ENERGY

# Renewables Advisory

## Marine Energy Technology & Deployment Panel

**BOEM Offshore Renewable Energy Workshop**

**Sacramento, CA**

**Jarett Goldsmith**

July 30, 2014

# Two complementary players joining forces


Founded 1864

## DNV GL Group

- Global companies with strong heritage as ship and offshore classification societies
- Complementary market segments in maritime, oil and gas and energy markets
- Shared ambition for quality and innovation
- Common values
- Complementary skills


Founded 1867

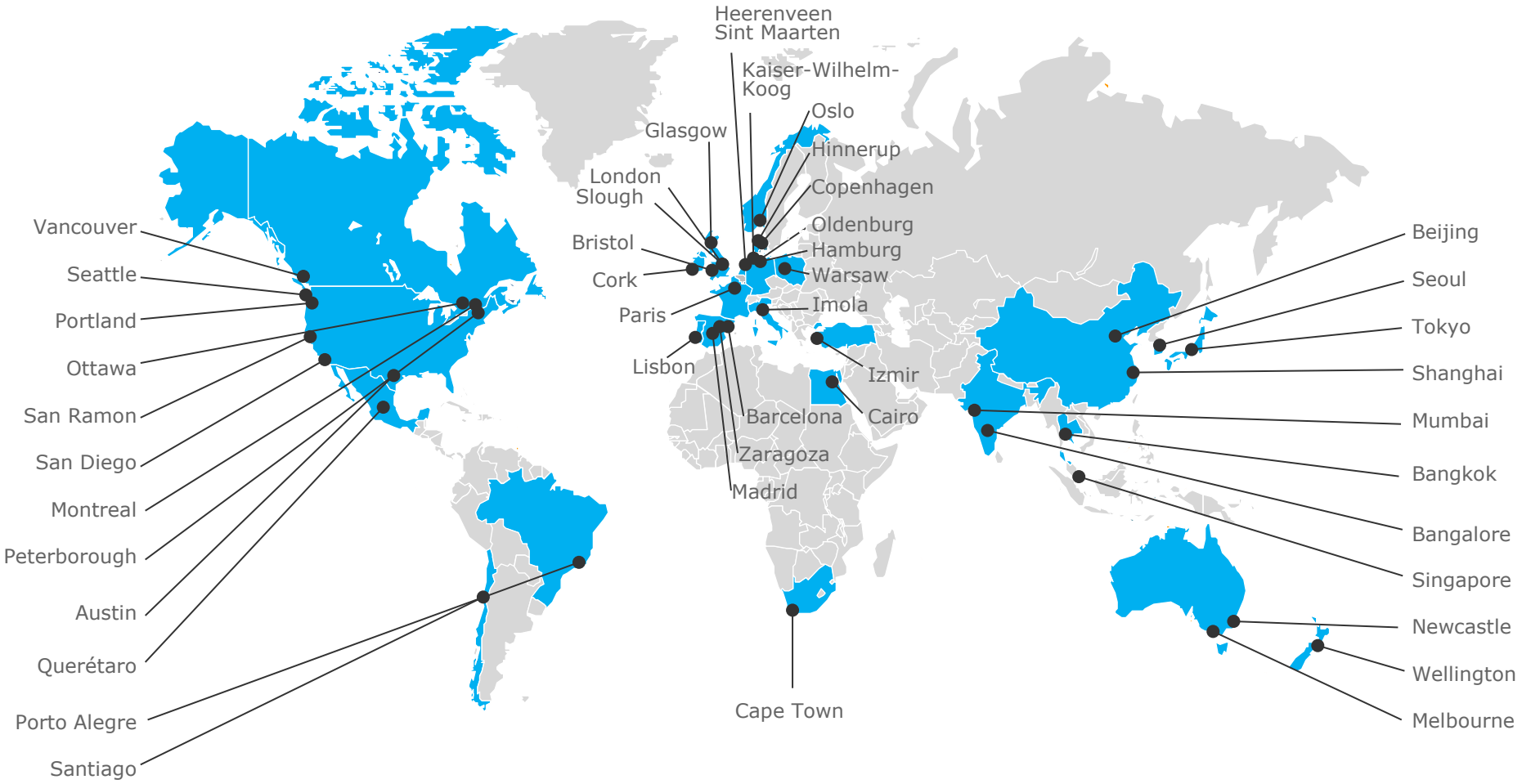
# DNV GL: An energy technology powerhouse

**We are a world leader in testing, certification and advisory services for companies and organizations in the electrical power value chain**

- 3,000 energy experts
- Headquartered in Arnhem, the Netherlands & Bristol, the UK
- Worldwide competence centers and laboratories
- Offices and agents in over 30 countries
- **The worlds largest renewable energy advisory**

# Geographical reach in renewables

More than 1000 renewables staff, in 50 locations, across 27 countries






DNV·GL

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# Does anyone here know when the first WEC prototypes were deployed in California?



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# The first California Wave Energy projects…

- The early days of wave energy in California began in the 1870s.
- Although the challenge of finding investors and backers was the same for the early visionaries, inventors appear to have had quite the liberty to test and deploy prototypes when they did secure funding.
- Throughout the late 1800s and turn of the century, experiments occurred from Imperial Beach in San Diego to Trinidad in Humbolt county and a number of places in between.[1]
- Perhaps it's a shame that modern offshore know-how and technology was not up-to speed with such an innovation friendly environment

[1]Source: Info compiled by Christine Miller at the Western Neighborhoods Project: http://www.outsidelands.org/wave-tidal.php



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## Who here has heard of

# Achilles Tognini?



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# Achilles B. Tognini & his WEC
# Cayucos, California (San Luis Obispo County) - Circa 1913


Photo courtesy of the George Canet Collection.
http://www.sanluisobispo.com/2014/02/27/2947358/cayucos-wave-power-pioneer-achille.html#storylink=cpy

- Patent filed May 7, 1913 – Built in 1913
- U.S. Patent 1127934 granted February 9, 1915



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# Achilles B. Tognini & his WEC
# Cayucos, CA (SLO County) - Circa 1913


Photo courtesy of the George Canet Collection.
http://www.sanluisobispo.com/2014/02/27/2947358/cayucos-wave-power-pioneer-achille.html#storylink=cpy

- Spent $20,000 of his own money
- All work done at low tide, to permit pouring concrete foundations: construction done by both day and night as tides allowed
- After months of work, hoisted into position Nov 5, 1913

# Achilles B. Tognini & his WEC
# Cayucos, CA (SLO County) - Circa 1913


Photo courtesy of the George Canet Collection.
http://www.sanluisobispo.com/2014/02/27/2947358/cayucos-wave-power-pioneer-achille.html#storylink=cpy

- Cast-iron gears soon smashed by incoming surf
- Tognini replaced the broken gears with an identical set made of steel
- The improved device lasted a bit longer, but it too soon failed.

