Harnessing the Power of Wave Energy Converters

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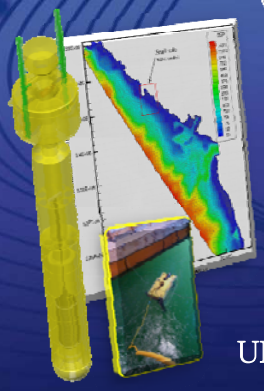
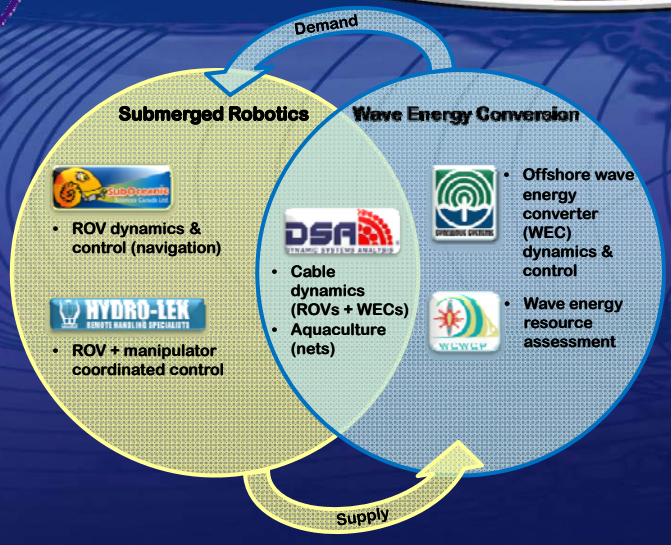


UBC Engineering Physics Project Fair

2 March 2011

Who is involved?



Overview

- Wave Energy?
- Resource Assessment.
  - West Coast Wave Collaboration Program (WCVI).
  - SyncWave Energy + BC Hydro (Hesquiaht).
- Wave Energy Converter (WEC) Technology Modelling.
- Integration – Remote Communities.

Wave Energy Conversion – the Canadian Context

"Ocean: A body of water occupying about two-thirds of a world made for man - who has no gills."

Ambrose Bierce (1842-1914)

Wave Energy Conversion – the Canadian context

- There is no debating the importance of ocean resources, and thus ocean technologies in Canada's scientific, economic and cultural contexts.
  - A variety of cultures across the nation celebrate logistical, economic, or hallowed connections with Canada's coastlines and coastal waters.
  - Canada's continental shelf is the second largest in the world covering over 3.7 million square kilometres.
  - Canada is an international leader in the collection of scientific information needed to execute the **precautionary approach** to **sustainable ocean development**.

Wave Energy Conversion – the Canadian context

"… Canada promotes the understanding of oceans, ocean processes, marine resources and marine ecosystems to foster the ***sustainable development*** *of the oceans and their resources;*

… Canada ***promotes the wide application of the precautionary approach*** *to the conservation, management and exploitation of marine resources in order to protect these resources and preserve the marine environment;"*

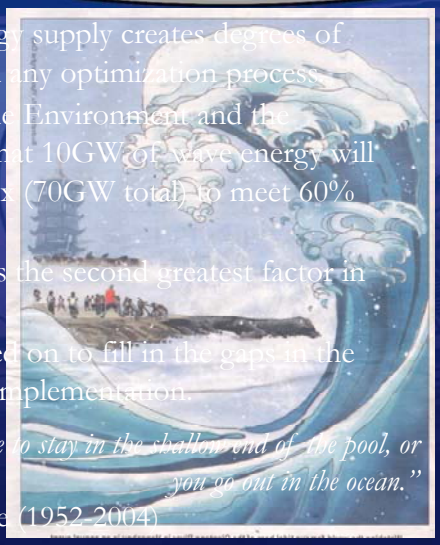
Canada's Oceans Act (1996)

"…the precautionary approach [takes] action to anticipate and protect the oceans when scientific information is lacking or incomplete."

Canada's Ocean Strategy (2002)

Wave Energy Conversion – the Canadian context

- Diversification of the nation's energy supply creates degrees of freedom that can be drawn upon in any optimization process.
  - The National Roundtable on the Environment and the Economy (NRTEE) suggests that 10GW of wave energy will be needed in the renewables mix (70GW total) to meet 60% GHG reduction targets.
  - Renewable energy technology is the second greatest factor in the GHG reduction strategy.
  - Technology developers are relied on to fill in the gaps in the NRTEE plan for wave energy implementation.



"Either you decide to stay in the shallow end of the pool, or you go out in the ocean."

Christopher Reeve (1952-2004)

Wave Energy Conversion – the BC Context

B.C.'S WAVE ENERGY POTENTIAL

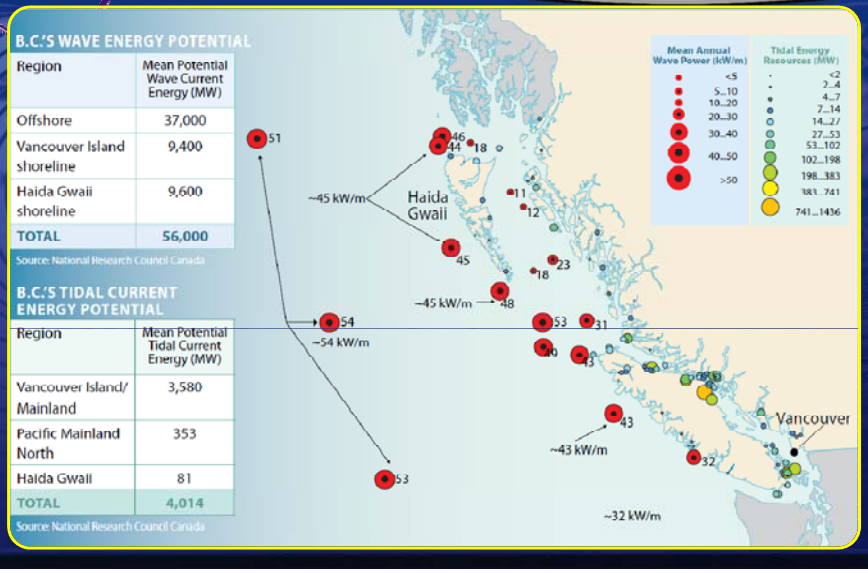
Region	Mean Potential Wave Current Energy (MW)
Offshore	37,000
Vancouver Island shoreline	9,400
Haida Gwaii shoreline	9,600
TOTAL	56,000

Source: National Research Council Canada

B.C.'S TIDAL CURRENT ENERGY POTENTIAL

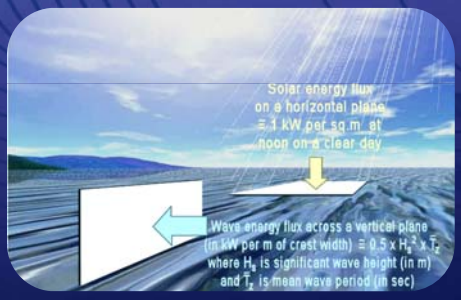
Region	Mean Potential Tidal Current Energy (MW)
Vancouver Island/ Mainland	3,580
Pacific Mainland North	353
Haida Gwaii	81
TOTAL	4,014

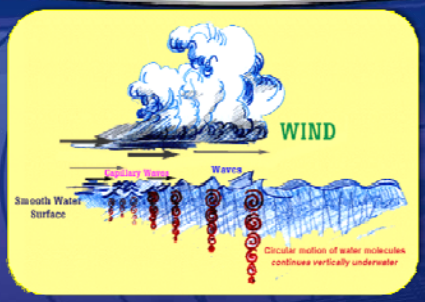
Source: National Research Council Canada



What Waves are We Working With?

