Development of Marine Energy in the Global Context

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UNICPOLOS, New York
29 May – 1 June 2012

OceanEnergyResources

Ocean Energy

- Tidal Rise & Fall
- Tidal/ocean Currents
- Waves
- Salinity Gradient
- Thermal Gradient





- OES covers all forms of ocean energy, including submarine geothermal, but NOT offshore wind - seawater must be the motive power
- Products can include: electricity, heat, cooling, water (drinking and pressurized), biofuels, chemicals
- Ocean energy is a nascent but truly international industry

Technologies with a long history...

1885: First motor car 1908: Firstcarinseries

1888, 12 kW 1941, 1.25 MW 2007, 5 MW

1985, 100 W 1985, 500 kW 1995 2004 2008, 750 kW array

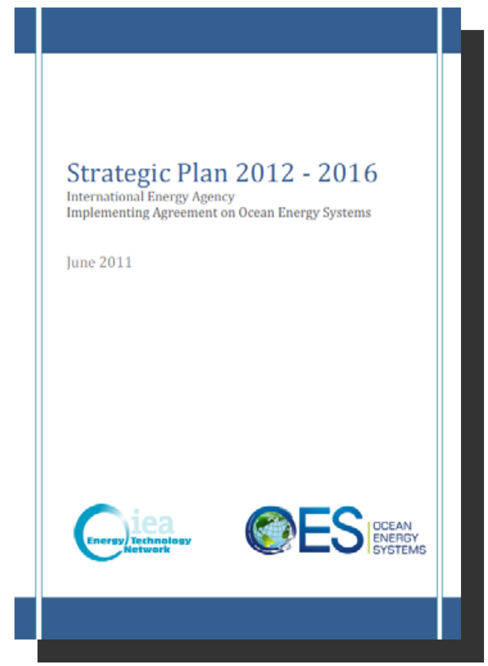
Whois OES?

The Ocean Energy Systems Implementing Agreement (OES):

- Intergovernmental collaboration between countries
- Operating under a framework established by the International Energy Agency (IEA) in Paris
- OES was founded by three countries in 2001 and has grown to its present 19 country governments
- 3rd 5-year mandate approved by IEA on 28 February 2012

