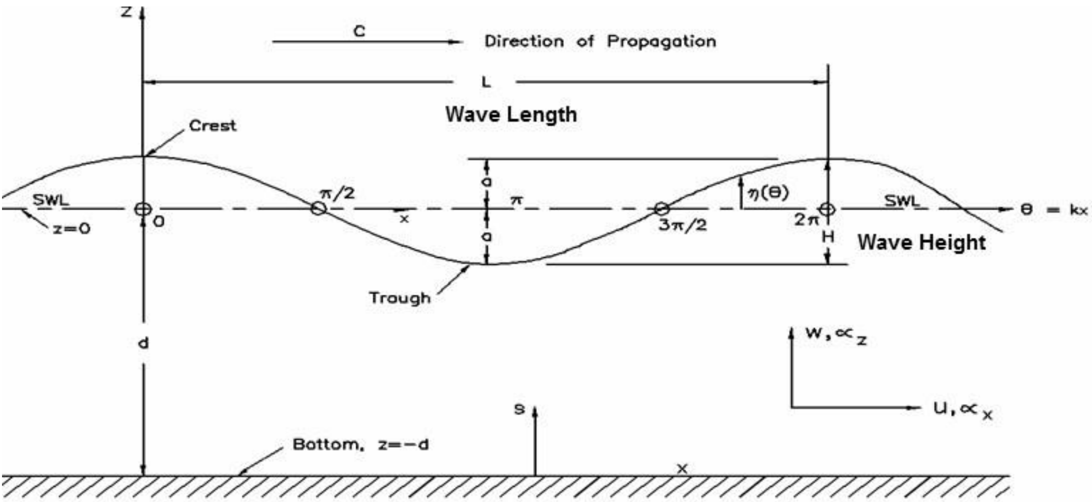
Renewable Hydrogen from Ocean Waves at North Pacific

Quinault Indian Nation
February 21, 2018

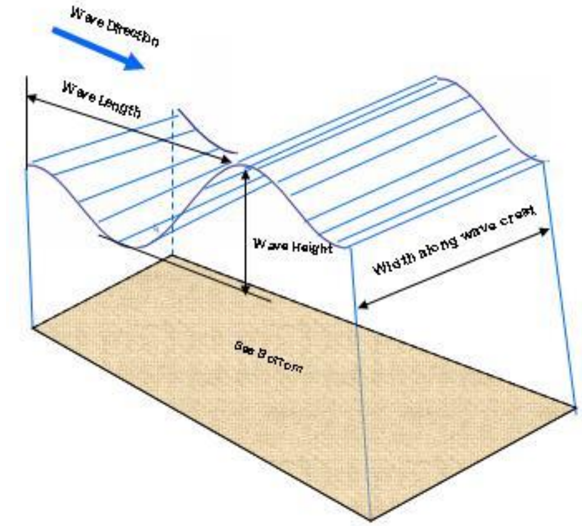
by
Applied Ocean Energy Corporation
Dr. Vladimir Shepsis

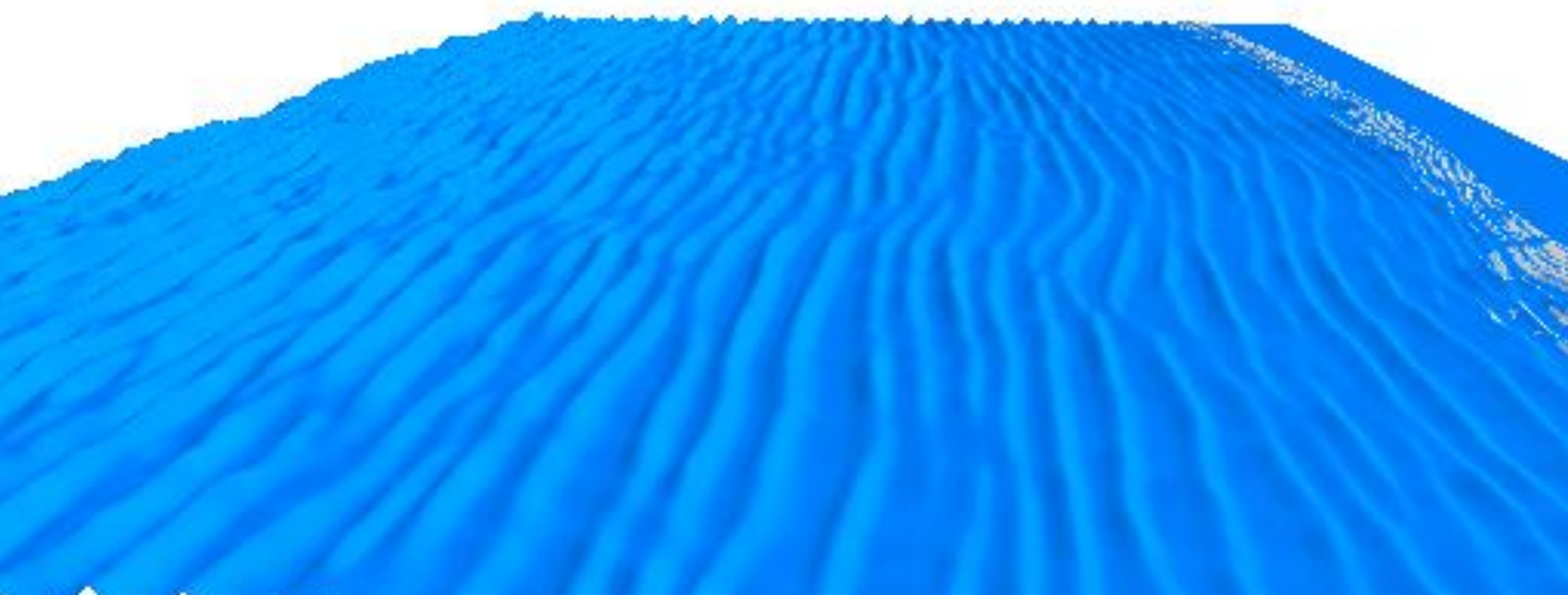
Content

- Assessment of available wave energy at Pacific Coastline
- Overview of existing technologies
- New renewable wave energy technology
- Path forward

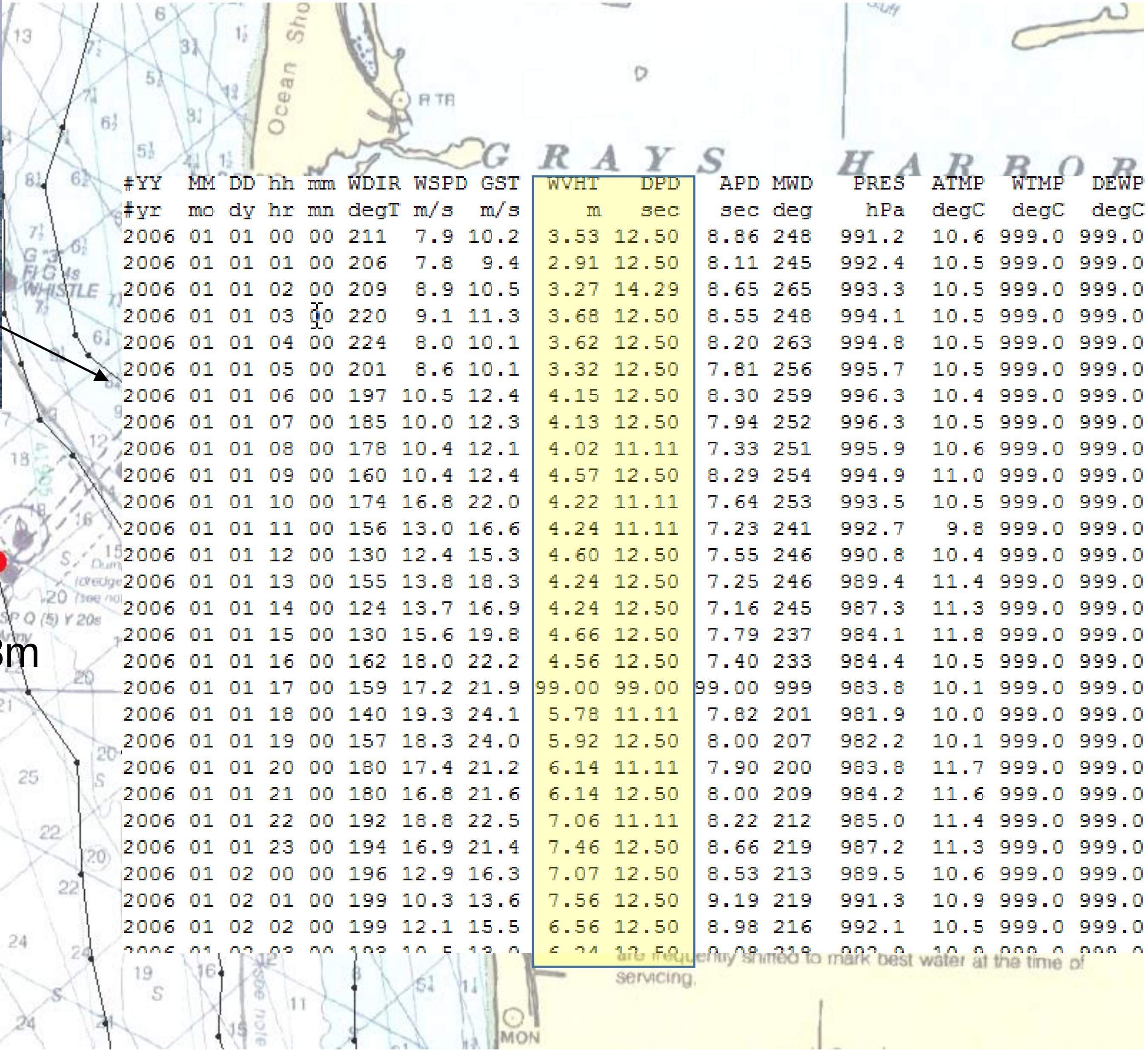


$E_F = 0.42\ H_s^2\ T_2 = 00.8\ H_s^2\ L^{1/2}$ (kW/m)