# Achilles B. Tognini & his WEC
# Caycuos, CA (SLO County) - Circa 1913


Photo courtesy of the George Canet Collection.
http://www.sanluisobispo.com/2014/02/27/2947358/cayucos-wave-power-pioneer-achille.html#storylink=cpy

- Tognini had other ideas he put forward: a float which rose and fell with the tides, and a plan to pump seawater up to a reservoir on a cliff
- Finally he became discouraged by his lone attempts to electrify the town using the nearby Pacific ocean resource
- "Occasionally he found a prospective investor who seemed interested, but who wanted to see the device work before putting up any money" – Caycuos Constable Genardini, recalling Tognini in 1951



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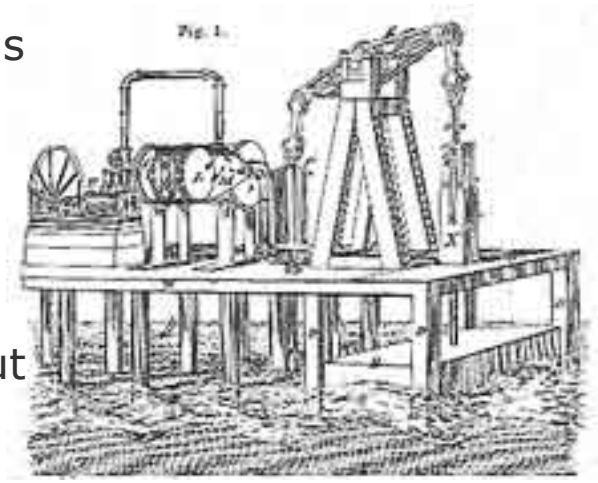
# But back before Achilles[2]…

- In the 1870's Californians began establishing themselves as inventors of WECs: 3 patents from San Franciscans
  - Charles Buckner, in 1873 (#138,474 pictured) & 1875
  - William Filmer, in 1878



- San Francisco Newsletter published an article in 1881 about a wave motor developed by John Swailes of California.
- In 1886 an inventor named E.F. Steen was granted permission to build a wave power machine on Adolph Sutro's (an engineer/business man) property in San Francisco.
  - In 1887, accidently dynamited when a schooner carrying 40 tons of dynamite on the way to Astoria, Oregon ran aground nearby. Exploded in a blast felt as far away as Sacramento.
  - His machine was totally gone by 1891 when a new wave motor was built in the same location. The changes he made to the rocky beach are the only remnants of San Francisco's first full scale wave motor project.

[2]Source: Info compiled by Christine Miller at the Western Neighborhoods Project: http://www.outsidelands.org/wave-tidal.php

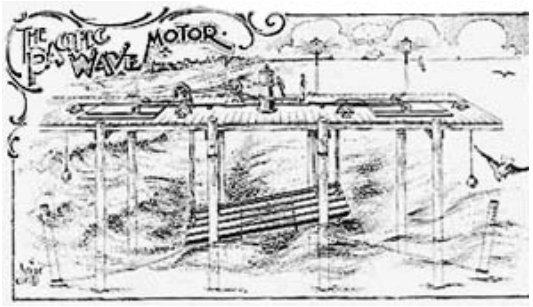
# But back before Achilles[2]…

- Projects enjoyed success, popularity & funding in the 1890s
- In 1891, a wave motor was constructed by Henry Holland and his financier J.A. Fischer on a large rock.
  - "Worked from the rise and fall of the waves moving a large buoy. From this movement a pump was activated which raised water through a pipe up the side of a cliff nearby. From the top of the cliff the water would be run through a series of water wheels that they hoped would generate electricity. The inventors intended to sell this electricity to manufacturers."
  - Abandoned in the early 1890's but it remained attached to its rock for another 59 years before it was finally blown away in a storm. First it was a subject of several postcards and even placed in tour guide books.
- In 1893, a small-scale project known as the Surf Power Pump had a successful test near the Cliff House.

[2]Source: Info compiled by Christine Miller at the Western Neighborhoods Project: http://www.outsidelands.org/wave-tidal.php

# But back before Achilles[2]…

- In SF, numerous experiments from small models to large construction projects.
  - In 1896, J.M. Dwyer had a working model at the foot of Powell St. and hopes for another at Baker Beach
  - In 1897, Henry Shomberg of Los Gatos had a working model of his machine on 20th St. and hopes for a larger version was planned for a spot near Santa Cruz.
  - Wave Power & Compressing Company, Hercules Wave Motor Company, and Pacific Wave Motor Company all were established in SF in the late 1890s.
- In 1895 the *San Francisco Examiner* newspaper held a contest seeking write-ins for the best ideas to improve the city and increasing the number of residents.
  - The winning entry included the idea to "offer fifty thousand dollars 'bonus' to any inventor of a practical mechanism capable of commercially utilizing ocean 'wave power'"



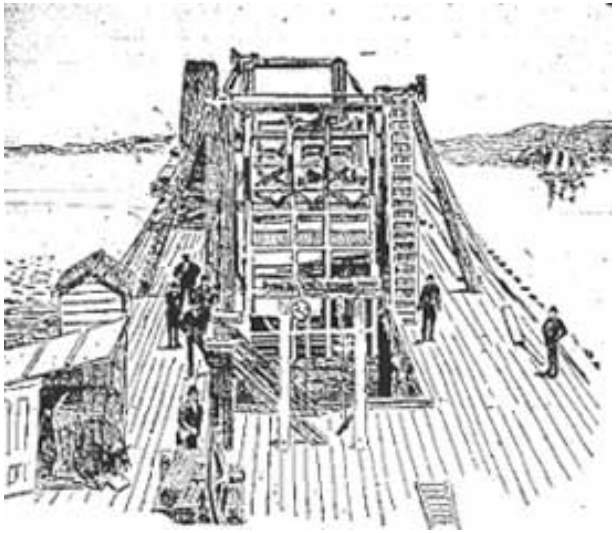


[2]Source: Info compiled by Christine Miller at the Western Neighborhoods Project: http://www.outsidelands.org/wave-tidal.php

# But back before Achilles[2]…

"In 1894, the *Los Angeles Times* ran an article about a wave motor in Long Beach that was being tested by Emil Gerlach of Santa Monica. The machine was, thus far, a success but it remained to be seen if it could pump water with sufficient force to pipe it up a hill to a basin where the water would then be run back down through electric dynamos. Mr. Gerlach wanted to build a larger version of his invention in Santa Monica but in July of 1895 it was announced that the small resort town of Capitola near Santa Cruz had been selected as the site of the Gerlach wave motor, the first large scale wave motor project for generating electricity for commercial purposes."

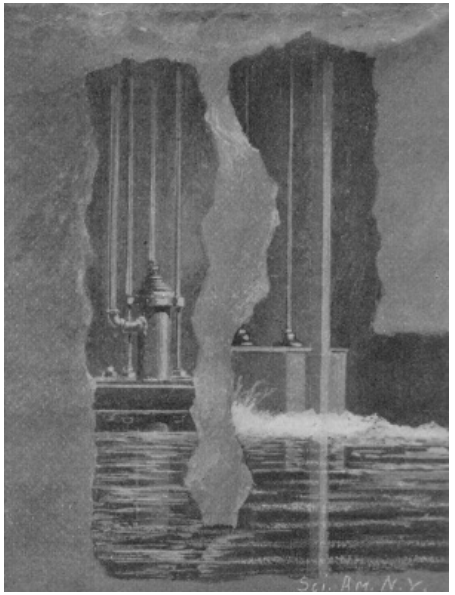
- In June 1896 the project's failure was announced in the *Sentinel:* "The Gerlach Wave Motor at Capitola does not allow itself to be disturbed by the waves. This we regret…"



[2]Source: Info compiled by Christine Miller at the Western Neighborhoods Project: http://www.outsidelands.org/wave-tidal.php

# But back before Achilles[3]…

- The Santa Cruz Wave Motor the first "success" in 1898
  - Invented by brothers William and John Armstrong.
  - First built a small model of their wave motor in the cliffs off Black Point and the city officials who came to see it were impressed. The Armstrongs then made an agreement with the City of Santa Cruz to install their device.
  - Not built to supply electricity, but to supply ocean water for sprinkling streets and keeping down dust. Provided water for 12 years.
  - Dismantled in 1910 when improved street paving made it unnecessary to water down the roads.
  - Written about in Scientific American in magazine on July 4, 1902.