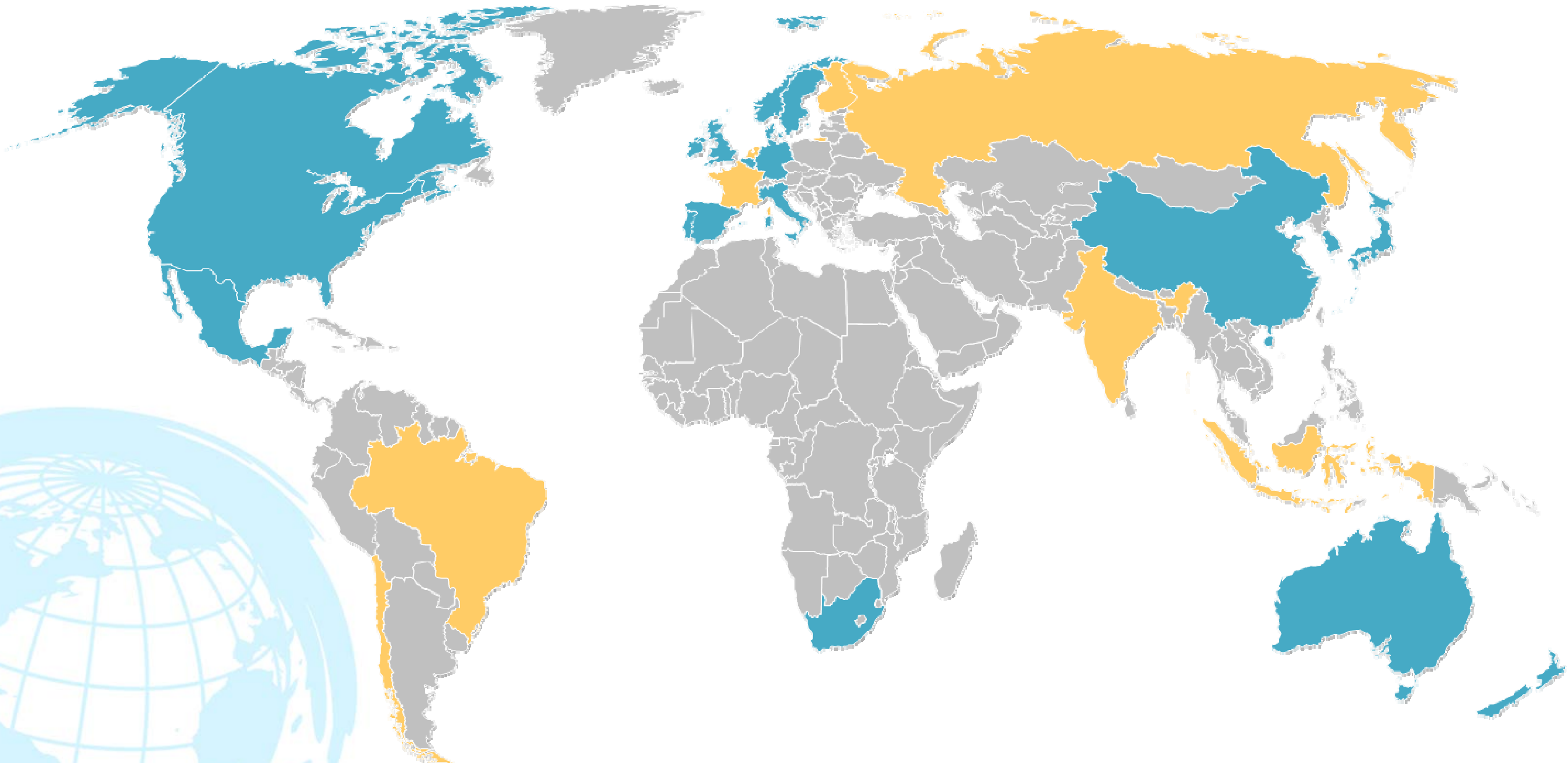
2012 – 2016 VISION

As the **Authoritative International Voice on Ocean Energy** we collaborate internationally to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable way


Strategic Plan 2012 - 2016
International Energy Agency
Implementing Agreement on Ocean Energy Systems

June 2011

MembersandObservers



Member countries

Countries invited to join

InternationalVision for OceanEnergy

OCEAN ENERGY SYSTEMS

An International Vision for Ocean Energy

SOCIETAL GOAL

By 2030 ocean energy will have created 160,000 direct jobs and saved 5.2 billion tonnes of CO_2 emissions.

- **20-page full-colour brochure**
- **Facts and figures as well as scenarios to 2050**
- **All forms of ocean energy in proportion to their present status**
- **Updated costs figures and 'iconic figures'**
- **People, water and energy nexus**