Assessment of available wave energy



#YY	MM	DD	hh	mm	WDIR	WSPD	GST	WVHT	DPD	APD	MWD	PRES	ATMP	WTMP	DEWP	VIS	TID
#yr	mo	dy	hr	mn	degT	m/s	m/s	m	sec	sec	deg	hPa	degC	degC	degC	mi	f
2006	01	01	00	00	211	7.9	10.2	3.53	12.50	8.86	248	991.2	10.6	999.0	999.0	99.0	99.0
2006	01	01	01	00	206	7.8	9.4	2.91	12.50	8.11	245	992.4	10.5	999.0	999.0	99.0	99.0
2006	01	01	02	00	209	8.9	10.5	3.27	14.29	8.65	265	993.3	10.5	999.0	999.0	99.0	99.0
2006	01	01	03	00	220	9.1	11.3	3.68	12.50	8.55	248	994.1	10.5	999.0	999.0	99.0	99.0
2006	01	01	04	00	224	8.0	10.1	3.62	12.50	8.20	263	994.8	10.5	999.0	999.0	99.0	99.0
2006	01	01	05	00	201	8.6	10.1	3.32	12.50	7.81	256	995.7	10.5	999.0	999.0	99.0	99.0
2006	01	01	06	00	197	10.5	12.4	4.15	12.50	8.30	259	996.3	10.4	999.0	999.0	99.0	99.0
2006	01	01	07	00	185	10.0	12.3	4.13	12.50	7.94	252	996.3	10.5	999.0	999.0	99.0	99.0
2006	01	01	08	00	178	10.4	12.1	4.02	11.11	7.33	251	995.9	10.6	999.0	999.0	99.0	99.0
2006	01	01	09	00	160	10.4	12.4	4.57	12.50	8.29	254	994.9	11.0	999.0	999.0	99.0	99.0
2006	01	01	10	00	174	16.8	22.0	4.22	11.11	7.64	253	993.5	10.5	999.0	999.0	99.0	99.0
2006	01	01	11	00	156	13.0	16.6	4.24	11.11	7.23	241	992.7	9.8	999.0	999.0	99.0	99.0
2006	01	01	12	00	130	12.4	15.3	4.60	12.50	7.55	246	990.8	10.4	999.0	999.0	99.0	99.0
2006	01	01	13	00	155	13.8	18.3	4.24	12.50	7.25	246	989.4	11.4	999.0	999.0	99.0	99.0
2006	01	01	14	00	124	13.7	16.9	4.24	12.50	7.16	245	987.3	11.3	999.0	999.0	99.0	99.0
2006	01	01	15	00	130	15.6	19.8	4.66	12.50	7.79	237	984.1	11.8	999.0	999.0	99.0	99.0
2006	01	01	16	00	162	18.0	22.2	4.56	12.50	7.40	233	984.4	10.5	999.0	999.0	99.0	99.0
2006	01	01	17	00	159	17.2	21.9	99.00	99.00	99.00	999	983.8	10.1	999.0	999.0	99.0	99.0
2006	01	01	18	00	140	19.3	24.1	5.78	11.11	7.82	201	981.9	10.0	999.0	999.0	99.0	99.0
2006	01	01	19	00	157	18.3	24.0	5.92	12.50	8.00	207	982.2	10.1	999.0	999.0	99.0	99.0
2006	01	01	20	00	180	17.4	21.2	6.14	11.11	7.90	200	983.8	11.7	999.0	999.0	99.0	99.0
2006	01	01	21	00	180	16.8	21.6	6.14	12.50	8.00	209	984.2	11.6	999.0	999.0	99.0	99.0
2006	01	01	22	00	192	18.8	22.5	7.06	11.11	8.22	212	985.0	11.4	999.0	999.0	99.0	99.0
2006	01	01	23	00	194	16.9	21.4	7.46	12.50	8.66	219	987.2	11.3	999.0	999.0	99.0	99.0
2006	01	02	00	00	196	12.9	16.3	7.07	12.50	8.53	213	989.5	10.6	999.0	999.0	99.0	99.0
2006	01	02	01	00	199	10.3	13.6	7.56	12.50	9.19	219	991.3	10.9	999.0	999.0	99.0	99.0
2006	01	02	02	00	199	12.1	15.5	6.56	12.50	8.98	216	992.1	10.5	999.0	999.0	99.0	99.0

— Depth Contour in meters

Assessment of available wave energy

$E_F = 0.42\ H_s^2\ T_2 = 00.8\ H_s^2\ L^{1/2}$ (kW/m)

#YY	MM	DD	hh	mm	WDIR	WSPD	GST	WVHT	DPD	APD	MWD	PRES	ATMP	WTMP	DEWP	VIS
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2006	01	01	00	00	211	7.9	10.2	3.53	12.50	8.86	248	991.2	10.6	999.0	999.0	99.
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2006	01	01	17	00	159	17.2	21.9	99.00	99.00	99.00	999	983.8	10.1	999.0	999.0	99.
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2006	01	01	20	00	180	17.4	21.2	6.14	11.11	7.90	200	983.8	11.7	999.0	999.0	99.
2006	01	01	21	00	180	16.8	21.6	6.14	12.50	8.00	209	984.2	11.6	999.0	999.0	99.
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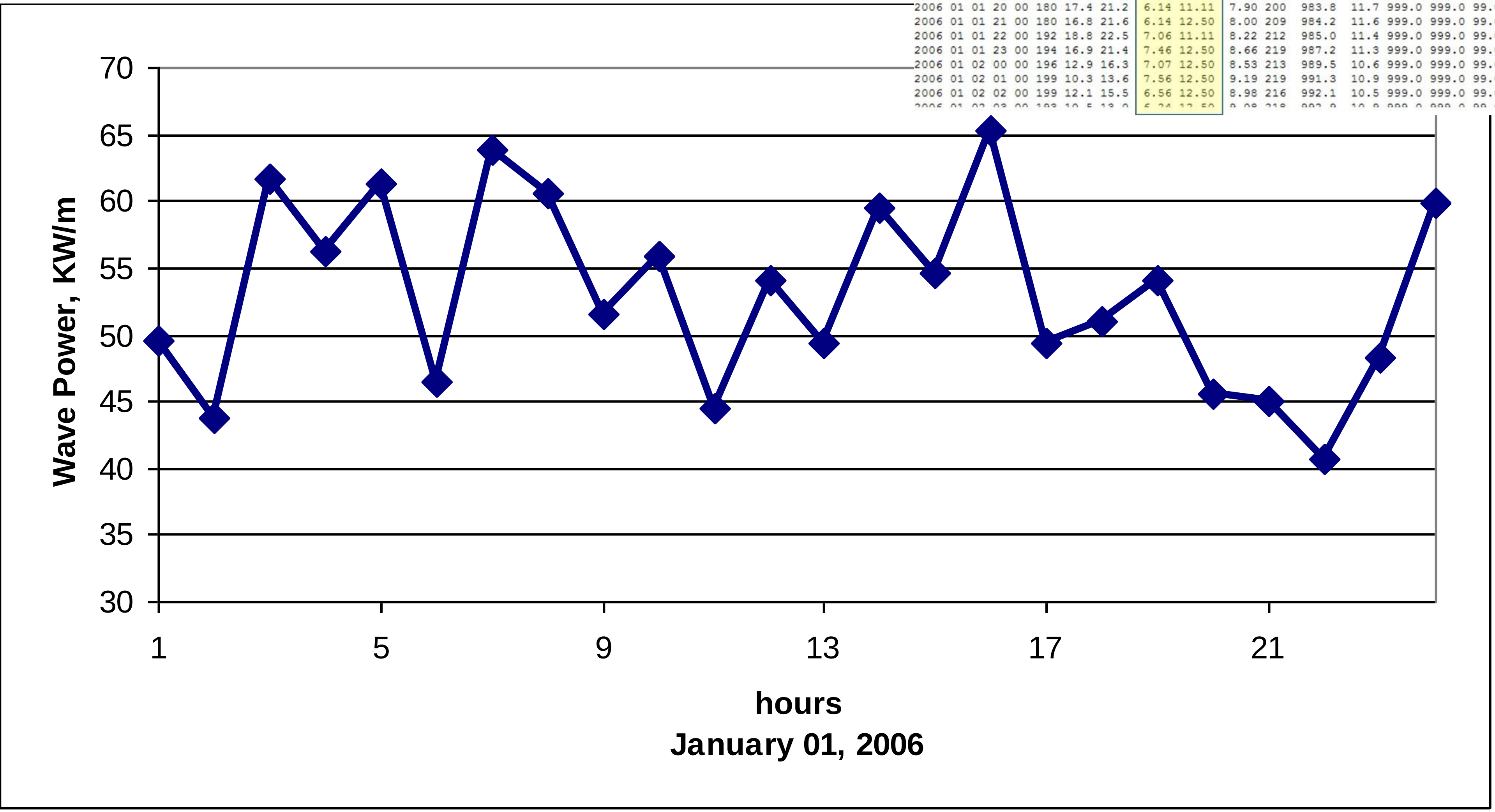
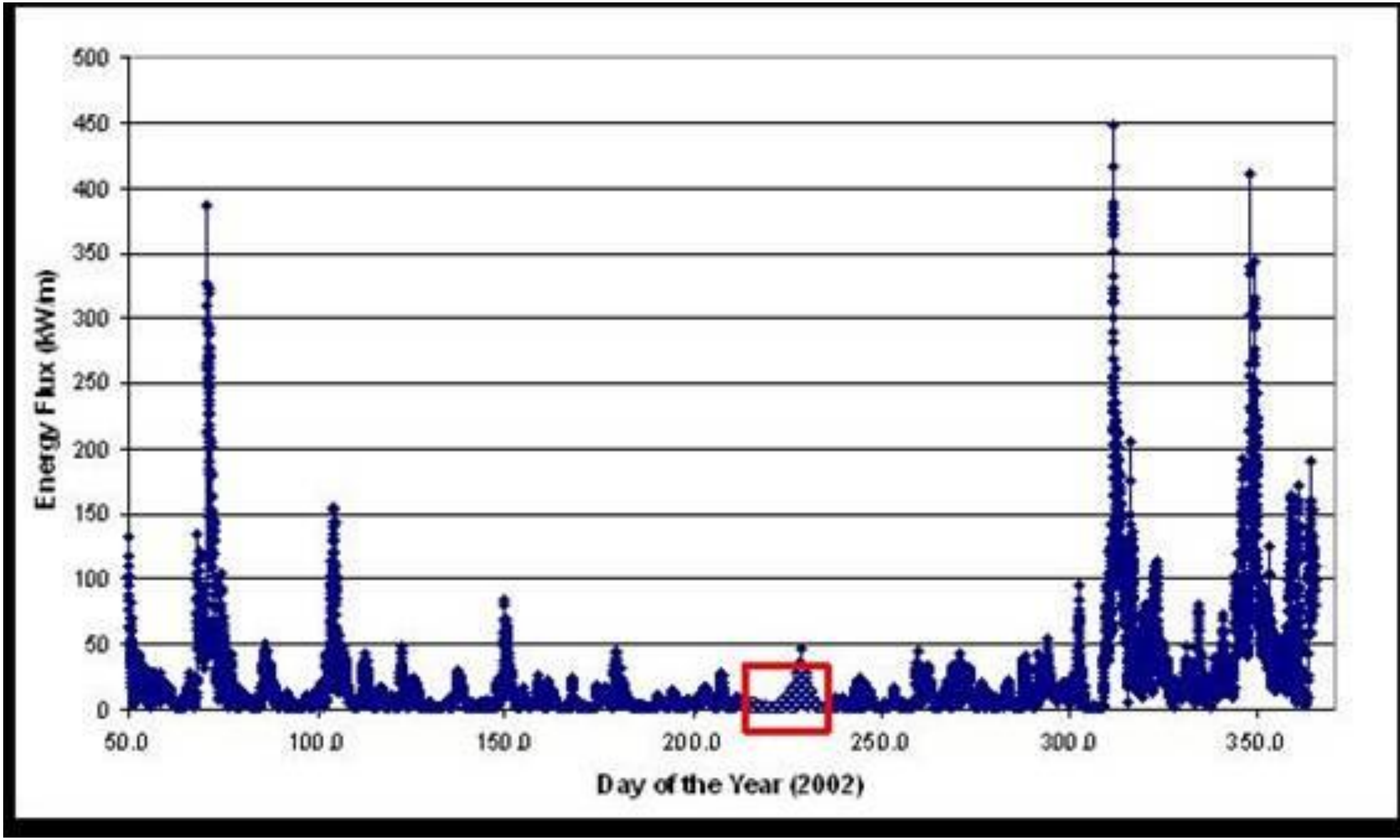
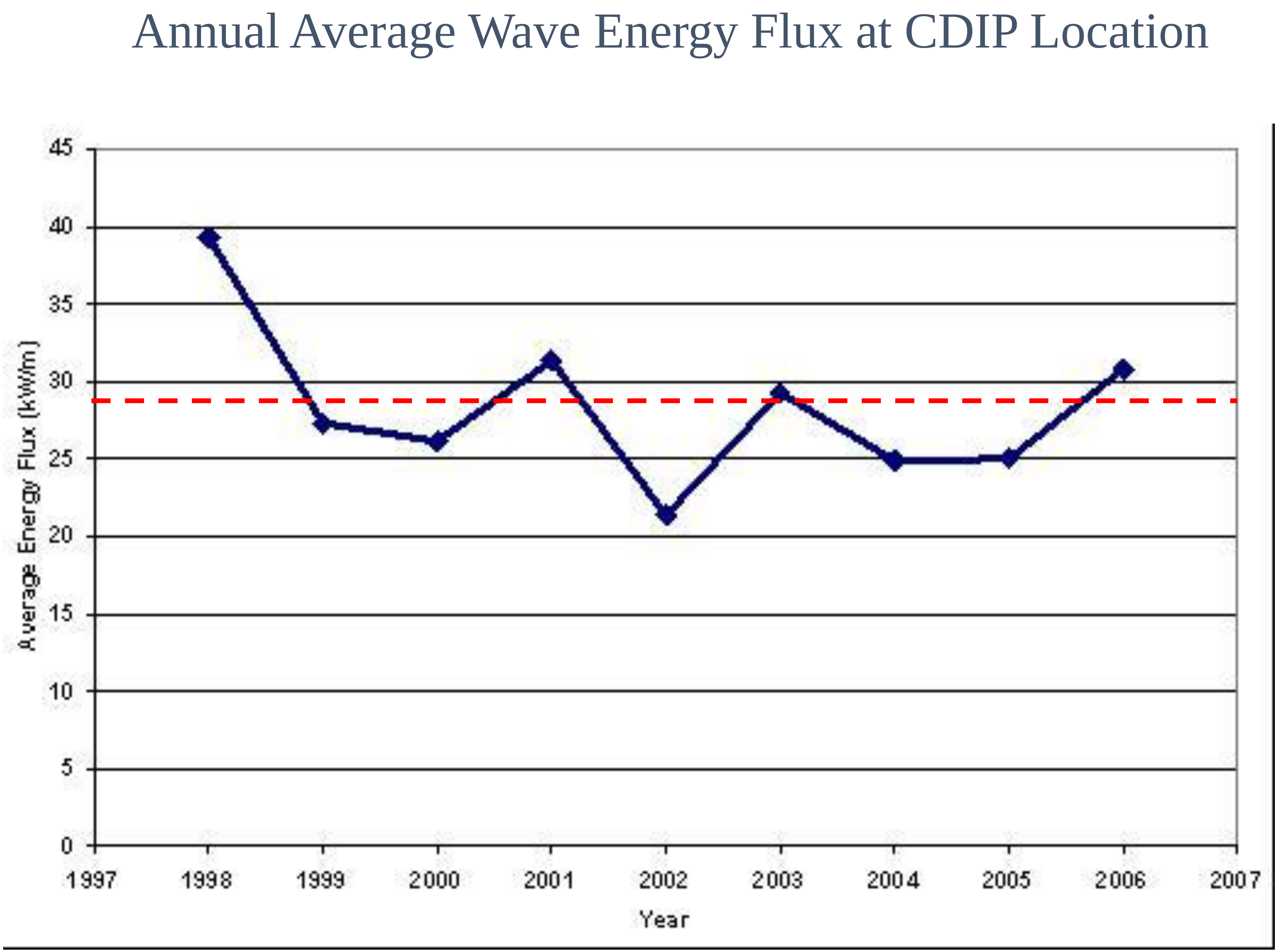