[3]Source: Info compiled by John Haskey: http://haskey.com/johnh/wave_motor/index.html

# The Santa Cruz Wave Motor[3]

- From H.W.H. Penniman in Scientific American, July 4, 1902.
  - *Ever since man first sought to render useful the various forces of nature the wonderful power in the mighty waves of the ocean has excited his awe and exercised his ingenuity. Fortune after fortune has been expended to carry out the carefully calculated plans of the mechanical engineer or the fancy of the sanguine theorist. A few have worked: stockholders were elated, the inventor hilarious; but soon the sea arose in wrath, restraints of wood, cement or steel were but playthings before the storm, and by morning the contrivances of man lay a crumpled wreck upon the beach. The city of Santa Cruz, California, owns what is perhaps the only practical and efficient Wave motor in existence to-day, and it has stood the test of four years' operation.*

[3]Info compiled by John Haskey:
http://haskey.com/johnh/wave_motor/index.html

# The Santa Cruz Wave Motor[3]: 1898-1910

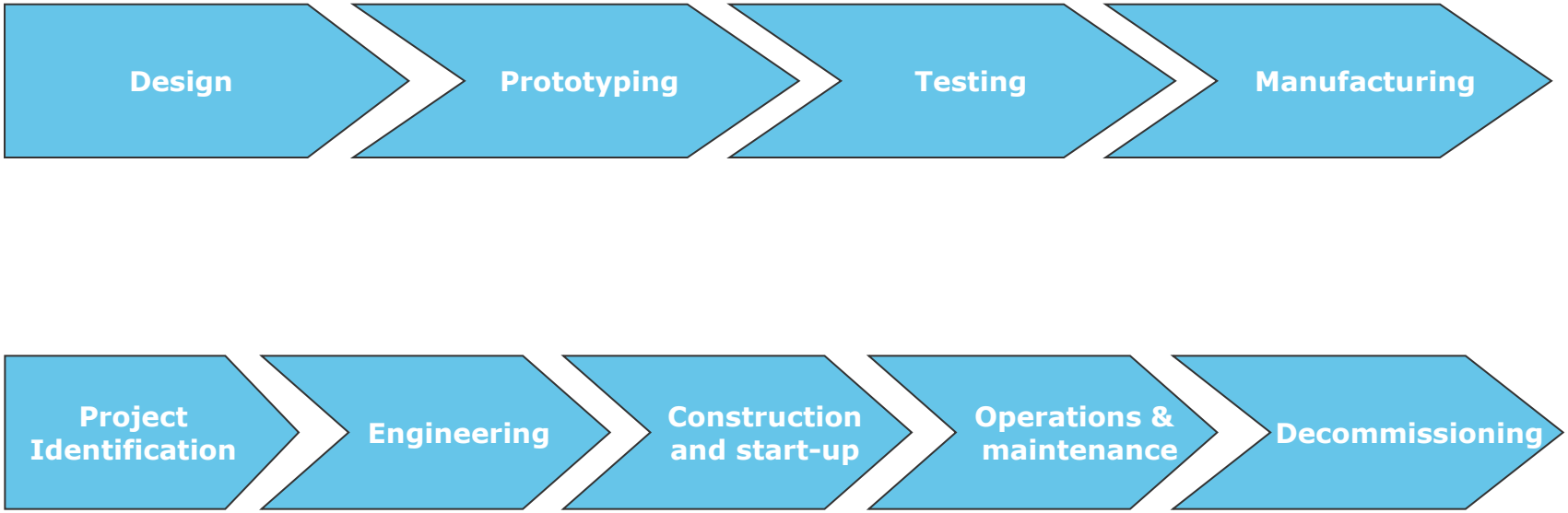

[3]Source: Photograph by Charles Weidner of SF, CA. Info compiled by John Haskey: http://haskey.com/johnh/wave_motor/index.html

## In Southern California[2]…

- From 1890-1910, the pattern was to announce a new patent, put a model on display, and let the public/investors examine it. Then small trials and, if successful, full scale plants would be built.
- Only a few wave motors made it to that final full-scale stage.
  - Starr Wave Motor of Redondo Beach began construction in 1907. Large project that hoped to supply power for six counties. The enormous machine collapsed in 1909 because of the flimsy construction of the pier on which it was attached.
  - The Wright Wave Motor of Manhattan Beach (1897) – now buried under sand at the foot of the present pier.
  - The Reynolds Wave Motor of Huntington Beach (1906)
  - The Edwards Wave Motor of Imperial Beach (1909) also made it far enough to have full scale models built.
- Wave motors of various sizes and stages of development were experimented with in Long Beach, Manhattan Beach, Redondo Beach, Newport Beach, Oceanside, Laguna Beach, Catalina Island, Santa Monica, Venice, Huntington Beach, San Diego, Imperial Beach, and Ocean Park.

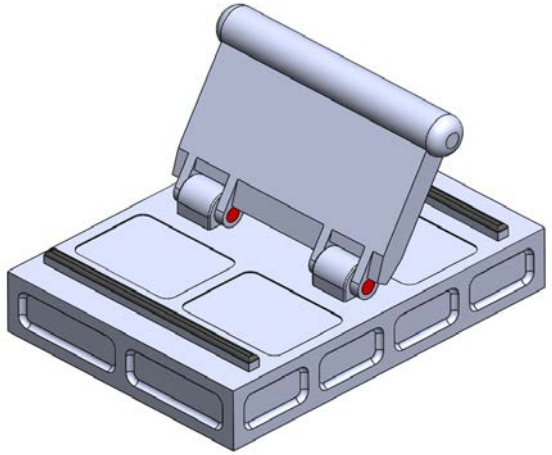
[2]Source: Info compiled by Christine Miller at the Western Neighborhoods Project: http://www.outsidelands.org/wave-tidal.php