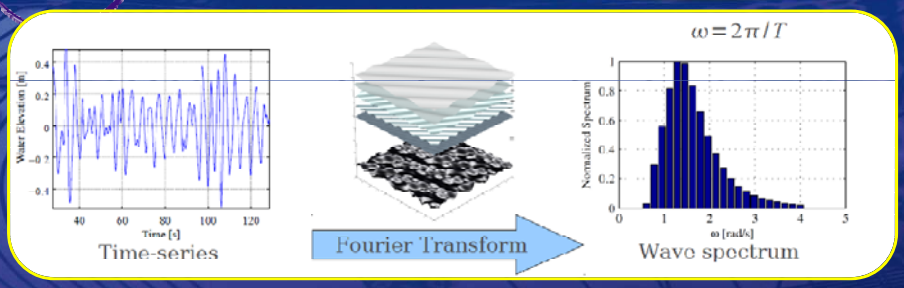
- Ocean Swell refers to long period water waves produced by consistent winds acting over a large fetch.
- Ocean swell can be considered as a concentration of solar (wind) energy.





- The magnitude of the power transport in an ocean wave has inspired a variety of WEC concepts
- Each class of WEC technology is distinguished by the water wave phenomena that drives it.

Wave Power Transport = J

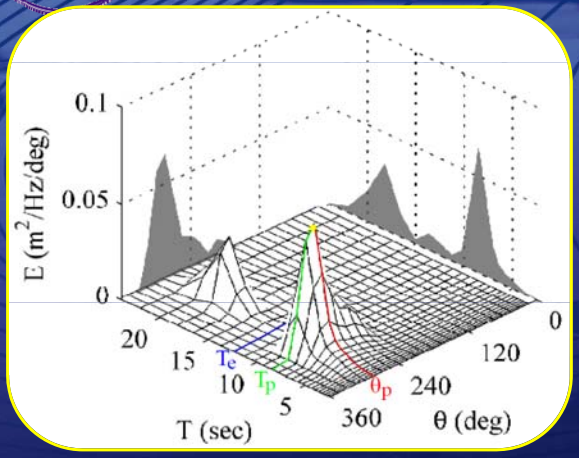


$$a_{i,j} = \sqrt{2E(f_i, \theta_j) \cdot \Delta f \cdot \Delta \theta}$$

$$J = \frac{1}{2} \rho g \sum_i \sum_j \left(a_{i,j} C_g(f_i, h) \right)$$

$$C_g = \frac{1}{2} \left(1 + \frac{2kh}{\sinh(2kh)} \right) \sqrt{\frac{g}{k} \tanh(kh)}$$

Wave Power Transport = J



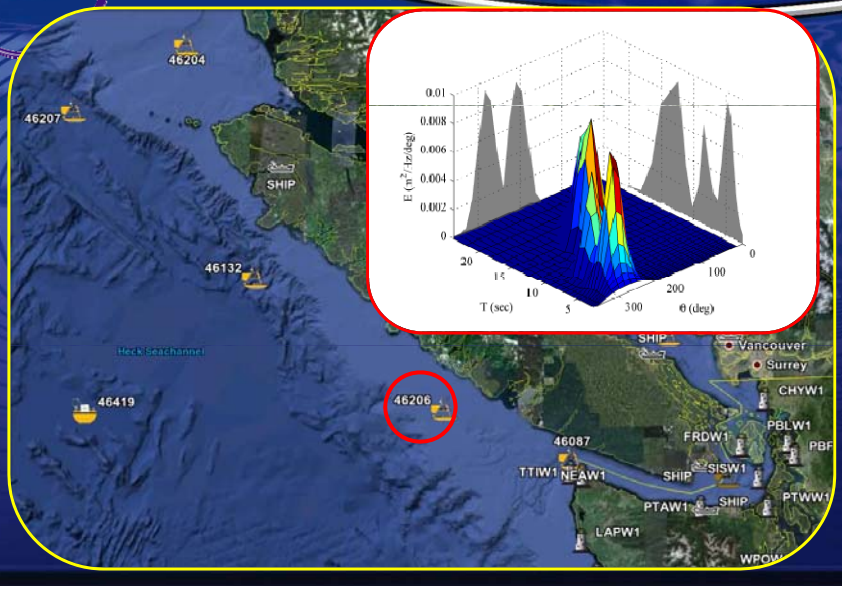
$$m_l = \sum_i \sum_j f_i^l E(f_i, \theta_j) \Delta f_i \Delta \theta_j$$

$$H_s = 4\sqrt{m_0}$$

$$T_e = \frac{m_{-1}}{m_0}$$

Wave Power Transport = J

Wave Energy? | Resource Assessment | Technology | Integration



Wave Energy Conversion – Why Not?

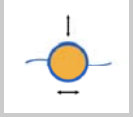
"...the question is not which technologies to deploy, but how to deploy many or even all of the potential GHG reduction technologies at unprecedented levels of implementation."

Canadian National Roundtable on the Environment and Economy.

"There is nothing new about generating power from water."

Discussion at the Natural Resources Canada Steering Committee for the Marine Renewable Energy Technology Roadmap.

WEC Technology Options?

Wave Device Class	Definition	Example
Attenuators (Pelamis, Biopower)	• Aligned parallel to the direction of wave propagation.	 
Overtopping Devices (Wave Dragon, Limpet, Manchester Bobber, OceanLinx, ORECON, SEEWEC)	• Top of breaking wave used to drive low-head turbine.	 
Point Absorbers (OPT, WaveBob, SyncWave)	• Omni-directional absorption – horizontal or vertical component of wave motion.	 
Terminators (AWS, OREC)	• Aligned perpendicular to the direction of wave propagation.	 