Variability of Wave Energy



Assessment of available wave energy



Wave Energy Assessment Summary

- The annual average wave power per linear meter of wave crest ~ 29 kW/m that corresponds to energy of 250 MWh/year per linear meter.
- The annual average wave power per 1,000 ft of shoreline is ~10 MW, that apparently equivalent to max power of Grays Harbor PUD.
- Maximum wave energy is at the deep water (>120 ft) but reduced while propagates toward the shoreline.

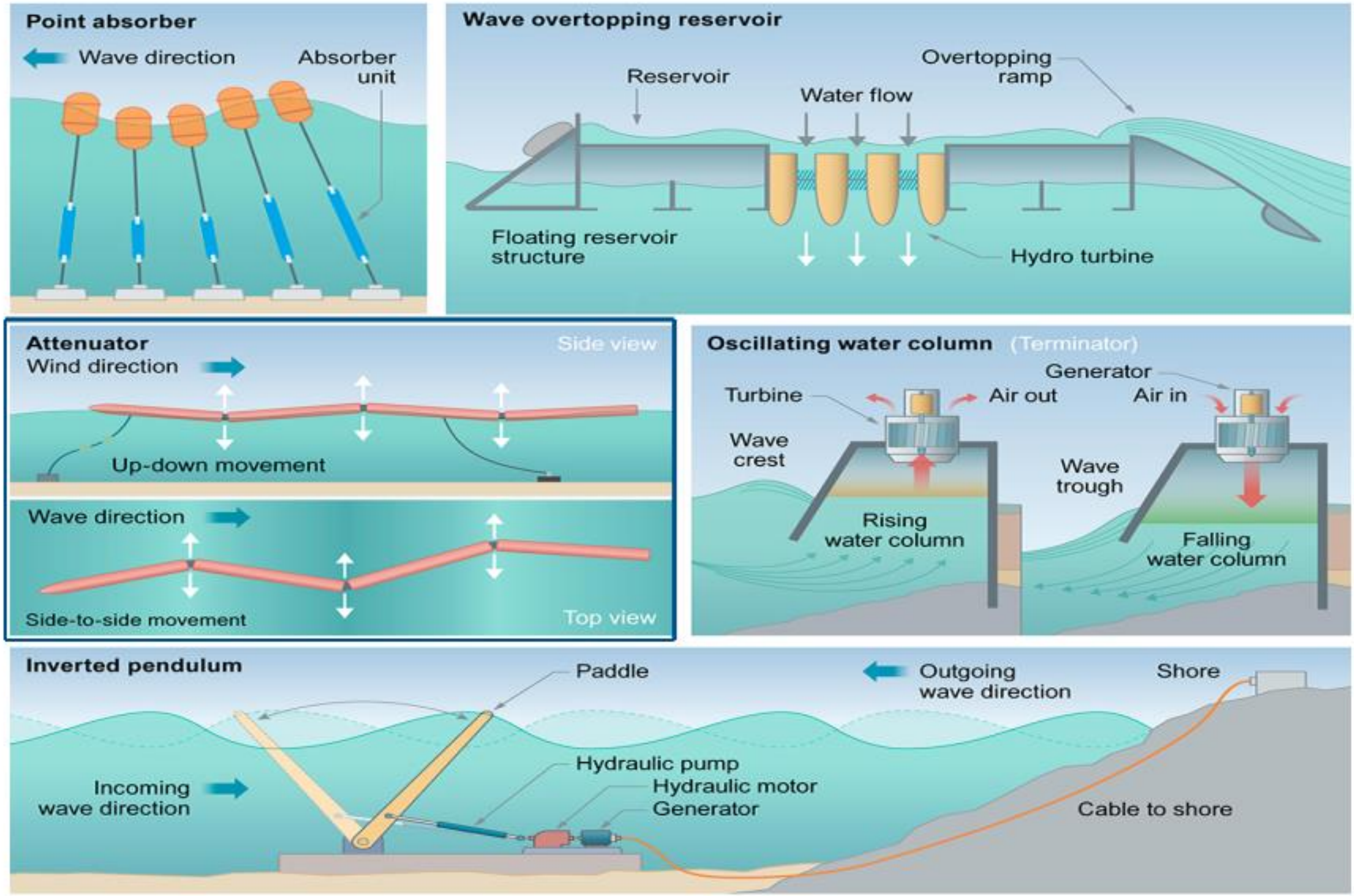
2012, Columbia Power Technologies, Inc.

2015, Northwest Energy Innovations

2016, Norwegian Co

2017, Wave4Power, Norway

Overview of Existing Technologies and Devices (Converters)



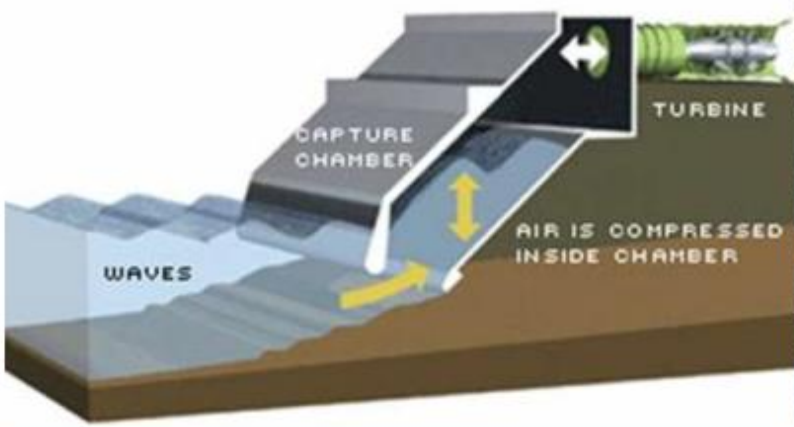
Source: Renewable Energy Futures Study NREL TP-6A20-52409-2