# DNV GL supports stakeholders at all stages of a project

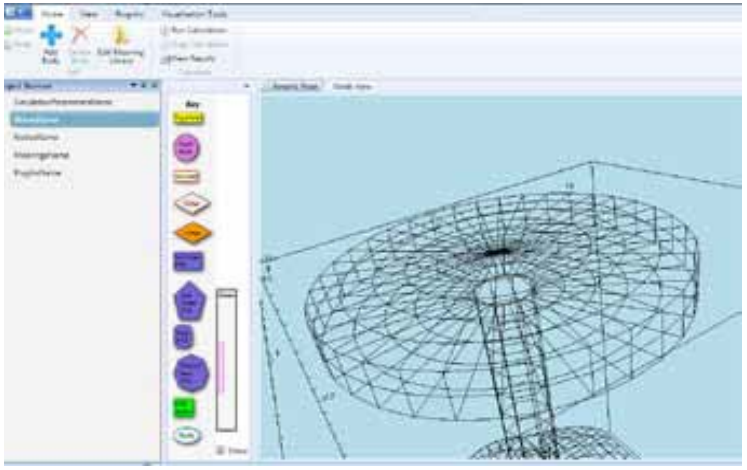


# Renewables Advisory - Scope of Services (Wave Energy)

- Technology evaluation studies
  - New concept review and optimisation
  - Technical due diligence review
- Wave Energy Converter concept design
- Wave Energy Converter preliminary design
  - Control system design
  - Loads calculations using GH WaveDyn software
  - Mechanical and structural design
  - Electrical design
- Wave Energy Converter detail design
- Test center development
- Prototype measurements and testing protocols
- Certification support
- Value engineering and optimization



Concept design and review



WaveDyn pre-processing

# Services, Software, Experience

| Device developers/ manufacturers | Project developers | Investors/lenders | Owners/operators | Government/NGOs |
|---|---|---|---|---|
| Device design | Project development support | Due diligence services | Owner's engineering support and FEED studies | Market intelligence |
| Control system development | Site feasibility studies | Marine warranty services | Due diligence | Policy and regulatory studies |
| Innovative technology evaluation | Environmental and permitting services | Strategic and policy advice | Asset management and optimisation services | Specialist strategic studies |
| Measurement services | Resource and energy analysis | Training courses | Energy assessment | |
| Device type approval and certification support | Site suitability studies | | Measurement services | |
| Marine warranty services | Device consulting | | Marine warranty services | |
| Strategic and policy advice | Due diligence | | Supply of SCADA systems | |
| Training courses | Interconnection | | Strategic and policy advice | |
| | Construction phase modelling and operations and maintenance modelling | | Training courses | |
| | Construction / installation services | | | |
| | Strategic and policy advice | | | |
| | Training courses | | | |



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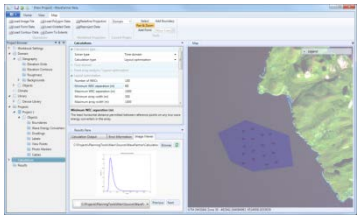
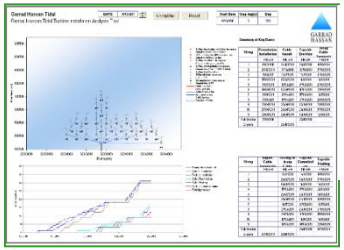
# Services, Software, Experience (Wave Energy)

**Device developers/ manufacturers** | **Project developers** | **Investors/lenders** | **Owners/operators** | **Government/NGOs**

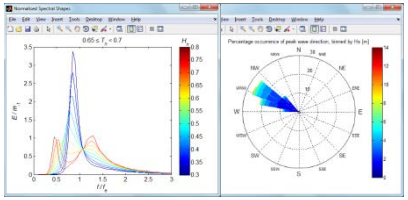

**WaveDyn**
WEC design & simulation software



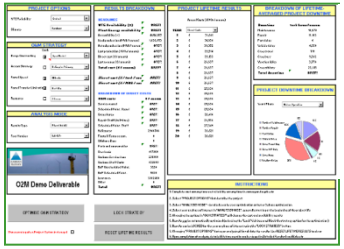
**WaveFarmer**
WEC array design software



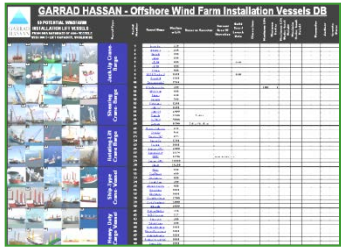
**O2C**
Optimization of Offshore Construction



**WAVE Climate Module**
Site data analysis and sea state simulation




**O2M**
Optimization of Offshore Maintenance




**Market Analysis Database**
Analysis of tidal device developers, global resource and projects



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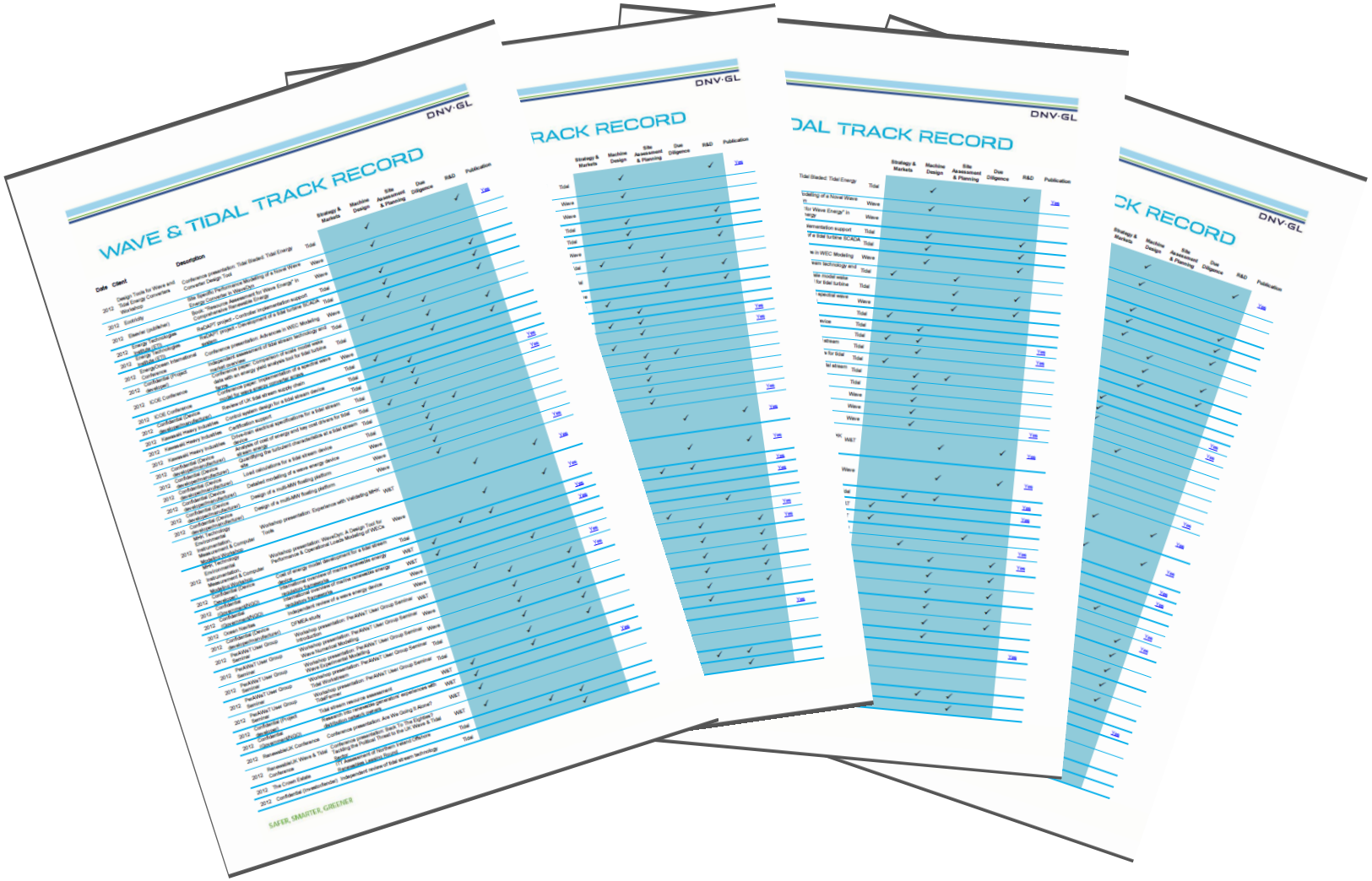
# Services, Software, Experience