WEC Technology Options

- Consider a modern attenuator, such as Pelamis:

WEC Technology Options

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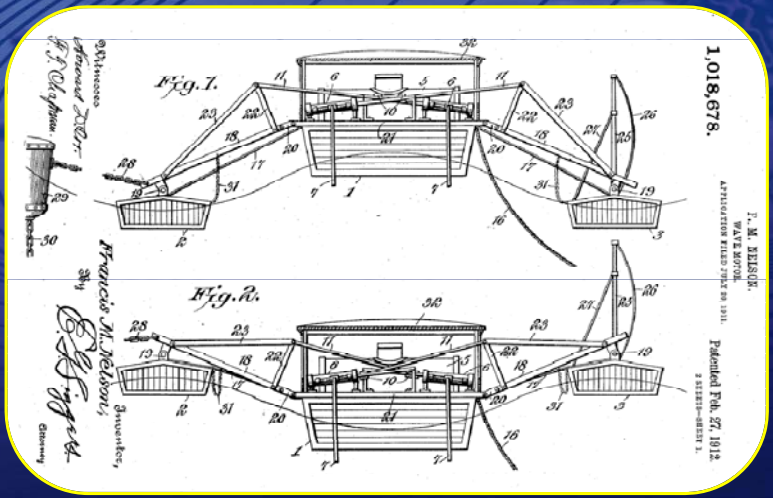

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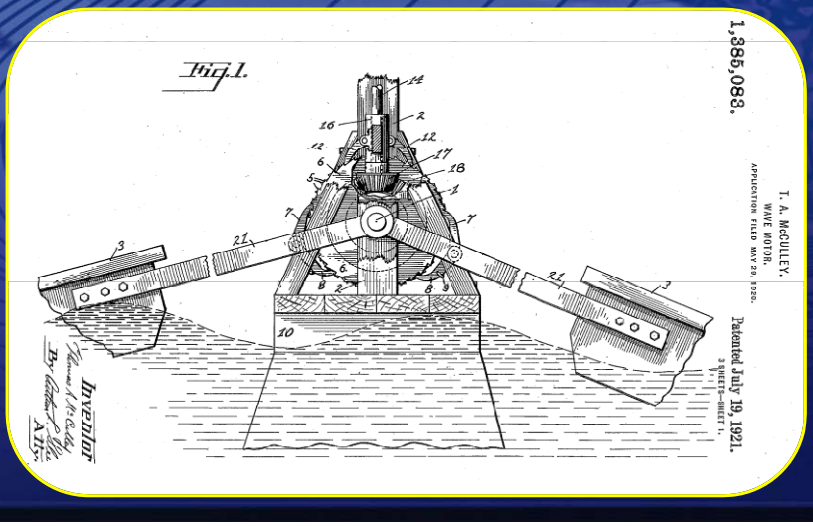

WEC Technology Options

Wave Energy? | Resource Assessment | Technology | Integration

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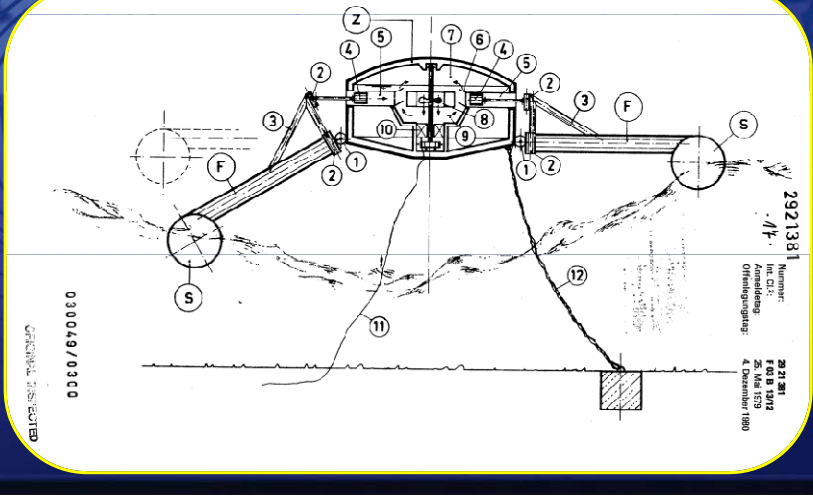
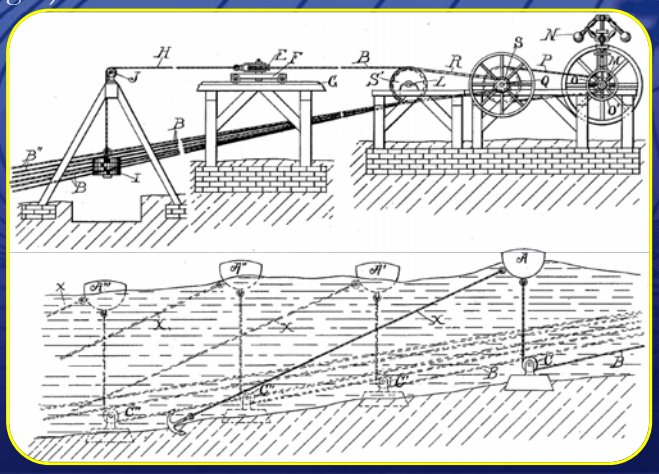


WEC Technology Options

- Or, consider modern point absorbers (either surface piercing or submerged).



WEC Technology Options

Wave Energy? | Resource Assessment | Technology | Integration

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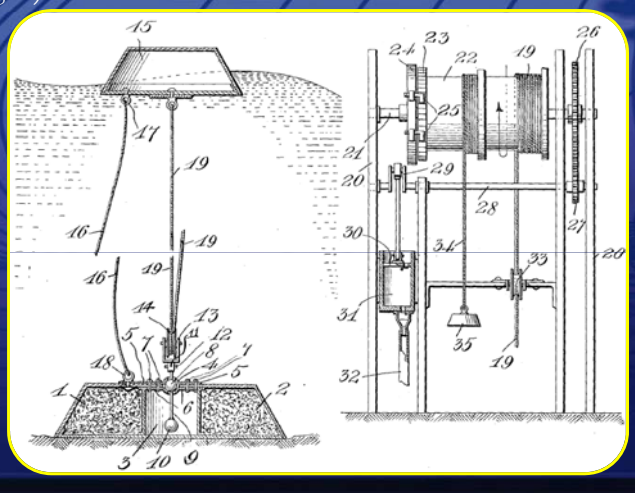

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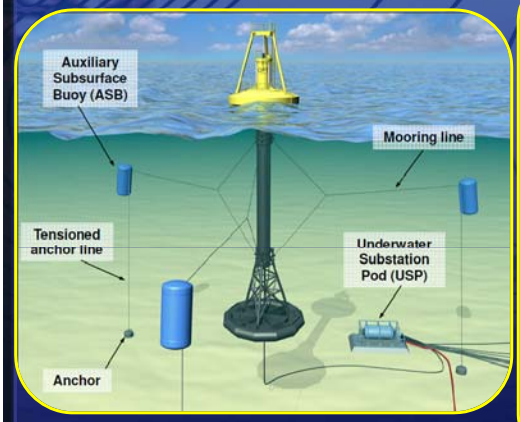
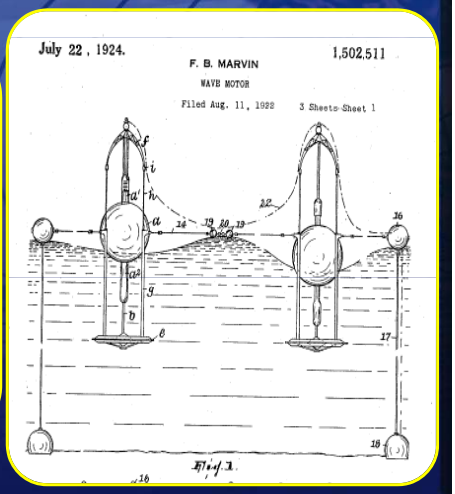