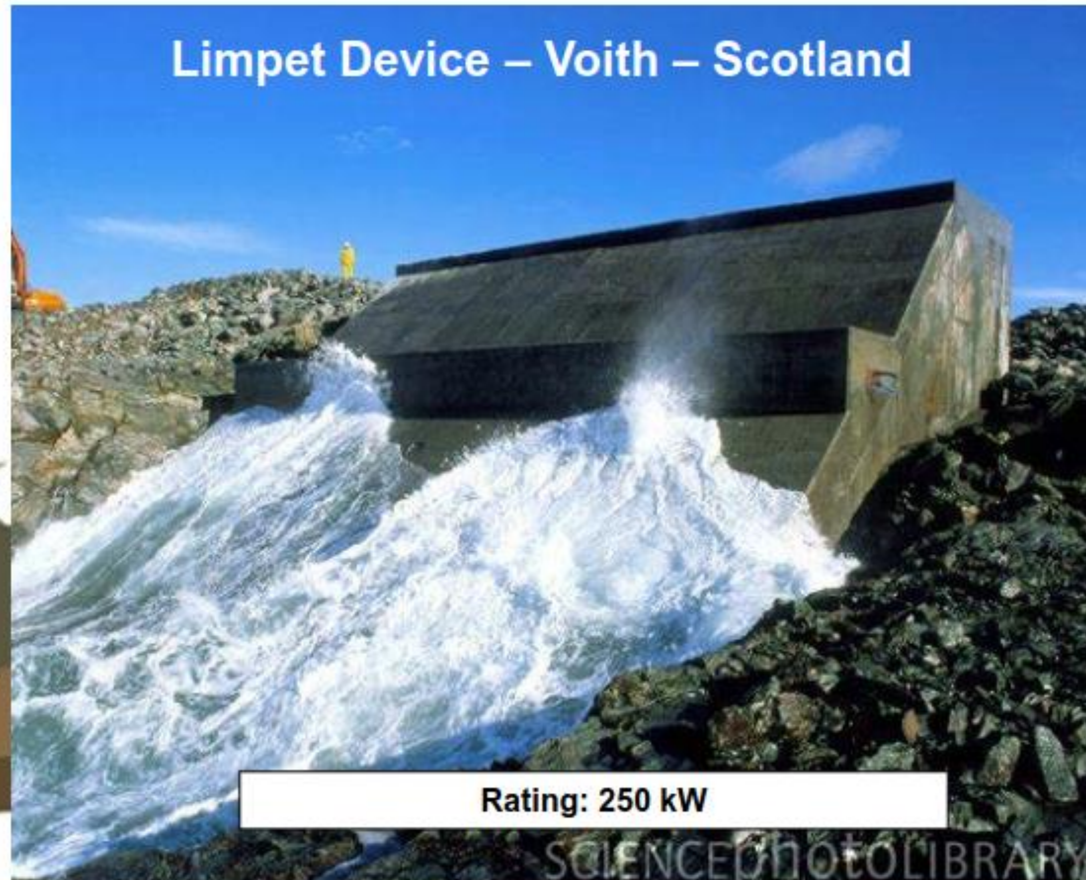
Technology Types – Wave

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

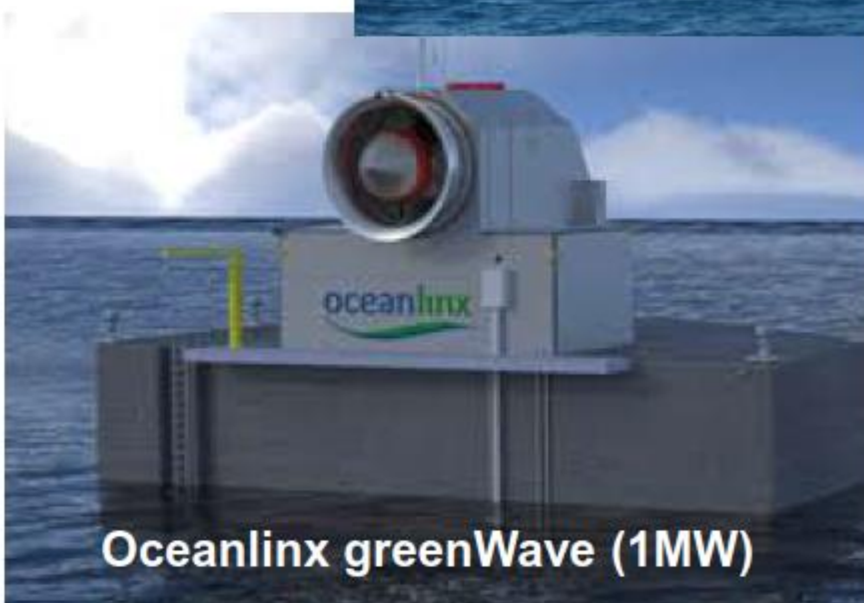
- Attenuator
- Overtopping
- **Oscillating Water Column (OWC)**
- Oscillating Wave Surge Converter (OWSC)
- Point Absorber
  - Floating
  - Submerged Pressure Differential
- Other

Description: There are two types of OWC: (1) shore/breakwater mounted and (2) floating. Both OWCs operate by the same principle in which water enters a chamber through a subsurface opening. The wave action causes this column of water to move up and down much like a piston - compressing and decompressing the air. The changes in air pressure are channeled through an air turbine (usually a bi-directional Wells turbine) making use of airflow in both directions.





Technology Types – Wave



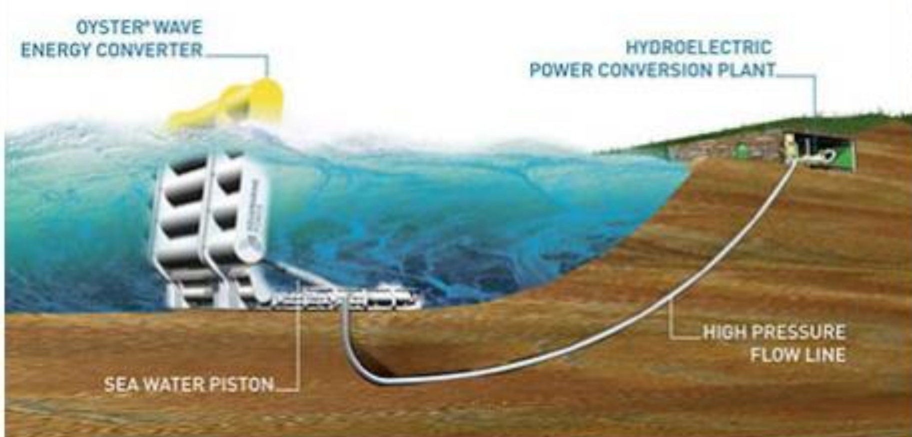
Pelamis – Scotland

Technology Types – Wave

- Attenuator
- Overtopping
- Oscillating Water Column (OWC)
- **Oscillating Wave Surge Converter (OWSC)**
- Point Absorber
  - Floating
  - Submerged Pressure Differential
- Other

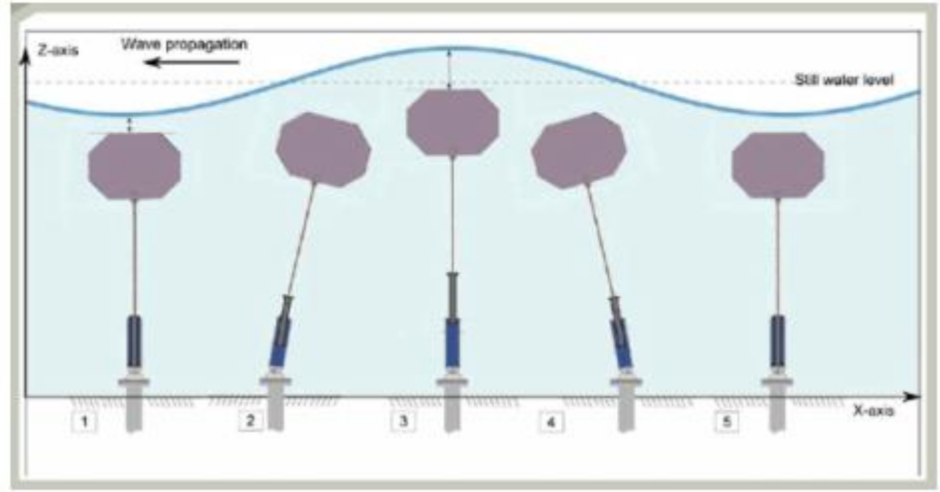
Description: An OWSC is a shoreline or near-shore device situated perpendicular to the direction of the waves that extracts the horizontal energy that exists in waves caused by the movement of water particles within them. The device consists of a paddle arm pivoting back-and-forth on a horizontal axis. The oscillation of the paddle arm is absorbed by a hydraulic pump to create electricity.

Oyster Device – Aquamarine Power – Scotland



Oyster 800 has a maximum generating capacity of 800kW

Technology Types – Wave



Rated Capacity: 240 kW

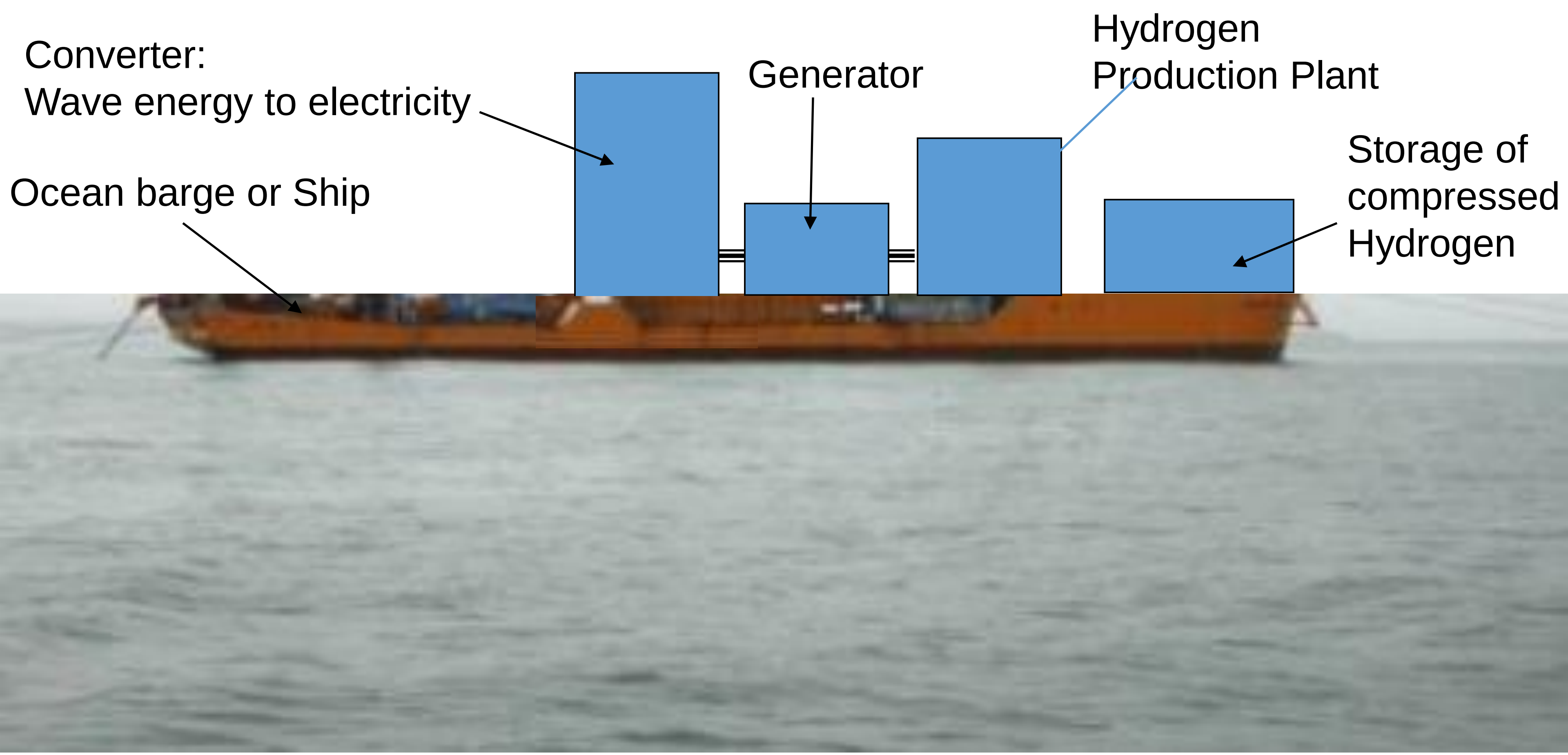
Wave 4Power Technology

The Waves4Power system started delivering electrical power to the Norwegian power grid on June 2, 2017 when the sea cable from the offshore system was connected to the land-based power grid.