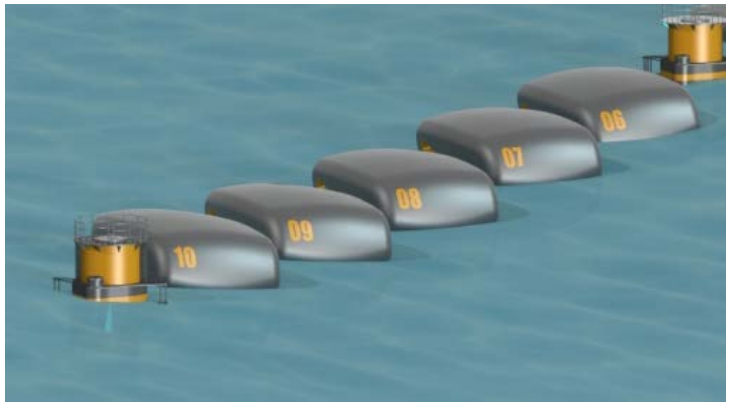

**Over 170+ jobs within marine energy (legacy GL Garrad Hassan)**

# Examples of Wave & Tidal Clients (Non-confidential)

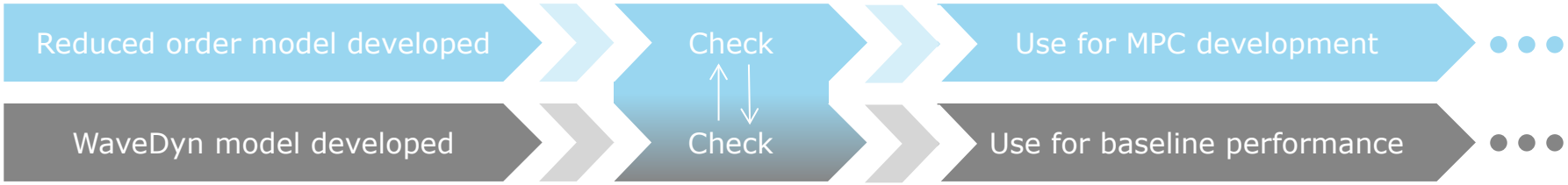
# One of our California Clients: Dehlsen Associates - Centipod

- First steps toward Advanced Control development:
  - Build reduced order model of Centipod for MPC development
  - Build fully-coupled model of Centipod in WaveDyn software to benchmark for comparison and verification of reduced order model.

- These models will be built in parallel by project partners at OSU and DNV GL




**Depiction of Centipod device**

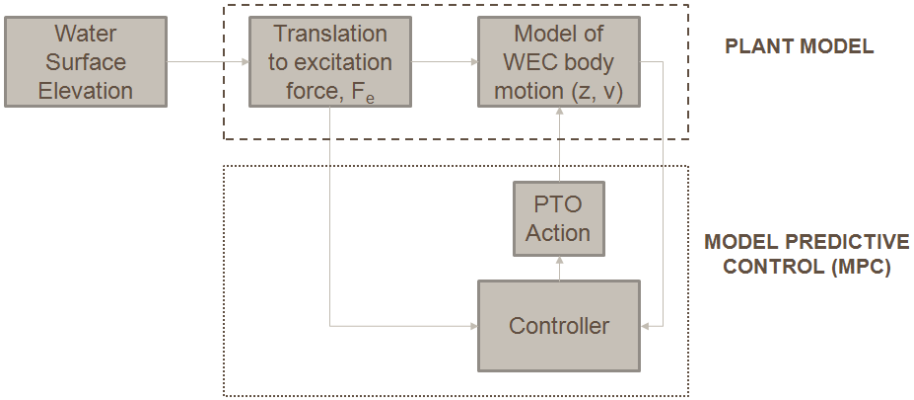



- After MPC is developed, controller DLL will be integrated into WaveDyn model
- WaveDyn baseline and MPC performance will be compared

# Centipod - Current Work - Status

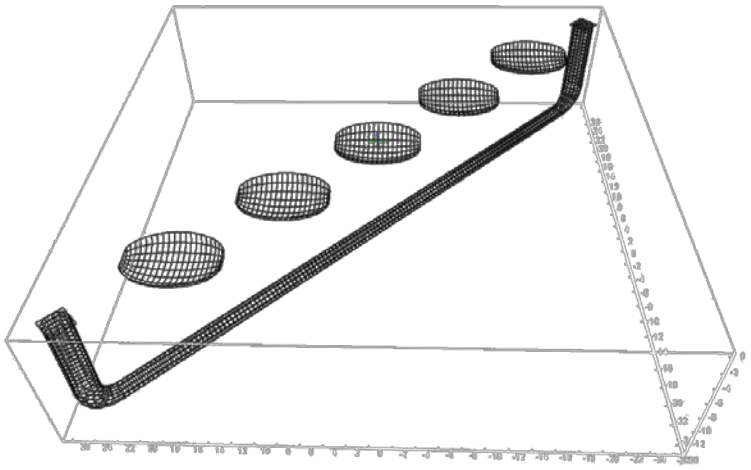
## Reduced order model

- Reduced order model framework completed (Plant model below)
- Awaiting Centipod hydrodynamic data.




## WaveDyn Model

- WaveDyn model is well underway
- Hydrodynamic data generated
- Structural model nearly complete