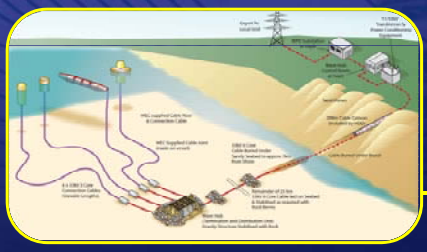


Wave Energy – the International Context

- There has been only limited deployment of demonstration/commercial devices.
- The UK has used public money to develop three independent test sites designed to facilitate "cluster growth"
  - Galway Bay, Marine Institute Ireland & Sustainable Energy Authority Ireland.
  - Cornwall Wave Hub, SWRDA & PRiMARE.
  - EMEC, Highlands and Islands Enterprise, UK Carbon trust, …

Wave Energy – the International Context

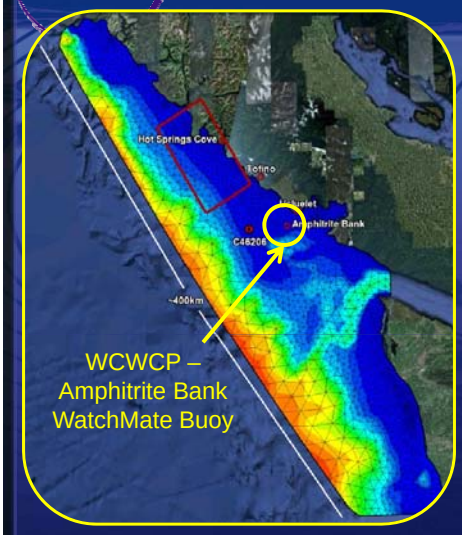
Wave Energy? | Resource Assessment | Technology | Integration



Wave Energy – the International Context

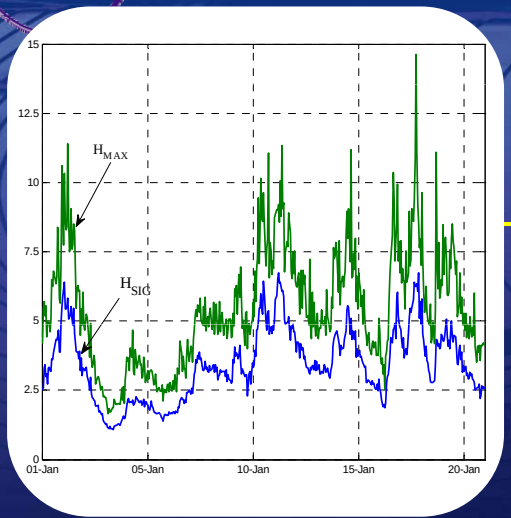
Wave Energy? | Resource Assessment | Technology | Integration

Wave Energy Conversion – the BC Context Cont'd



- How does the BC wave energy resource compare to the conditions in the UK?
- Does the potential warrant investment in infrastructure as has been done in the UK?
- Unfortunately, our knowledge of the wave energy resource is based on disparate buoy data sets.
- However, there are known locations where ...

Wave Energy Conversion – the BC Context Cont'd



Wave Energy Conversion – the BC Context cont'd

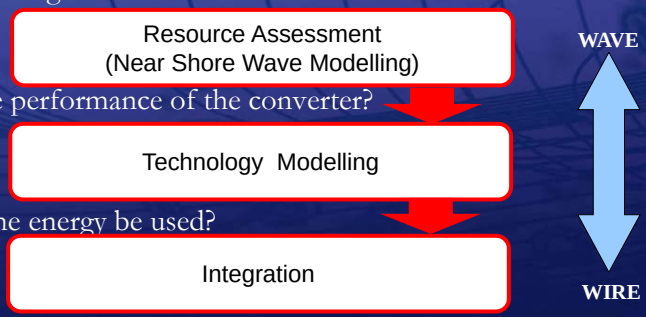
"We want to replace 100 per cent of our diesel dependency and start to generate it through wind, wave [and] solar…"

Hesquiaht Councillor, Carol Anne Hilton

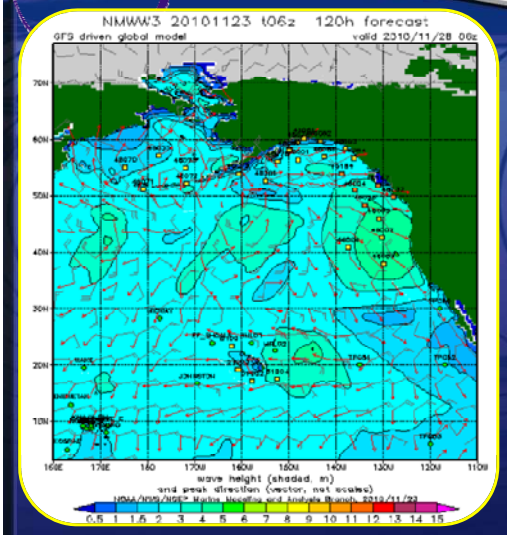
"Hesquiaht First Nation could be first Aboriginal community to become fossil-fuel free," *Westerly News*, 18 Feb. 2010, pg. 11.

Wave Energy Conversion – the BC Context Cont'd

- Q: What's keeping wave energy from contributing to BC's generation portfolio?
- A: A general lack of precision in the estimates of the raw and converted resource.
  - What is the magnitude of the resource?
  - What is the performance of the converter?
  - How can the energy be used?



BC Wave Energy Resource Assessment



- There will never be enough wave buoys in the water to precisely describe the resource.
- Near shore wave modelling software is needed to ramp up the spatial resolution.
- Global Wind Wave models include:
  - WaveWatch3
  - WAM
  - British Met Office Model.