General Observations on Existing Wave Energy Devices

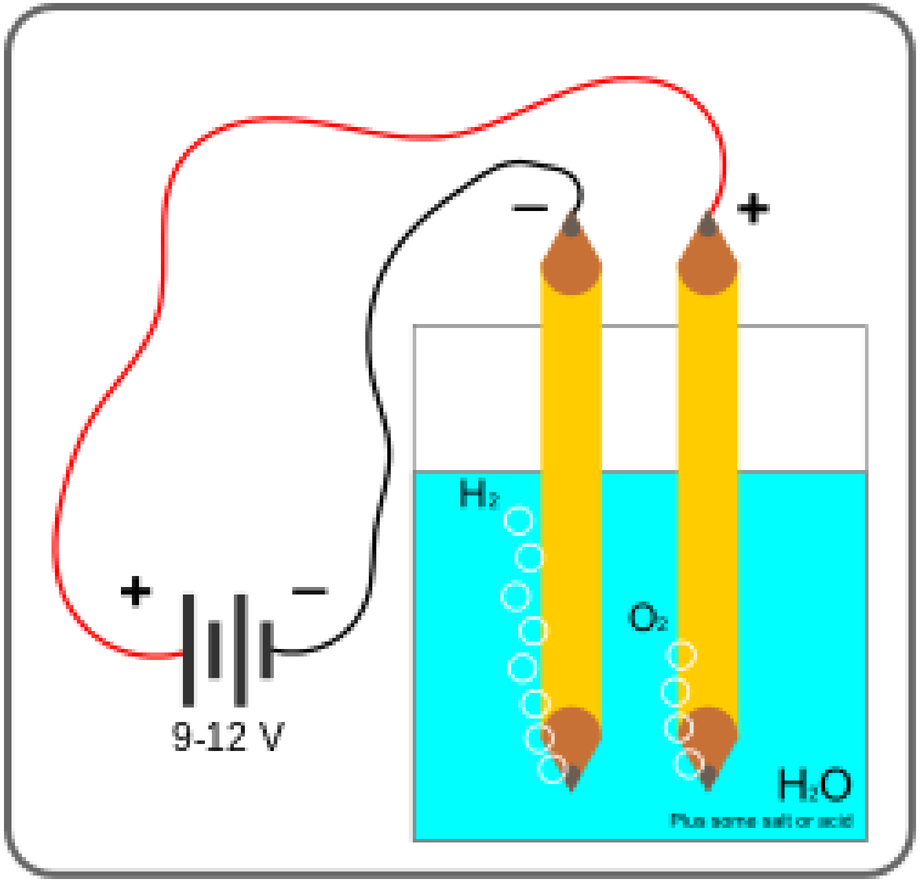
- Existing devices transmit power into the power grid with no storage capacity for the produced power (demand on energy in the grid may not coincide with rate of wave energy).
- Installation of wave energy devices in coastal areas is a subject to regulatory control and approval that may be very devastating process.
- Due to patterns of breaking wave the devices, installed at nearshore areas are impacted by violent wave forces that result in damages and high maintenance requirements.
- Existing devices are designed to extract wave energy by moving parts in a water column. Durability of such devices most likely is limited.
- Existing devices occupies a relatively small footprint. It require many of such devices to produce commercially valuable energy

New, Applied Ocean Energy Concept



Hydrogen- The World's Cleanest Energy

$$2H_2O \rightarrow 2H_2 + O_2.$$



9 L of Water + 50 KWh Electrical Energy=2 lbs of Hydrogen (H_2) + 16 lbs of Oxygen (O_2)

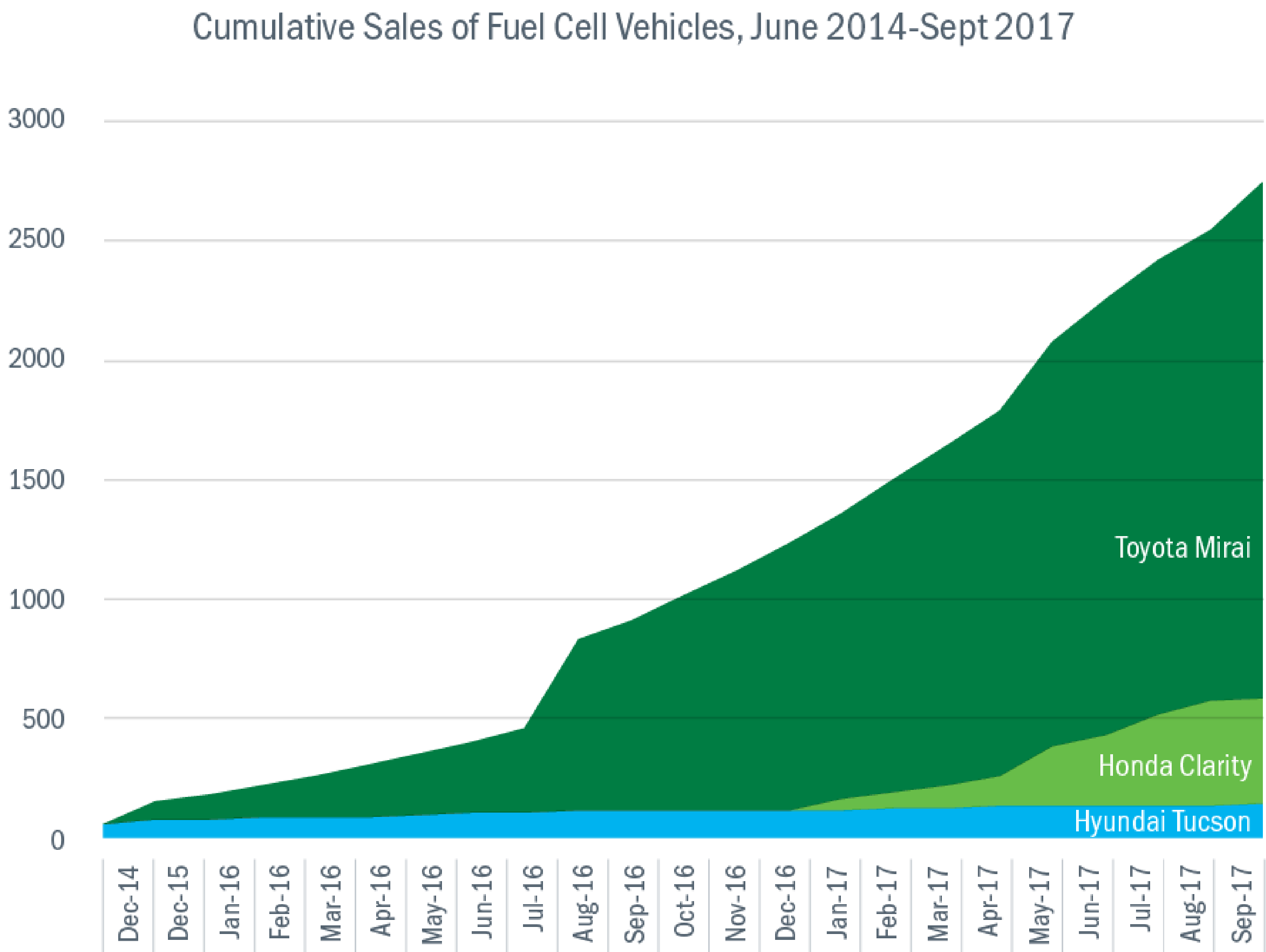

Hydrogen
Hydrogen


AIR
PRODUCTS

The 2015 Toyota Mirai is one of the first hydrogen-fuel-cell vehicles to be sold commercially

2017 Hyundai ix35 Fuel Cell

2017 Honda Clarity FCV



Cumulative Sales of Fuel Cell Vehicles, June 2014-Sept 2017
3000
2500
2000
1500
1000
500
0
Toyota Mirai
Honda Clarity
Hyundai Tucson
Dec-14
Dec-15
Jan-16
Feb-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Sep-16
Oct-16
Nov-16
Dec-16
Jan-17
Feb-17
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Sep-17


05
FCHV-BUS
FUEL CELL HYBRID VEHICLE
HINO
TOYOTA
EXPO
20-05

H_2 stations look similar to regular gas stations

Photo courtesy: CaFCP

Real World Applications – In the U.S.

Photo Credit: UPS

Fuel cell delivery and parcel trucks starting deliveries in CA and NY

Photo Credit: FedEx

First fuel cell tow truck fleet at airport in Memphis

World's first fuel cell for maritime ports in Hawaii

Photo Credit: Sandia National Laboratories

Real World Applications – In the U.S.

Fuel cell powered lights at Super Bowl in CA

Fuel cell buses in California surpass 17M passengers

Photo Credit: NREL

Industry demonstrates first heavy duty fuel cell truck in CA

Photo Credit: Toyota

ZH2: U.S. Army and GM collaboration First of its kind

Photo Credit: General Motors

Real World Applications – Abroad

World's first 4-seater fuel cell plane takes off at German Airport

Photo Credit: Christoph Schmidt/dpa via AP and phys.org.

Fuel cell cab fleet launched in Paris, France

Photo Credit: Hyundai

A town in in Fukuoka, Japan running on hydrogen

Photo Credit: Fukuoka Pref.