Meshed Centipod structure

# California has the resource

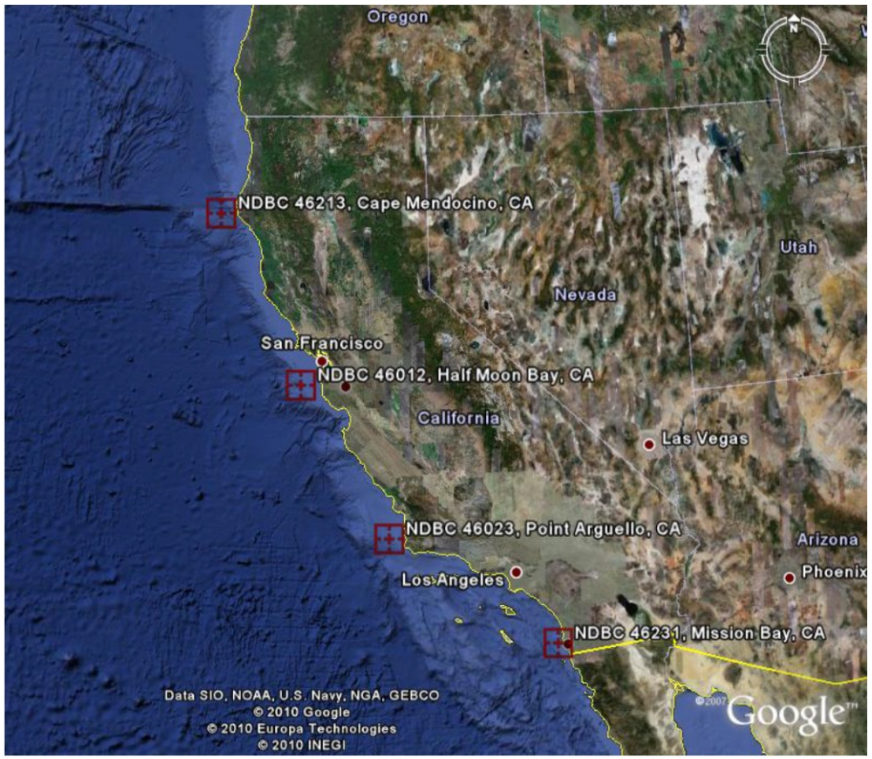
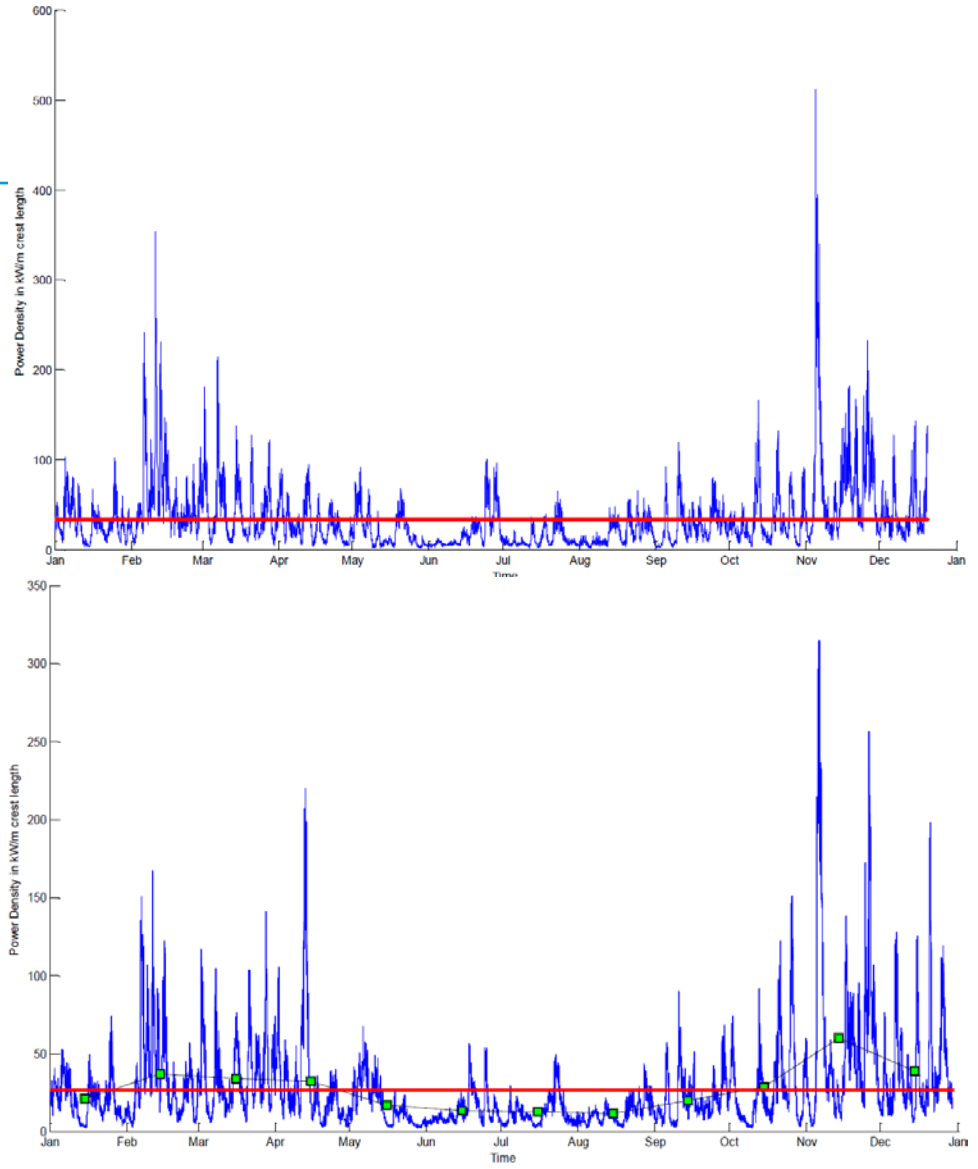



Table 4: Wave Climate Averages 2009.

| | Hs (m) | Tp (s) | Power Density (kW/m) |
|---|---|---|---|
| Cape Mendocino | 2.40 | 11.39 | 33.43 |
| Half Moon Bay | 2.20 | 11.64 | 28.80 |
| Point Arguello | 2.11 | 11.97 | 26.87 |
| Mission Bay | 1.09 | 13.31 | 7.34 |




Power density at Cape Mendocino (top) and Point Aguello Buoys in 2009



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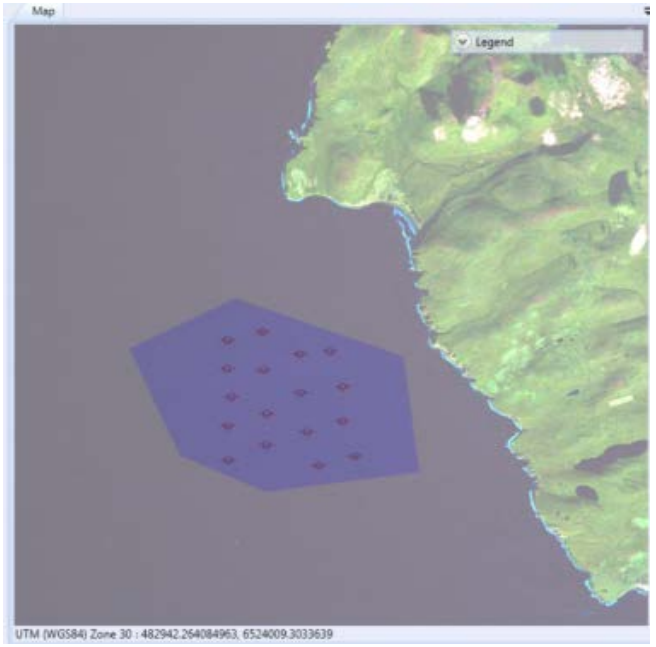
# Services for Wave Project Developers:

- Site screening and feasibility studies
- Resource analysis
- Energy yield prediction
- Project specific WEC design analysis
- Front End Engineering and Design
- Offshore operations development and optimisation for maintenance and construction
- Offshore project management services
- Cost of energy modelling