BC Wave Energy Resource Assessment

Medium Scale Modelling - WCWCP

Wave Energy? | Resource Assessment | Technology | Integration

- West Coast Wave Collaboration Program.
  - Produce the tools needed to fill in gaps in the knowledge of the Vancouver Island Wave Resource.
  - Provide an identity for the WEC Industry in Canada.
- WCWCP Contributing Partners:
  - Natural Resources Canada – CanmetENERGY MRET
  - University of Victoria - IESVic
  - BC Hydro
  - SyncWave Energy Inc.
  - Fred.Olsen Marine Renewables
  - AXYS Technologies
  - Natural Power Consultants
  - Triton Consultants
  - Ucluth Development Corporation
  - District of Ucluelet
  - Black Rock Resort

WCWCP

Medium Scale Modelling - WCWCP

Wave Energy? | Resource Assessment | Technology | Integration

- Medium scale wave propagation modelling: SWAN (Delft University of Technology)
  - Variable grid spacing, non-stationary computations.
  - Refraction, shoaling, bottom friction, breaking and current interactions, wave generation by wind can be modelled.
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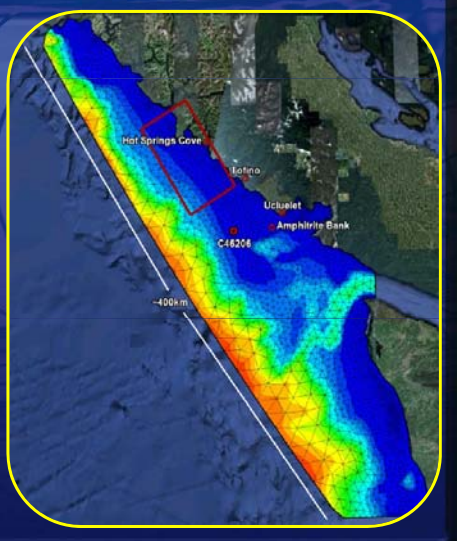

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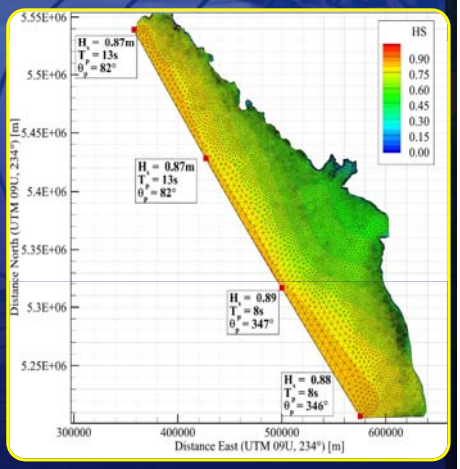
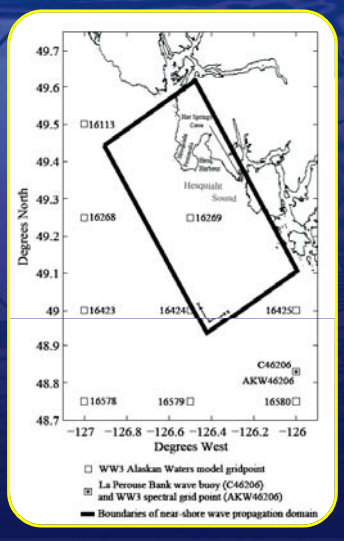


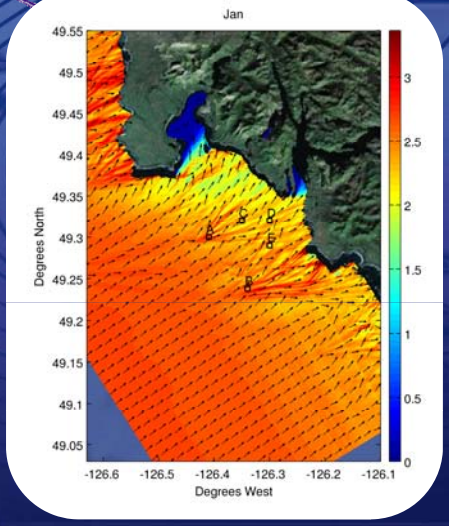
Fine Scale Modelling – SEI & BC Hydro

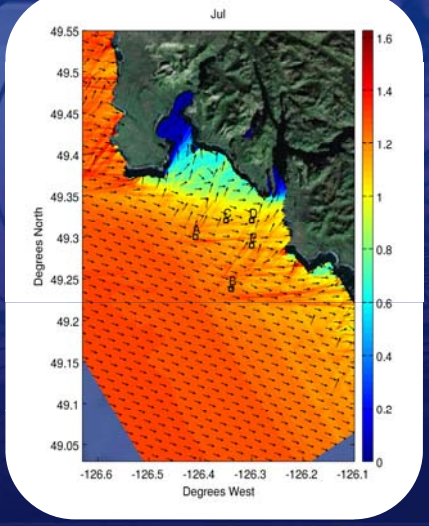
- Fine scale modelling: REF/DIF-1 (University of Delaware).
  - Use grid spacing of ~50m, stationary computations.
  - Refraction, diffraction, shoaling, bottom friction, breaking and current interactions can be modelled.
  - Used for precise WEC siting.



Fine Scale Modelling – SEI & BC Hydro

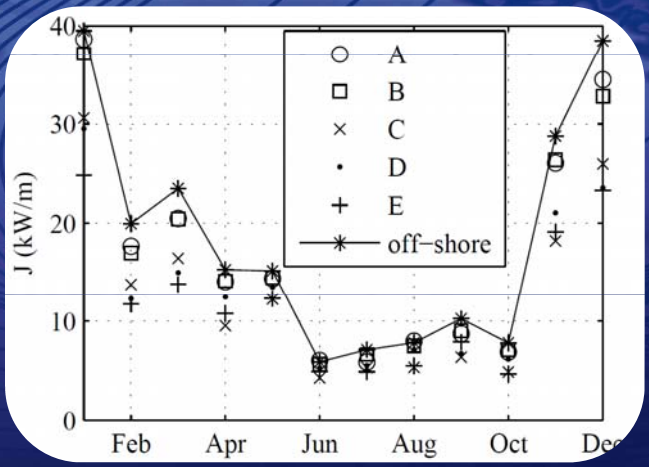
Wave Energy? | Resource Assessment | Technology | Integration





Fine Scale Modelling – SEI & BC Hydro

Wave Energy? | Resource Assessment | Technology | Integration



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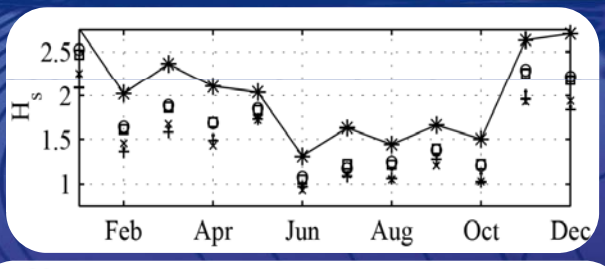
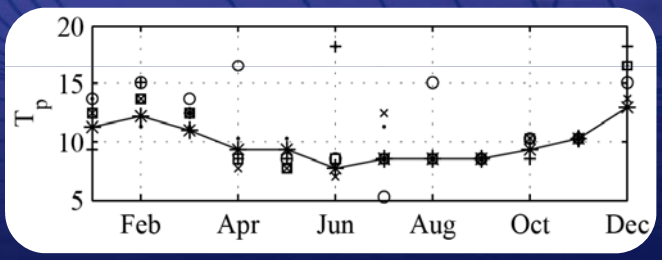
Wave Energy? | Resource Assessment | Technology | Integration