World's first hydrogen fuel cell train in Germany

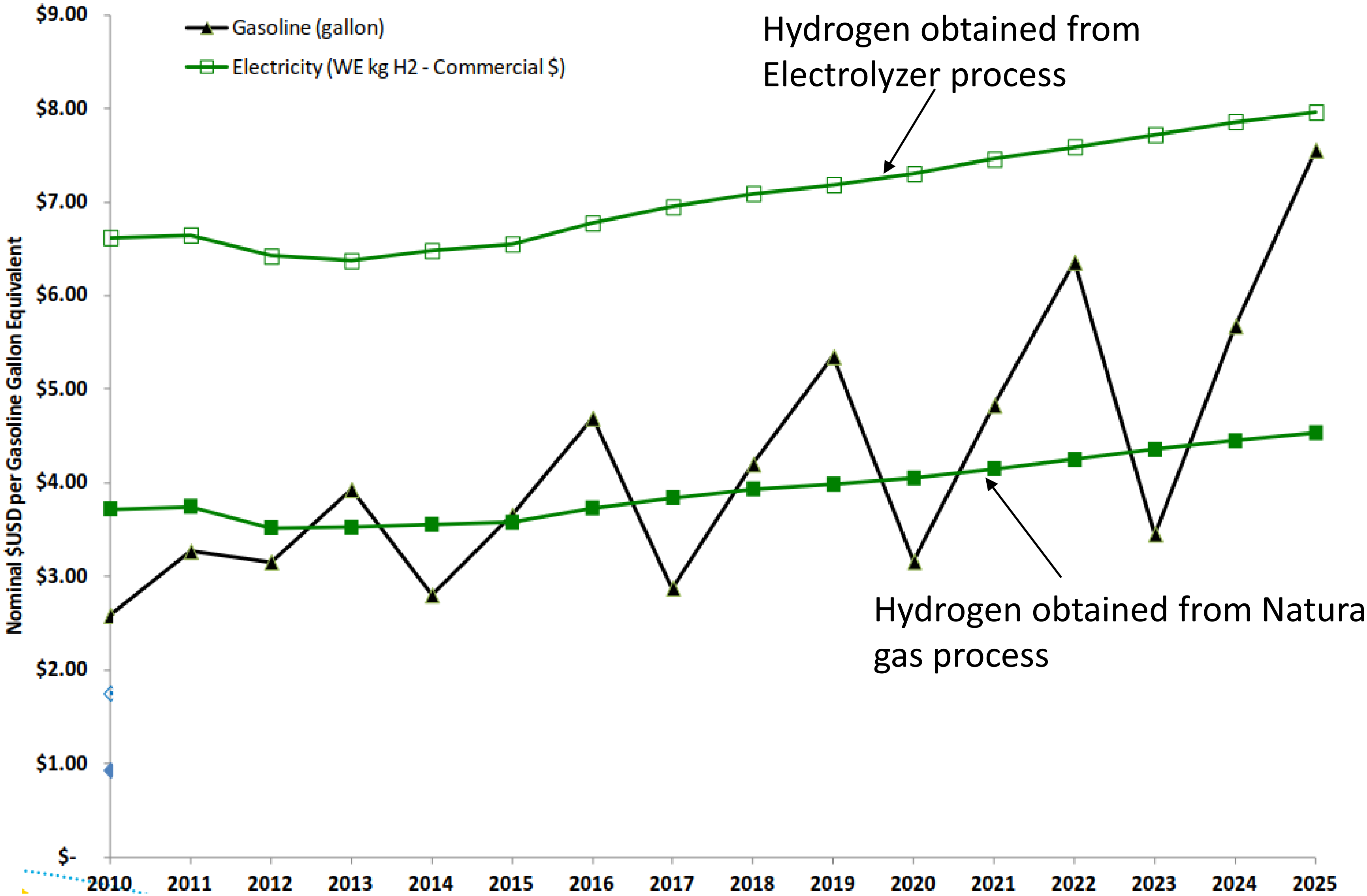
Photo Credit: Hydrogenics and Alstom

Hydrogen Market

The hydrogen generation market is expected to be valued at USD 115.25 Billion in 2017 and is projected to be worth USD 154.74 Billion by 2022, growing at a CAGR of 6.07%. The global hydrogen generation market is driven by factors such as government regulations for desulfurization of petroleum products and rising demand for hydrogen as a transportation fuel.

Today, 95% of hydrogen is produced from fossil fuels, such as natural gas and oil. The most common hydrogen production process is from natural gas by reforming (separating) methane (CH4) on hydrogen (H2) and carbon dioxide (carbon dioxide (co_2)).

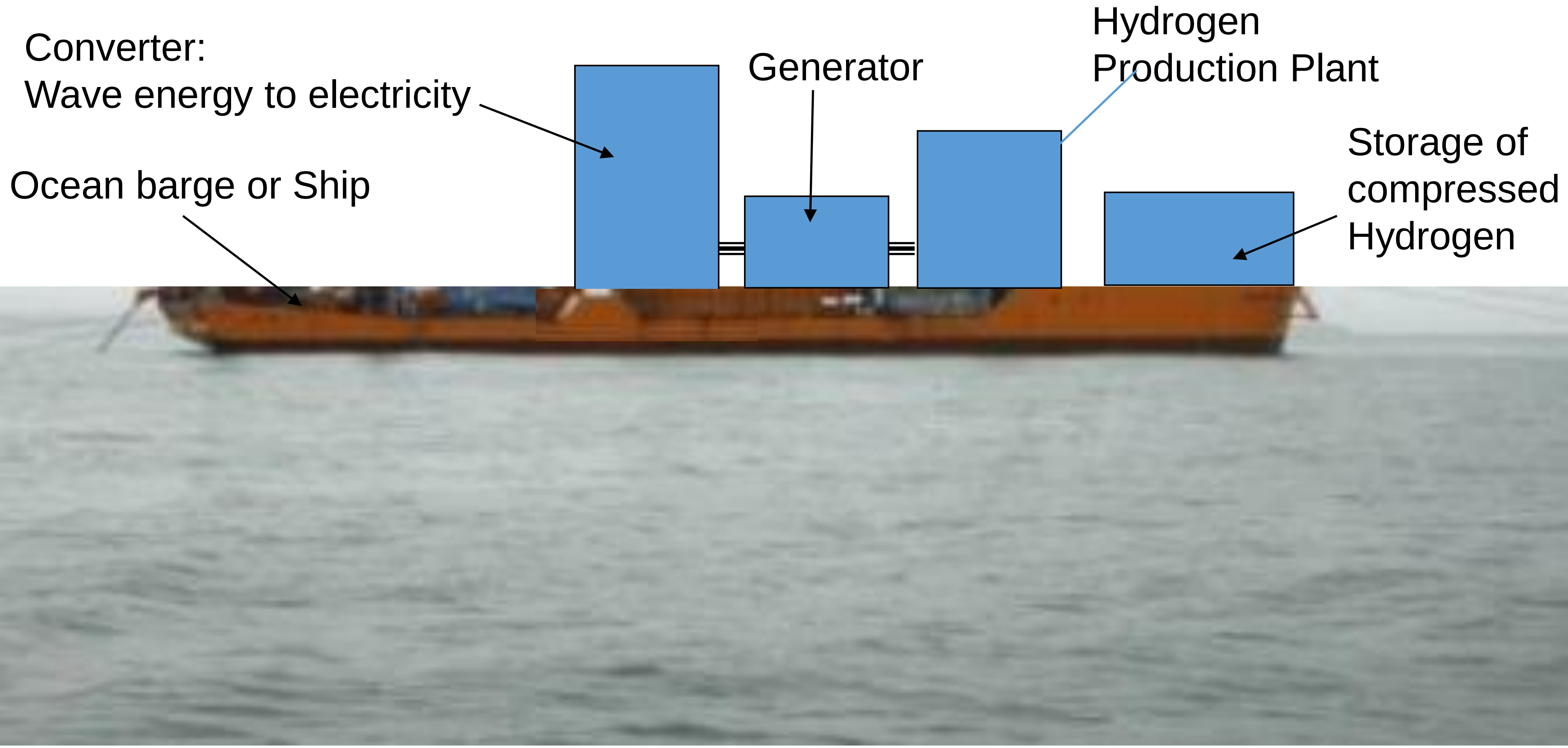
Hydrogen Energy Feedstock Cost to Gasoline Cost
EIA 2013 Energy Outlook - Reference Case