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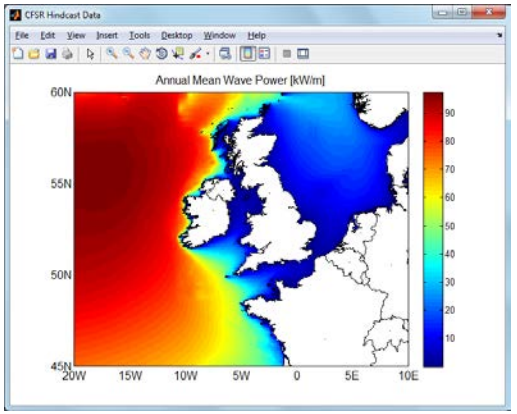
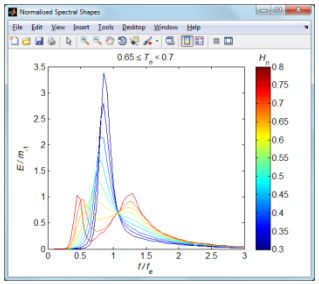
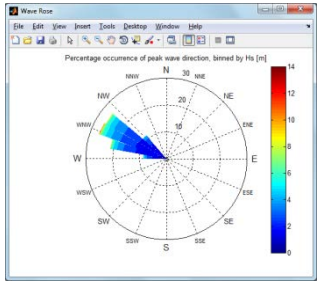
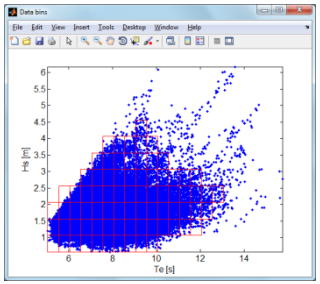
## Site data analysis and sea state simulation

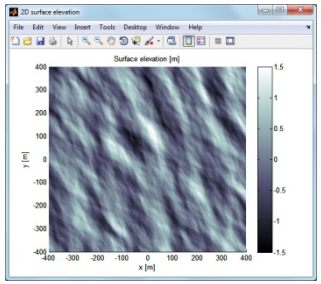
- Process and quality check site measurements
- Data visualisation and analysis
- Form a summary of spectral wave climate
- Analyse variability in spectral shapes
- Simulate sea states for use in WaveDyn and WaveFarmer
- Replicate experimental data in simulations

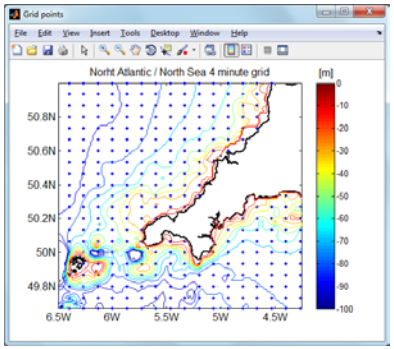


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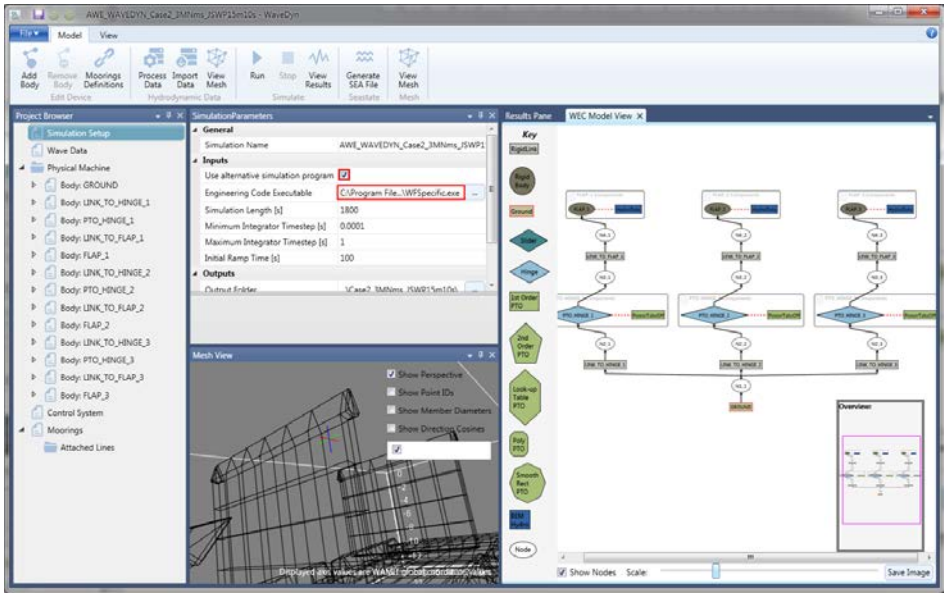
# WaveDyn

- First design tool for wave energy converters
- Multi-body formulation, suited for FDCs and beyond, with fully coupled approach
- Dedicated PTO and moorings modules
- Initial efforts started more than 5 years ago
- Multiple verification and validation exercises (commercial work and PerAWaT)
- **Official Launch: Oct 18th @ ICOE 2012**



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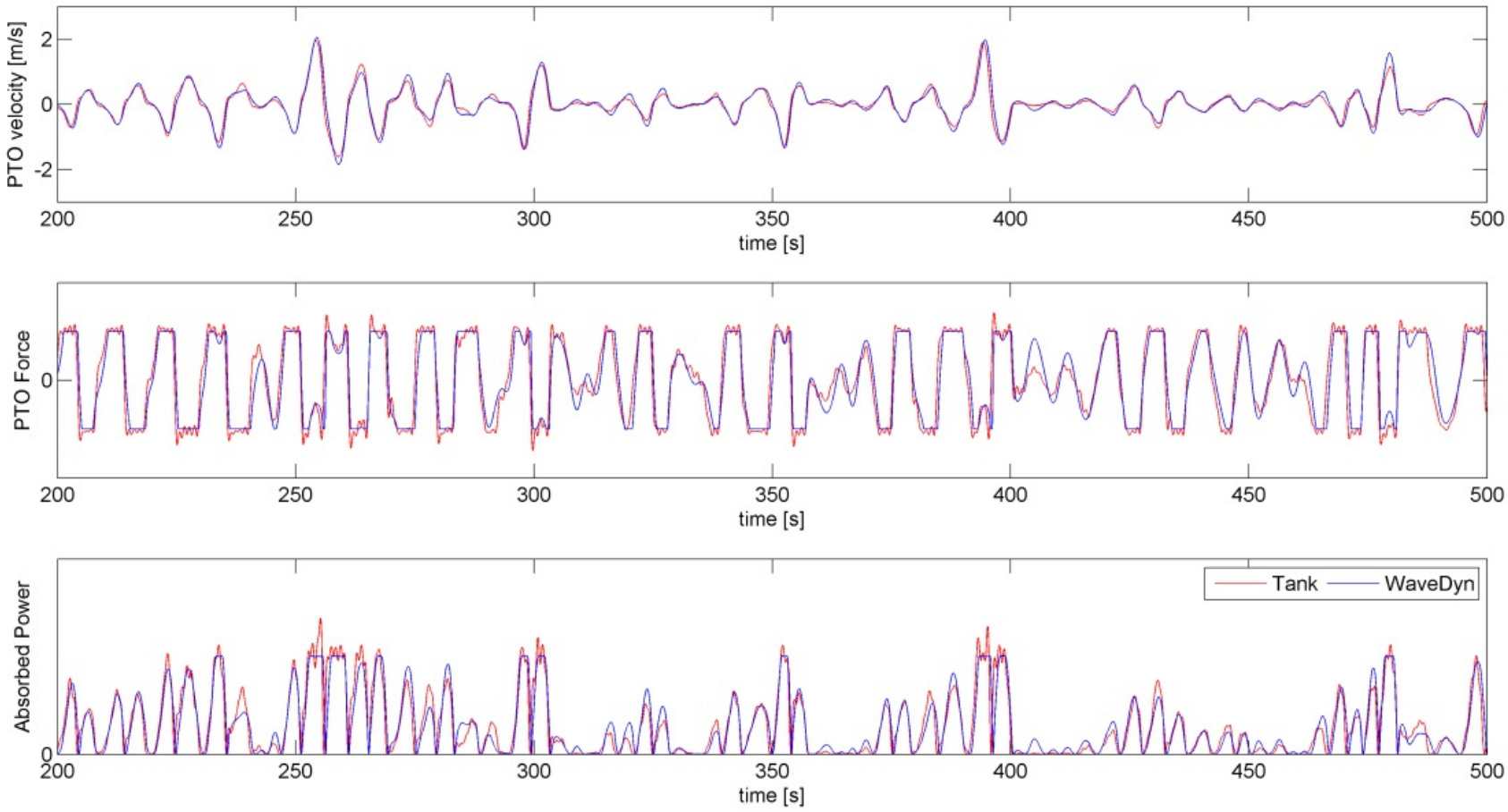
# WaveDyn