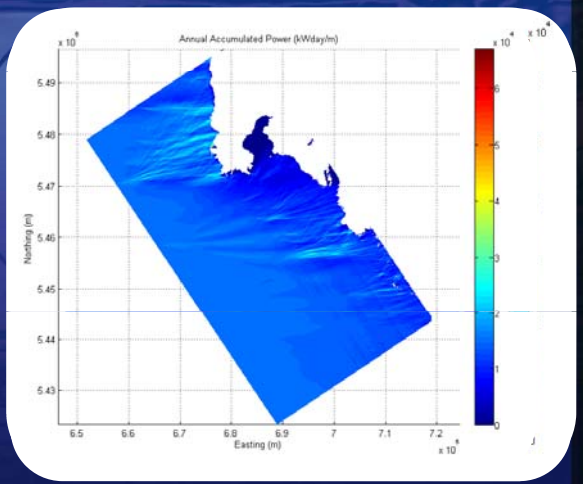




Fine Scale Modelling – SEI & BC Hydro

Wave Energy? | Resource Assessment | Technology | Integration

- To serve integration work, the offshore conditions were derived on a daily basis.
- Generated a synthetic year, based on archived WaveWatch3 data sets.
- Next step will be to nest the fine scale Hesquiaht model inside the medium scale SWAN model.



What is the WEC technology being developed?

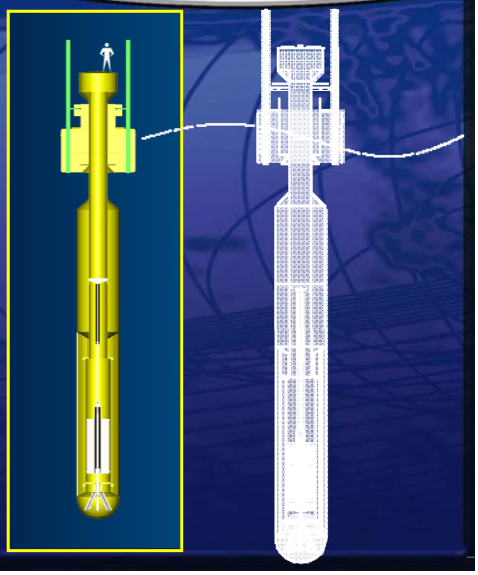
Wave Energy? | Resource Assessment | Technology | Integration

- Syncwave Power Resonator (2006).
  - of the Heaving Point Absorber wave energy conversion class.
  - Energy is absorbed through relative motion of surface piercing float and spar buoys.
  - Float follows wave surface, spar lags by design.
  - Spar lag is adjusted in pursuit of maximum energy conversion.
  - Patented variable inertia tuning system (SWELS) affords the spar response adjustment.

What is the WEC technology being developed?

Wave Energy? | Resource Assessment | Technology | Integration

- Float
- Spar
- Reaction Mass
- Rotational System with variable inertia
- Spring Support
- Hydraulic Rams (PTO)



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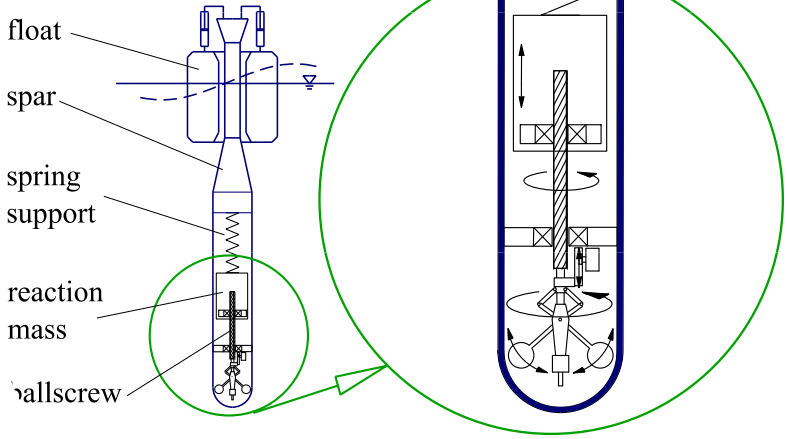
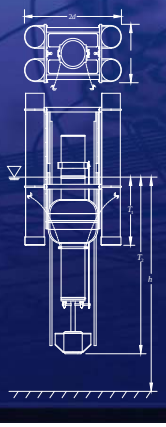


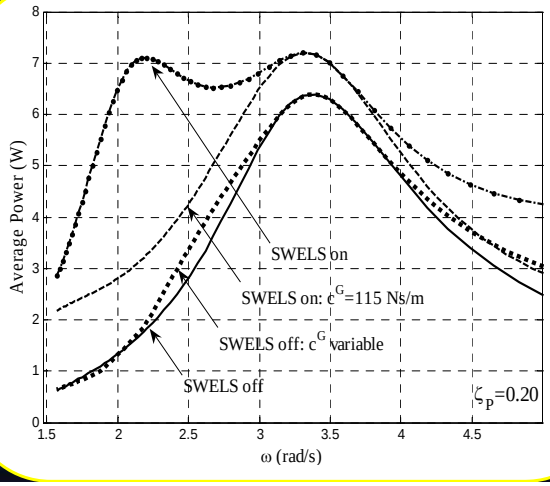
How does it work? How do we know?

- A 1:15 scale proof-of-concept model (*Charlotte*) was tested at the former BC Research tank facility in 2006.
- Goals of the tests were to validate the spar-float concept and a parametric dynamic model of the device.



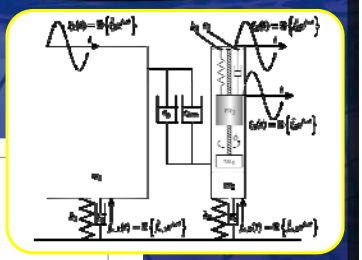
How does it work? How do we know?

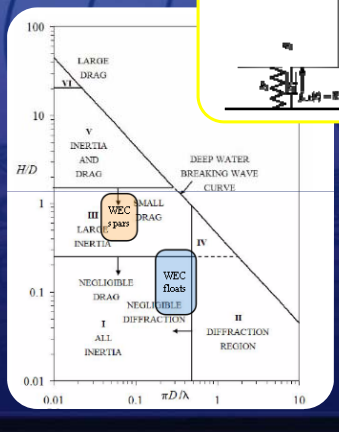
- The Charlotte test data, and subsequent dynamics modelling exercises, show the SWELS influence on power production.



How does it work? How do we know?