1kg hydrogen = 1 gasoline gallon; LHV basis

AIR PRODUCTS

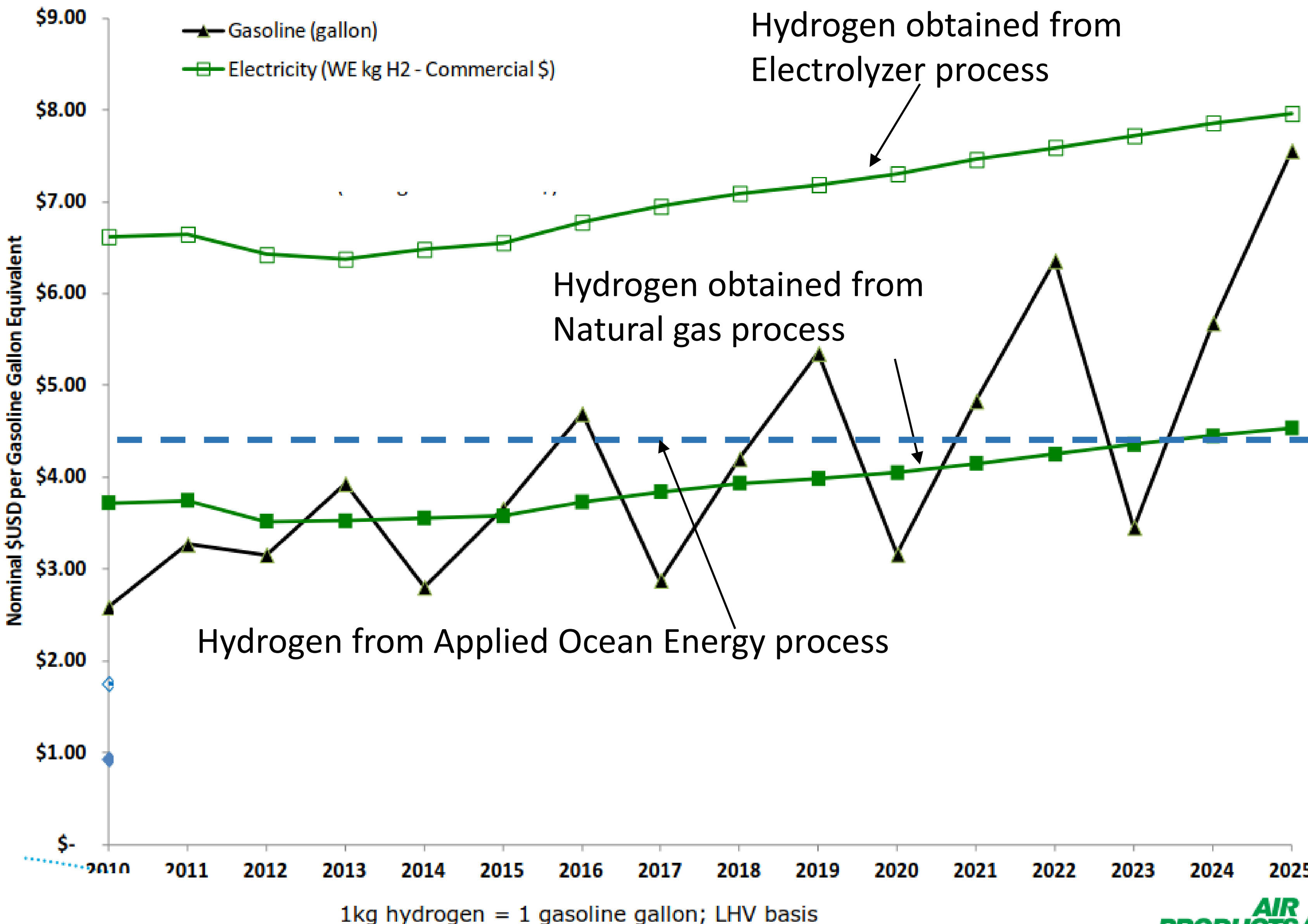
New, Applied Ocean Energy Concept



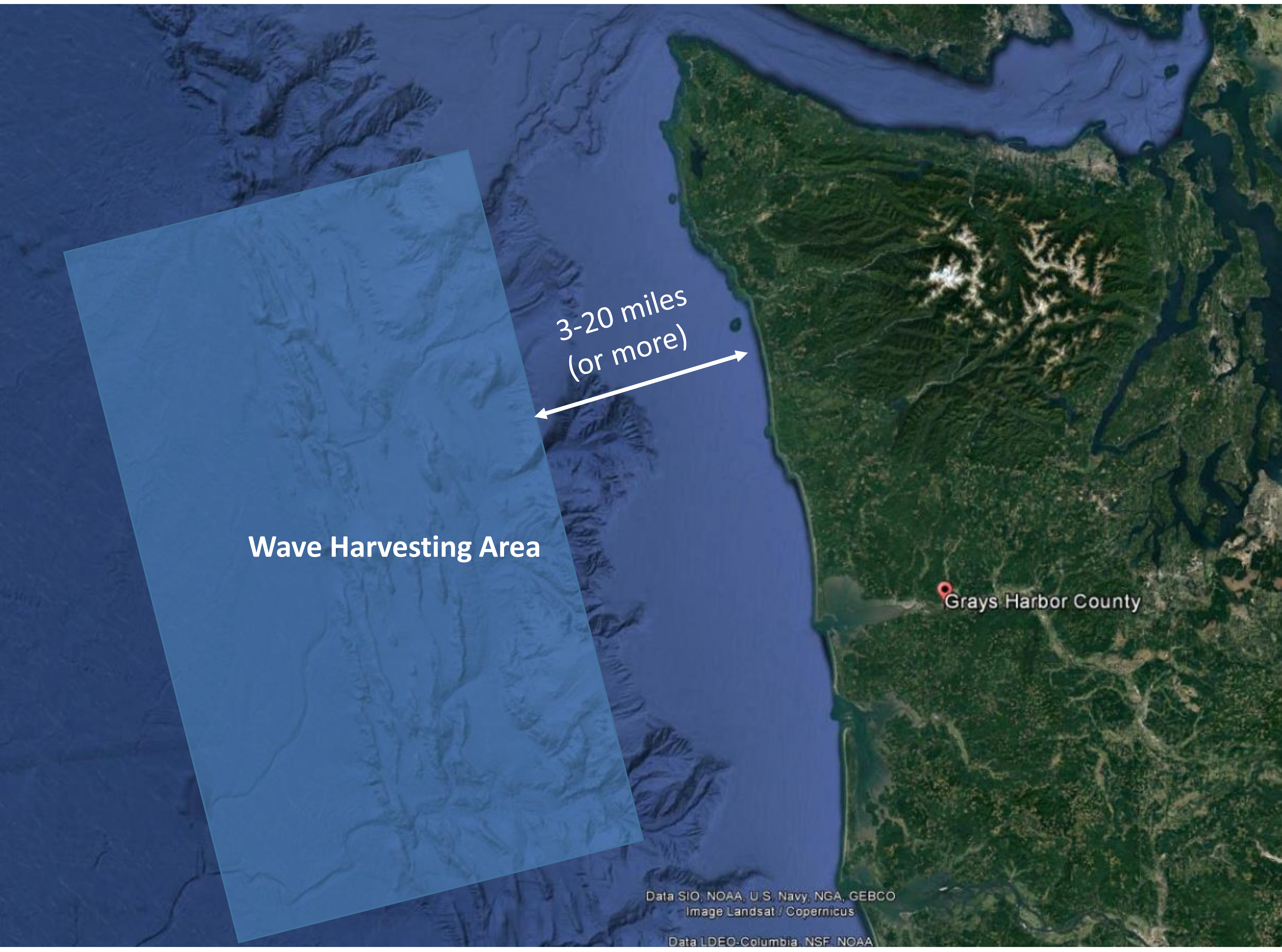
Hydrogen Production Estimates

- It takes 50 KWh of electrical energy to convert 9 liter of water into 1 kg of Hydrogen (H_2) and 8 kg of Oxygen (O_2) by means of commercially available electrolyzer
- How much hydrogen can be produced?
  - Estimated average (per year) available power = 29 KW/linear meter
  - Let’s assume: Barge length = 100 m
  - Let’s assume: Effectiveness of energy extraction = 0.3
  - Production rate of Hydrogen = 0.4 ton/day (plus Oxygen)
  - The energy from 0.4 ton of hydrogen equivalents to > 1.5 tons of gasoline

Hydrogen Energy Feedstock Cost to Gasoline Cost
EIA 2013 Energy Outlook - Reference Case

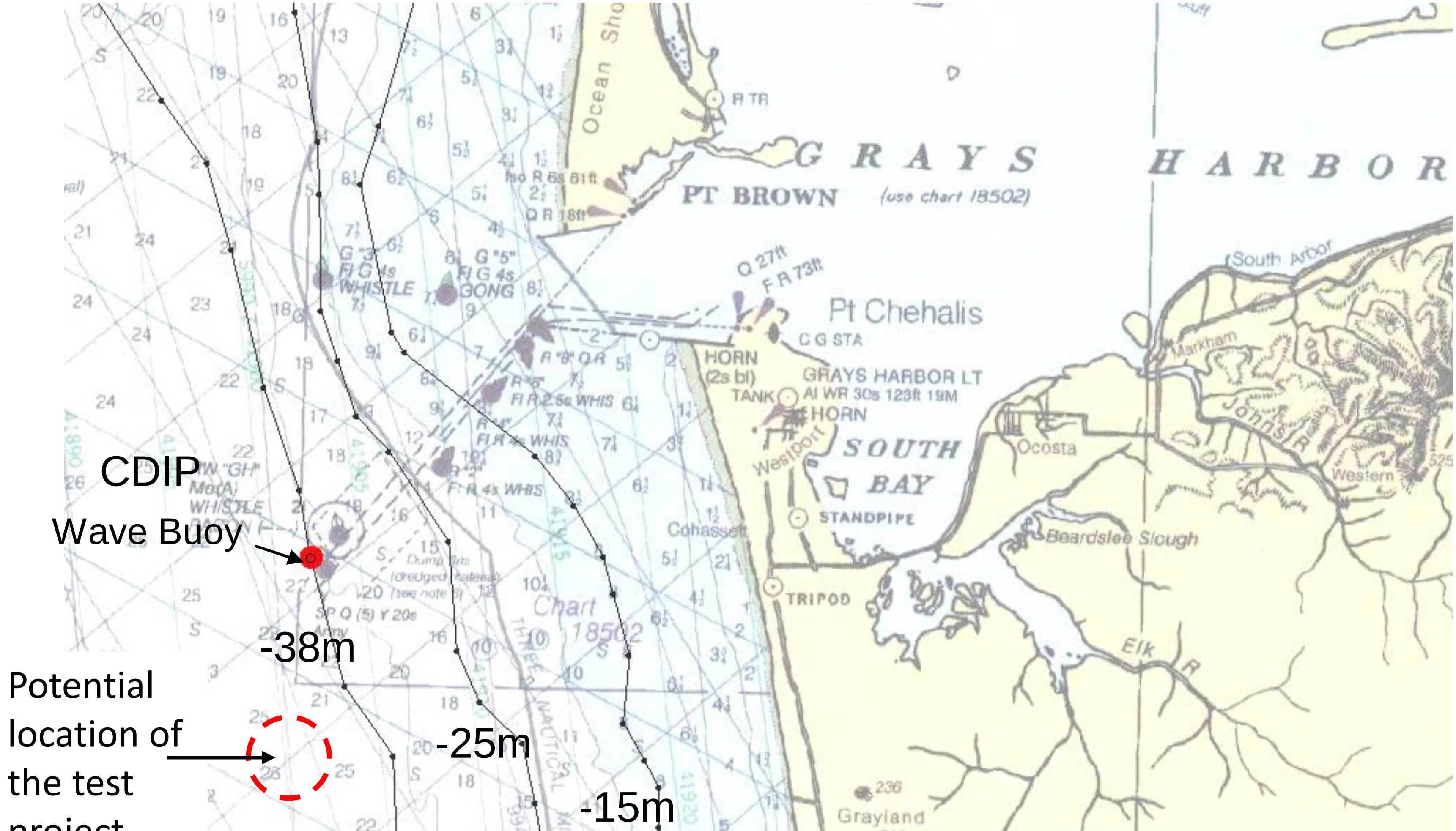


AIR PRODUCTS


3-20 miles
(or more)
Wave Harvesting Area
Grays Harbor County
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Data LDEO-Columbia, NSF, NOAA

Path Forward

- Phase 1 – Groundwork (0.5-1.0 year)
  - Conceptual level engineering
  - Patenting
  - Develop proposal and cost estimate
  - Develop support group
  - Identify and apply for grants
- Phase 2- Engineering (0.5-1.0 year)
  - Form the engineering team,
  - Preliminary and final design of the prototype
  - Permitting
- Phase 3 – Pilot Test - Commercial Size Prototype (1.0-1.5 years)
  - Build and test the prototype


CDIP
Wave Buoy
-38m
-25m
-15m
Potential location of the test project
G R A Y S H A R B O R
PT BROWN
(use chart 18502)
Pt Chehalis
C G STA
HORN
(2s bl)
TANK
GRAYS HARBOR LT
HORN
SOUTH BAY
Westport
STANDPIPE
TRIPOD
Ocosta
Beardslee Slough
Cohassett
Chart 18502
South Arbor
Johns R
Elk R
Grayland
Ocean Shores
CAUTION
Willapa Bay entrance channel is subject to continual changes. Buoys "A through D" are nonlateral aids which are frequently shifted to mark best water at the time of servicing.

eters

What help to expect from Local Communities?

- Leadership with obtaining State, Federal, and Private Grants
- Leadership with organizing State of Washington (and may be Oregon) coalition to support New Wave Energy Technology implementation
- Assistance during Pilot Project
  - Moorage of Pilot Barge
  - Moorage of tug boat
  - Offloading of Hydrogen
- Other possible help

Renewable Hydrogen from Ocean Waves at North Pacific

Quinault Indian Nation
February 21, 2018

by
Applied Ocean Energy Corporation
Dr. Vladimir Shepsis

THANK YOU

Grays Harbor Vessel Traffic Risk Assessment

March 28, 2018

Spills Prevention and Preparedness

DEPARTMENT OF ECOLOGY
State of Washington

Agenda

- Introductions
- Grays Harbor Vessel Traffic Risk Assessment overview
- Hazard Identification
  - Hazard Identification workshops
  - Response Capability Assessment
  - Commercial Fishing, Tribal Fishing, and Recreational Vessel workshop
- Public participation opportunities
- Next steps

Why are we conducting a study?