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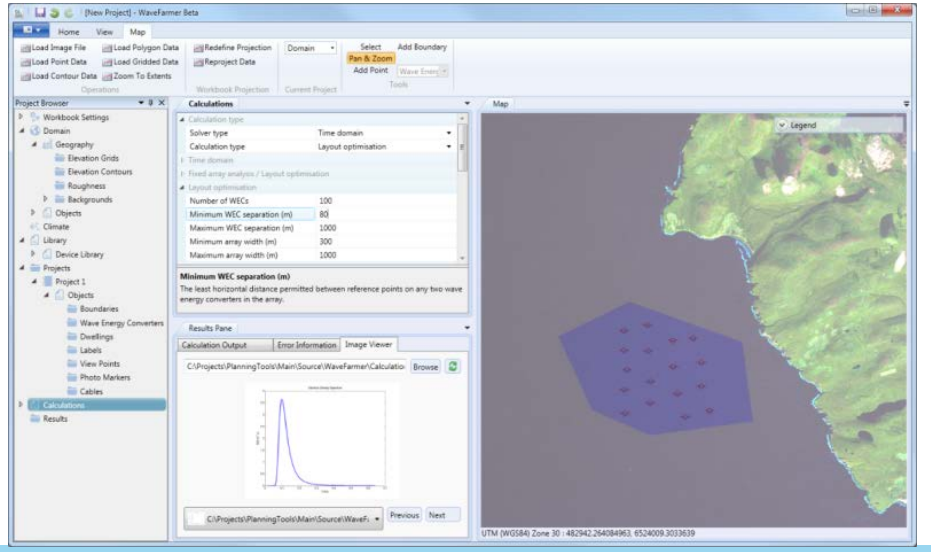
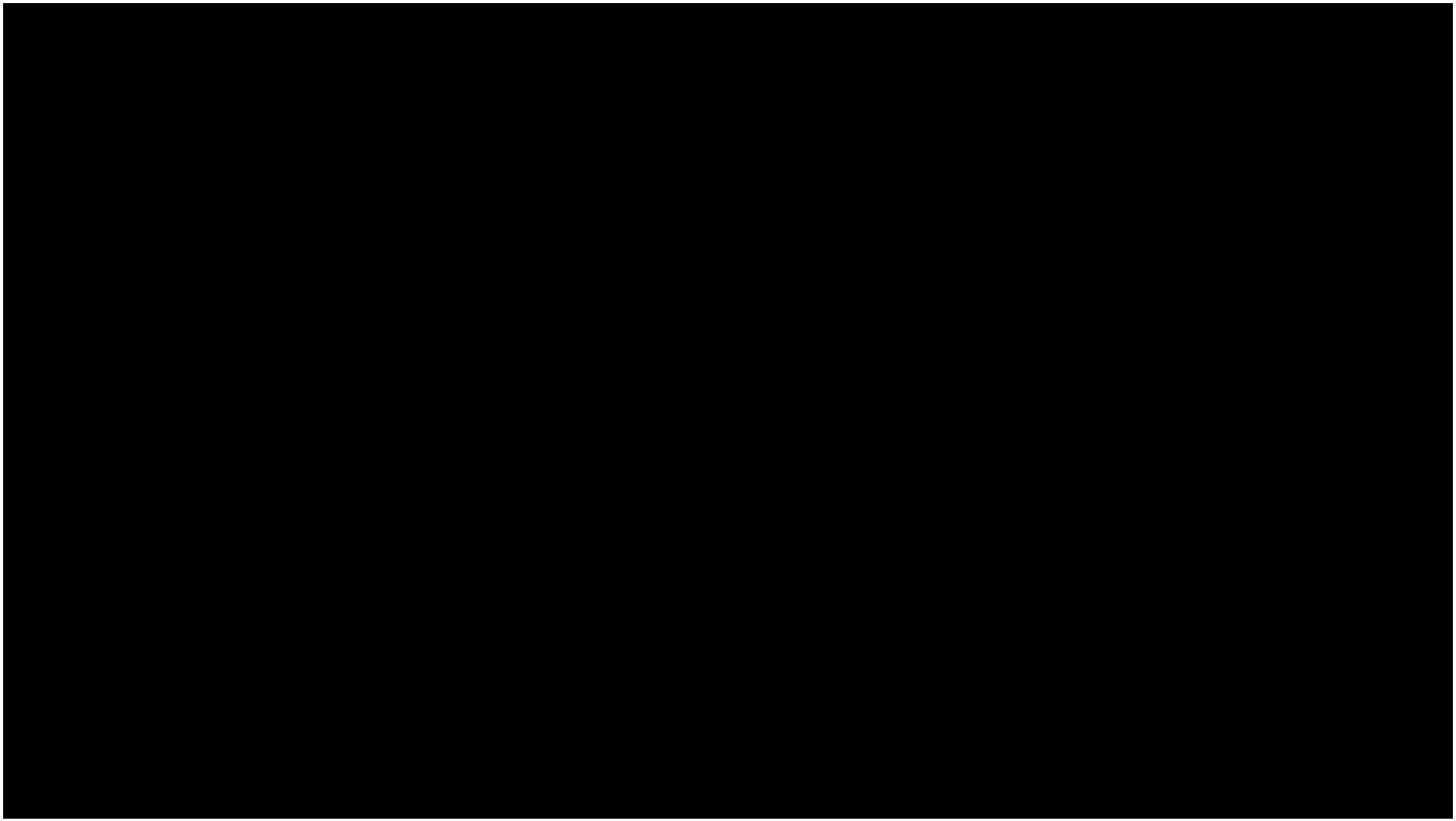
# Services for Wave Project Developers: WaveFarmer

- Aids **wave farm** planning
- Calculates **annual energy yield** incorporating interference effects and **optimises** locations of WECs in farm
- Incorporates realistic **constraints** on farm design and allows loading of relevant site data (wave climate, bathymetry etc.)
- Incorporates **three alternative numerical models**

# WaveFarmer





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# Thank you for your attention!

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