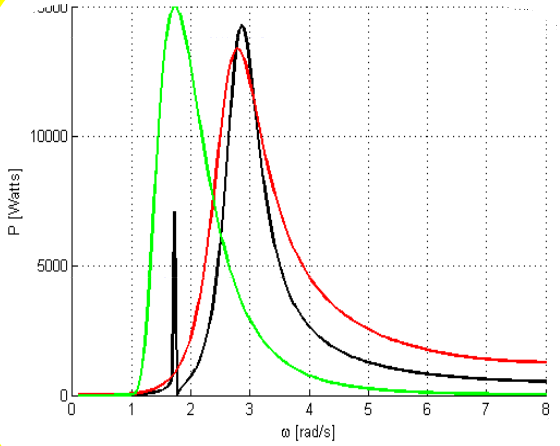
- The dynamics modelling of the SyncWave SPR occurs at two stages:
  - Stage 1: a linearized heave constrained model applied in the frequency domain. Used to drive optimization based studies.
  - Stage 2: a high fidelity, non-linear code developed by UVic and DSA Ltd. Used to verify results of Stage 1 and to incorporate the mooring

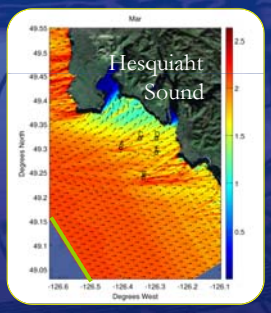




Why is this WEC so intriguing?

Wave Energy? | Resource Assessment | Technology | Integration





- The competitive advantage of the SWELS system depends on the deployment location.

Looking Inside the Point Absorber Class

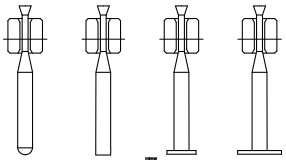
Wave Energy? | Resource Assessment | Technology | Integration

- The answer on how to best create the fill-in we are looking for may lie in other point absorber design features.

Existing WEC Configurations

OPT

Design Space Studies



Compare Power Capture for each Configuration

Looking Inside the Point Absorber Class

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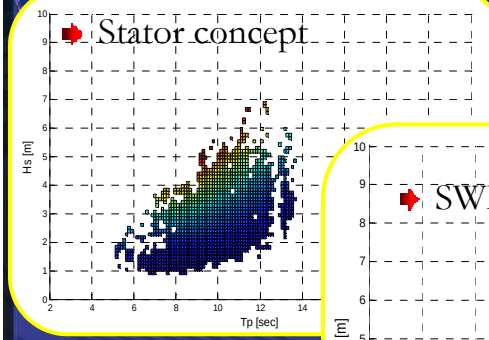
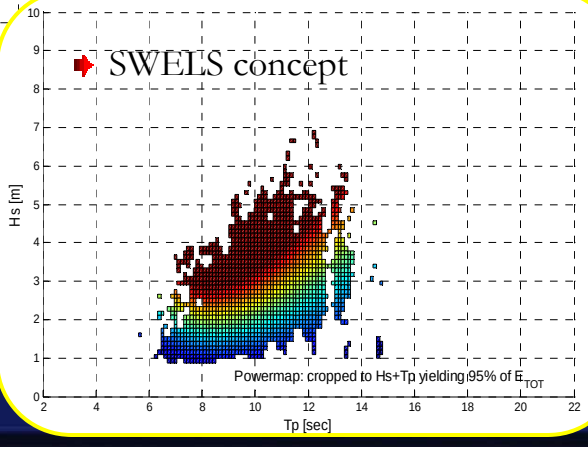
- Stator concept



- As the design changes we have to adjust the powermap for the device.
- Crop Hs-Tp conditions considered according to deployment location.
- SWELS concept



How does it work? How do we know? Cont'd

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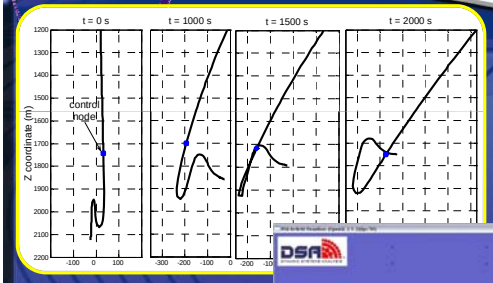
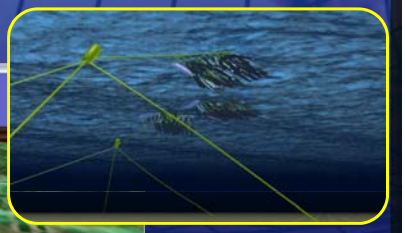
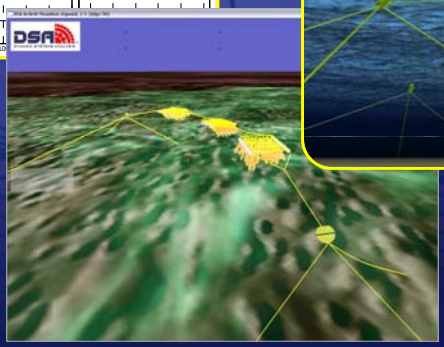


- Since 2000, a body of cable simulation codes have been developed to study ROV, towed underwater vehicle, wave energy and other applications.





- The software package allows for rapid prototyping of complex systems.
- *ProteusDS*
- The software is now nurtured by Dynamic Systems analysis (DSA) Ltd.

How does it work? How do we know? Cont'd

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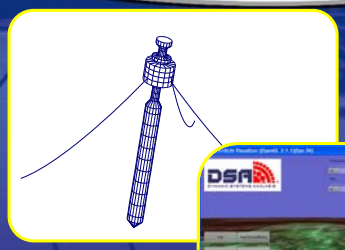
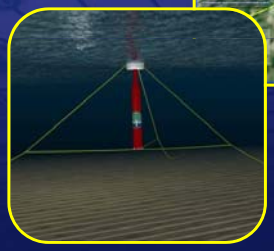
- Stage 2 of the WEC technology modelling program is built on the ProteusDS platform.
- Short term: mooring system design.
- Long term: time domain evaluation of control strategies.