- Ecology is funded in the 2017-2019 biennium to conduct a vessel traffic risk assessment (VTRA) for Grays Harbor

- This study builds on previous legislature-directed work
  - Marine and Rail Oil Transportation Study, 2015
  - Salish Sea Oil Spill Prevention Workshop, 2016
  - Update to Puget Sound VTRA, 2017
  - Columbia River Vessel Traffic Evaluation and Safety Assessment, 2017

- Opportunity to:
  - Document current baseline of oil spill prevention and preparedness in Grays Harbor
  - Develop regionally specific recommendations for improvement

Grays Harbor VTRA - Goals

- Assess baseline and changing oil spill risks
  - Identify measures that could help reduce the risks of oil spills

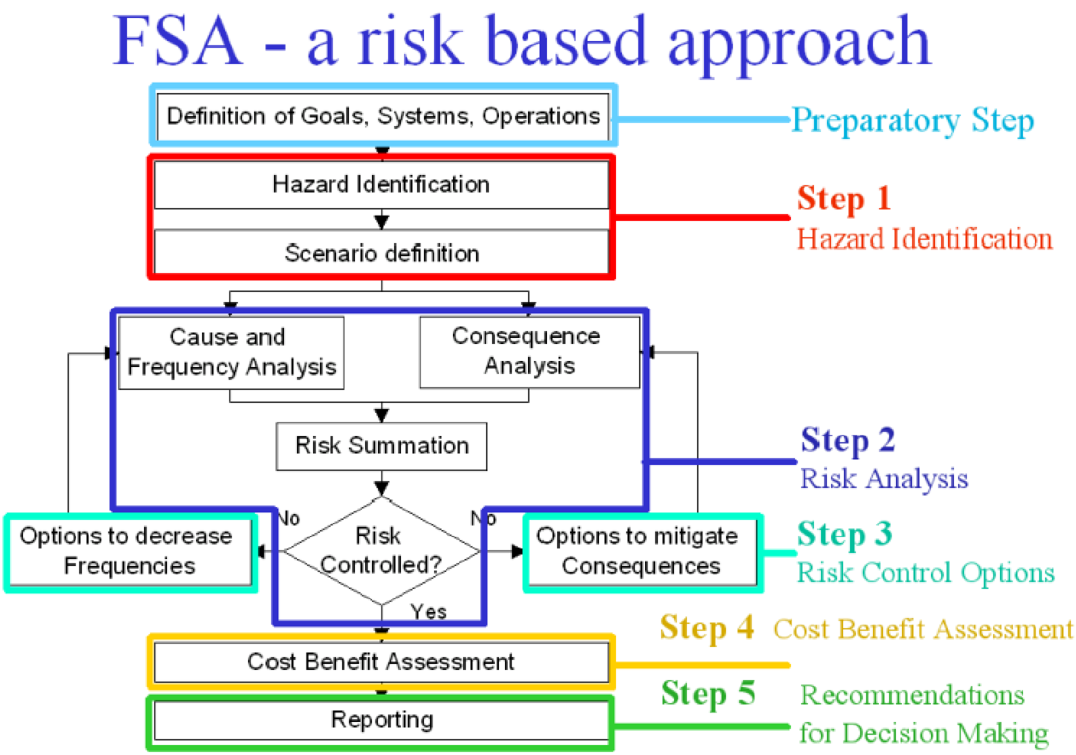
- Assess oil spill response preparedness
  - Identify baseline response capability

GH VTRA study approach

- Use the International Maritime Organization (IMO) Formal Safety Assessment framework
- Conduct a deliberative process
  - Engage the Grays Harbor community
  - Deliverables and decision points at each step
- Focus on regionally specific areas where improvements could be made

International Maritime Organization (IMO) Formal Safety Assessment

- Reference: IMO FSA
- 5-step process



International Association of Classification Societies
Presentation at MSC 75 – 16 May 2002

IMO Formal Safety Assessment steps

- Preparatory Step
  - Definition of Goals, Systems and Operations
- Hazard Identification
- Risk Analysis
- Risk Control Options
- Cost-Benefit Analysis
- Recommendations for Decision Making

Focus: Step 1, Hazard Identification

- Ecology's focus during Fiscal Year 2018 (July 1, 2017 – June 30, 2018) is on Step 1, Hazard Identification

- Accomplishing Hazard Identification through facilitated workshops

- Additional workshops will extend the Hazard Identification process to look at spill response capability, and oil spill prevention for smaller vessels

- Decision point in the spring of 2018 on the need to continue the Formal Safety Assessment
  - Process can stop after Hazard Identification
  - Decision based on the results of the Hazard Identification, and direction and funding from the 2018 legislative session

Workshop Schedule 2018

Date	Event
January 25, 2018	Hazard Identification Workshop 1
February 28, 2018	Hazard Identification Workshop 2
April 3, 2018	Response Capability Workshop
April 24, 2018	Commercial Fishing, Tribal Fishing, and Recreational Vessel Oil Spill Prevention and Preparedness Workshop
June, 2018	Hazard Identification and Response Capability Preliminary Report

Hazard Identification Workshop 1 Structure

- Scope
  - Identify local factors associated with hazards to commercial vessel operations in Grays Harbor that could result in an oil spill
- Method
  - Facilitate collaborative brainstorming with workshop participants
- Outcome
  - List of local factors

Hazard Identification Workshops Invited Participants

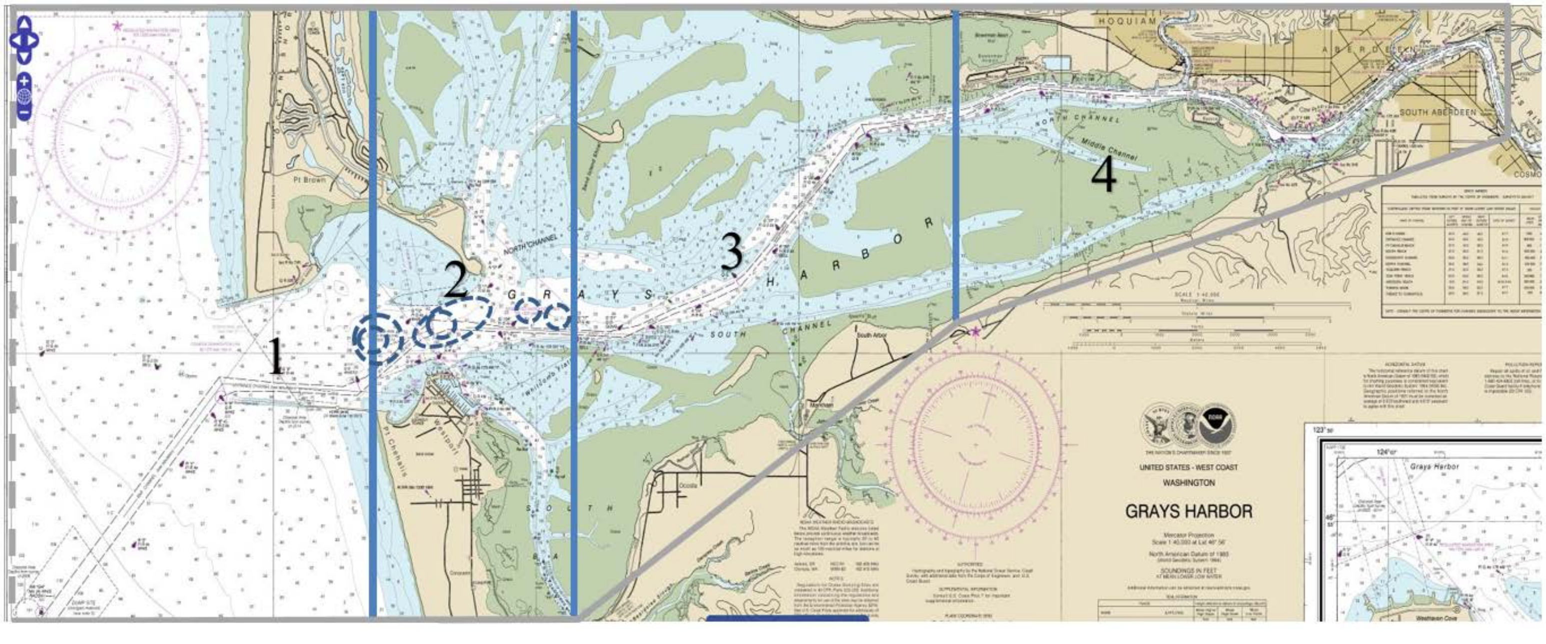
- Brusco Tug
- Confederated Tribes of the Chehalis Reservation
- City of Hoquiam
- Contanda
- General Steamship
- Grays Harbor Pilots
- Hoh Indian Tribe
- Jones Stevedoring
- Makah Tribe
- Marine Spill Response Corporation
- National Response Corporation
- NOAA
  - Office of Coast Survey
  - Scientific Support Coordinator
  - Olympic National Marine Sanctuary
- Ocean Companies
- Port of Grays Harbor
- Quileute Tribe
- Quinault Indian Nation
- REG Grays Harbor
- Shoalwater Bay Indian Tribe

Hazard Identification Workshop 1 Invited Participants

- The Nature Conservancy
- US Army Corps of Engineers
- US Coast Guard
  - MSU Portland
  - Station Grays Harbor
- Washington Department of Natural Resources
- Washington Dungeness Crab Fishing Association
- Washington State Maritime Cooperative
- Washington Trollers Association

Hazard Identification Waterway Areas

Waterway Areas



Discussion of offshore vessel traffic management may extend westward of buoy “GH”

Study boundary
Waterway Area division line
Non-designated Anchorage Areas (approximate locations)

- In our Hazard ID workshops we are looking at the risk of spills throughout the commercially navigable waterway of Grays Harbor
- We divided the waterway into four area to facilitate discussions
- Workshop participants systematically discussed the risks that could lead to an oil spill from a commercial vessel in each of the waterway areas

Hazard Identification Template Example

Template 1: Area 1, Underway, Collision

Area 1: Bar Channel and Entrance Channel to Point Chehalis Reach (inside buoy 11)
Vessel Activity: Underway
Incident Category: Collision

How could an incident occur (examples)?

- Contact with a fishing net or crab pot
- Difficulty crossing the bar
- Failure to maintain position in channel
- Failure to negotiate turn to entrance channel
- Failure to take action to avoid another vessel
- Incident related to vessels offshore, including areas westward of buoy “GH”

Possible immediate causes/contributing factors (examples)

- Environmental
- Equipment failure
    - Resulting in full or partial loss of electrical power
    - Resulting in full or partial loss of propulsion
    - Resulting in loss of navigational equipment
    - Resulting in loss of steering
- Human error
- Organization/maintenance failure
- Other

Local factors

-
-
-

Hazard Identification Workshop 2

- Scope
  - Review local factors identified in Workshop 1
  - Describe safeguards and high-level recommendations related to the local risk factors

- Method
  - Facilitate collaborative brainstorming with workshop participants

- Outcome
  - For each local factor identified in Workshop 1 - a description of the safeguards intended to prevent the hazard, and any high-level recommendations to reduce the likelihood or consequence of the hazards

Response Capability Assessment

Study Goals

- Characterize the response systems capability (skimming) not the impact of the spill to the environment
- Use the Response Options Calculator – a modeling tool developed by NOAA
- Model parameters to account for risk scenarios identified by the workgroup in Hazard ID workshop 1 & 2
- Considerations include location, time of the spill, type of oil, season, wind speed, and spill volume - these impact the maximum capacity of response resources to recover oil
- Identify an estimated maximum potential response capacity for on-water recovery

Response Capability Workshop structure

- Propose parameters of response equipment assessment
- Discuss and agree on study scope and purpose of resulting recommendations

Commercial, Tribal Fishing and Recreational Vessel Workshop

- Planning a workshop for late April, 2018
- Intended audience is commercial fishermen, tribal fishermen, and recreational vessel operators
- Goal is to review historic oil spill incidents, and identify potential practices/solutions that could reduce oil spills

Public Participation and Comment Opportunities

- Review our progress
  - Information about the GHVTRA study will be posted on the Ecology webpage throughout the study process
- Attend Grays Harbor Safety Meetings
  - Meetings are public and will include regular progress updates about the study
- Review and comment on the draft report
  - Report will be posted at https://ecology.wa.gov/Spills-Cleanup/Spills/Oil-spill-prevention/Oil-transportation-in-Washington
  - Public comments will be taken for 30 days following posting
  - Ecology will consider all comments submitted

Next steps

- Conduct Response Capability Assessment
- Hold Commercial Fishing, Tribal Fishing, and Recreational Vessel Spill Prevention and Preparedness workshop
- Determine whether to continue the Formal Safety Assessment process

Questions?

- Contact Brian Kirk (brian.kirk@ecy.wa.gov) with any questions about the Grays Harbor VTRA or the Hazard Identification process.

- Contact Sonja Larson (sonja.Larson@ecy.wa.gov) with any questions about the Response Capability Assessment