How does it work? How do we know? Cont'd

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BRIDLE MOORING RESPONSE

Significant wave height, Hs (m)	Dominant period, Tp (s) Tp = 5	Tp = 8	Tp = 11
Hs = 2	1.19	0.69	0.80
Hs = 5	1.24	1.00	0.75
Hs = 8	1.03	1.07	0.81

Table B1: Scaled system: RAO of float heave for bridle mooring

Significant wave height, Hs (m)	Dominant period, Tp (s) Tp = 5	Tp = 8	Tp = 11
Hs = 2	1.05	0.77	0.86
Hs = 5	1.36	1.30	0.99
Hs = 8	0.90	1.21	1.06

Table B2: Scaled system: RAO of spar heave for bridle mooring

Significant wave height, Hs (m)	Dominant period, Tp (s) Tp = 5	Tp = 8	Tp = 11
Hs = 2	1.46	0.54	0.56
Hs = 5	1.31	1.10	0.68
Hs = 8	0.94	0.84	0.66

Table B3: Scaled system: RAO of *spar-float relative heave for bridle moori*

IDEAL MOORING RESPONSE

Significant wave height, Hs (m)	Dominant period, Tp (s) Tp = 5	Tp = 8	Tp = 11
Hs = 2	0.96	1.00	1.03
Hs = 5	0.96	1.02	1.03
Hs = 8	1.14	0.99	1.03

Table B5: Scaled system: RAO of float heave for ideal mooring

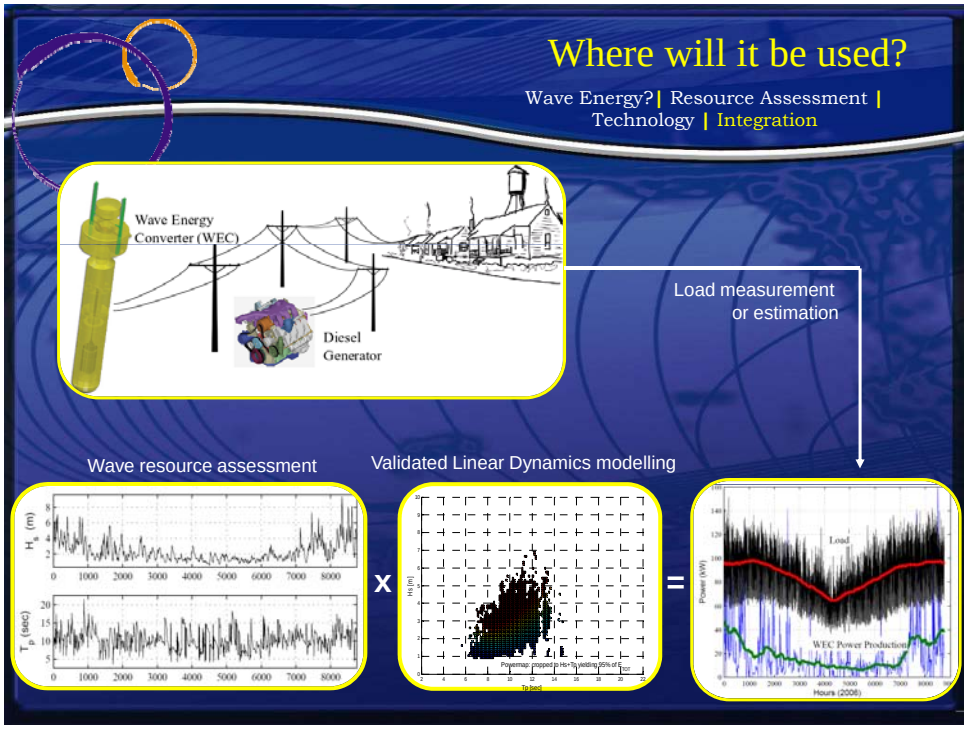
Significant wave height, Hs (m)	Dominant period, Tp (s) Tp = 5	Tp = 8	Tp = 11
Hs = 2	0.89	1.05	1.15
Hs = 5	0.71	0.73	0.86
Hs = 8	1.00	0.70	0.82

Table B6: Scaled system: RAO of spar heave for ideal mooring

Significant wave height, Hs (m)	Dominant period, Tp (s) Tp = 5	Tp = 8	Tp = 11
Hs = 2	1.12	0.95	0.92
Hs = 5	0.93	0.63	0.56
Hs = 8	1.01	0.59	0.54

Table B7: Scaled system: RAO of *spar-float relative heave for ideal mooring*


Where will it be used?
Wave Energy? | Resource Assessment | Technology | Integration
St. George Island
Hesquiaht
Hot Springs Cove
TRITON
MITACS


Where will it be used?
Wave Energy? | Resource Assessment | Technology | Integration
Wave Energy Converter (WEC)
Diesel Generator
Load measurement or estimation
Wave resource assessment
Validated Linear Dynamics modelling
x
=
Load
WEC Power Production

Where will it be used?

- Results indicate that a single WEC has the potential displace a significant amount of diesel generation & save hundreds of tonnes of CO_2.
- Results shown are based on the demonstration device design which produces 18-20 kW (mean yearly output).

	St. George Island	Hot Springs Cove
Location	56.57°N, 169.61°W	49.36°N, 126.27°W
Population	100	180
Electricity Demand	1380 MWh	965 Mwh
Wave generated electricity	122 MWh	161 Mwh
Fuel Saving	1.85E5 L / year	1.78E5 L / year
CO_2 savings	480 tCO_2 / year	475 tCO_2 / year

Who is involved?

- Point Absorbing WEC technology


- Dr. Brad Buckham: WEC dynamics & control, marine cable dynamics.


- Dr. Peter Wild: mechanical design, integration (techno-economic modelling).

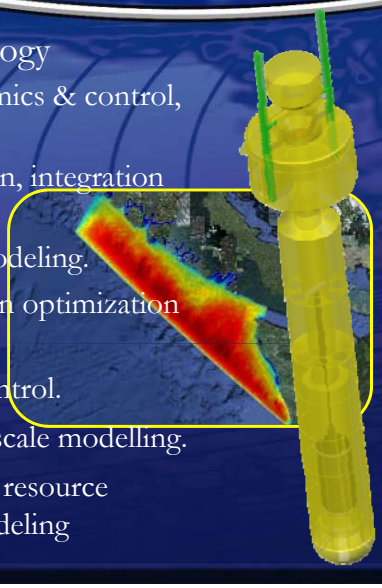

- Dr. Peter Oshkai: small scale modeling.


- Scott Beatty (Ph.D.): WEC design optimization and control.


- Mark Mosher (MASc.): WEC control.

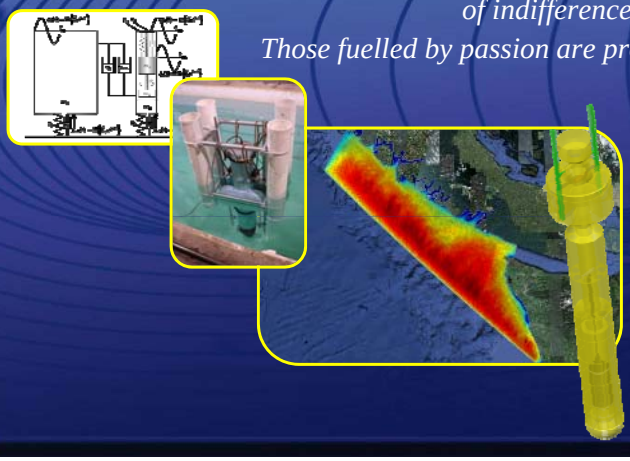

- Mercedes Baylis (MASc): small scale modelling.


- Mr. Clayton Hiles (MASc): wave resource assessment, near shore wave modeling



Closing

"There are two fundamental motivators – fear and passion.
Of the two, one is useless: fear is reactionary, produced by a partnership of indifference and short-sightedness.
Those fuelled by passion are proactive and prepared."



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