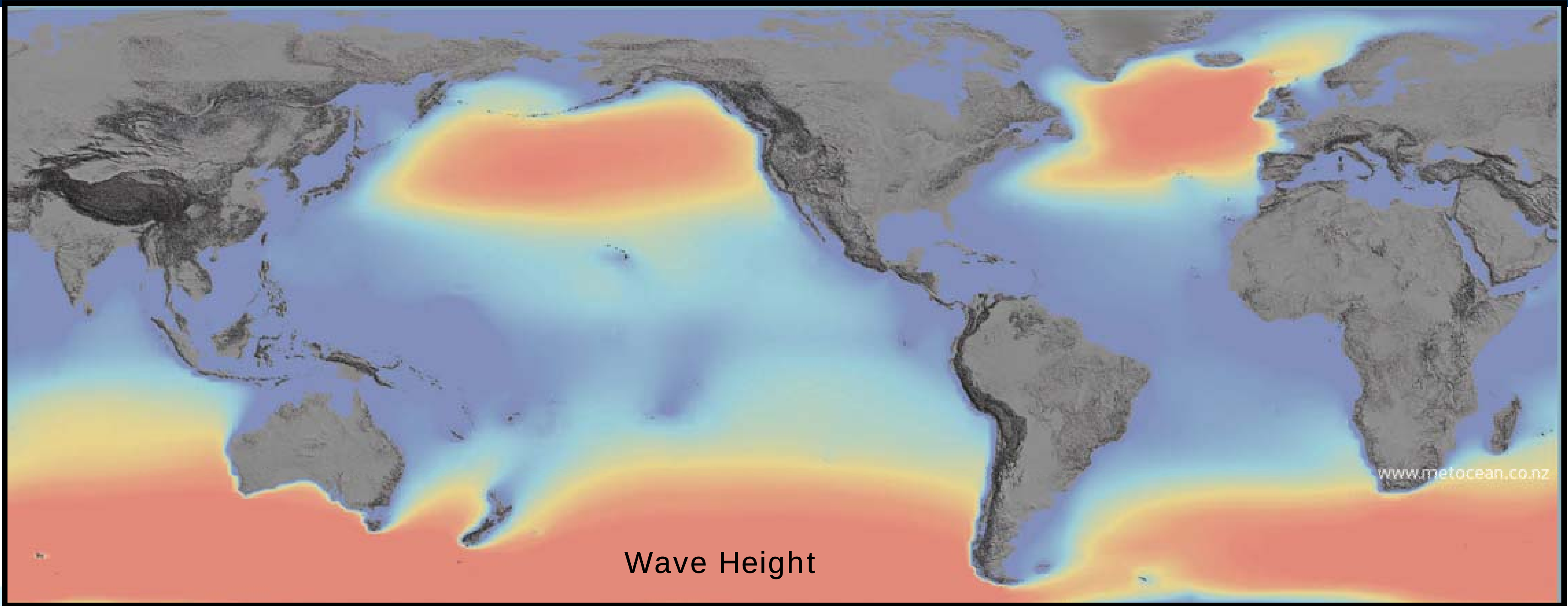
Phase II (2012): Market Development

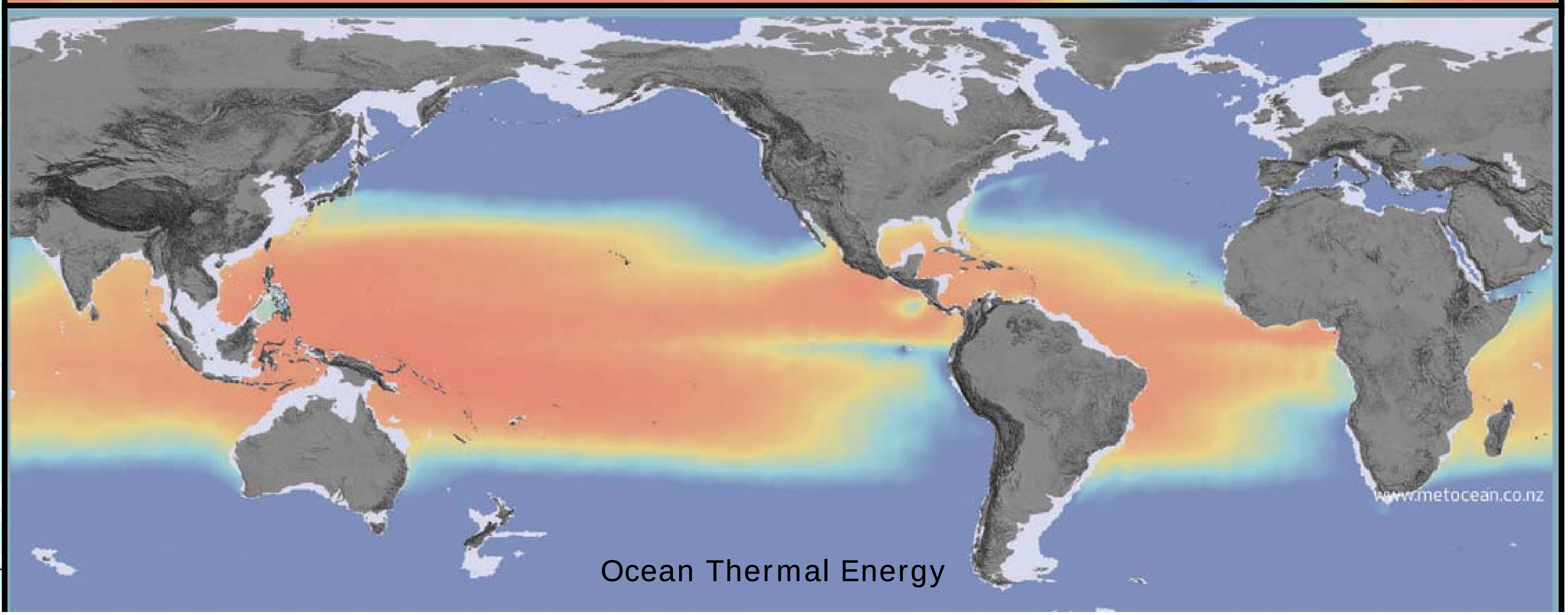
- **Simple, contestable scenarios for market growth**
- **MARKAL modelling with IEA Modelling Group in Paris**
- **Forecast of 337 GW of wave, tidal current & rise/fall by 2050**

Marine Energy – Key Messages

- Marine Energy Resources
  - Widespread and close to 1/3 of world's population
  - Wave and tidal energy at mid-high latitudes
  - OTEC at tropical latitudes, so complementary with wave and tidal
  - High energy density, so space requirements will be limited
- Technologies
  - Technologies are still immature and diverging
  - Tidal: some convergence towards horizontal axis turbines
  - Unit costs of generated electricity (in $/kW and $/kWh) will be deciding factors
- Environmental Dividend
  - Very little environmental impact, particularly for wave and tidal
  - Marine energy resources have no other uses
  - Competition for space for other uses should be manageable
- Markets for Marine Energy
  - Utility-scale electricity generation
  - Integration with desalination/production of drinking water
  - Remote/island/indigenous community supply

Marine Energy – Global Distribution





Wave Power Technologies

- Wave Energy
  - Potential energy and kinetic energy
  - Resolution into heave, surge and pitch
  - Rotational particle motion decays with depth
- Convergence of technologies?
  - There are at least 5 distinct ways to convert wave energy
  - Technologies are currently diverging
  - Convergence will only result from extended sea-time
  - Unit cost of generated electricity (in $/kW and $/kWh) will be deciding factors
- Scale and Arrays
  - Wave devices cannot go on increasing in size as wind turbines have done
  - Wave devices will be deployed in multi-unit arrays
- Tuning
  - Wave devices must tune to incident waves
  - May tune to individual forecast waves

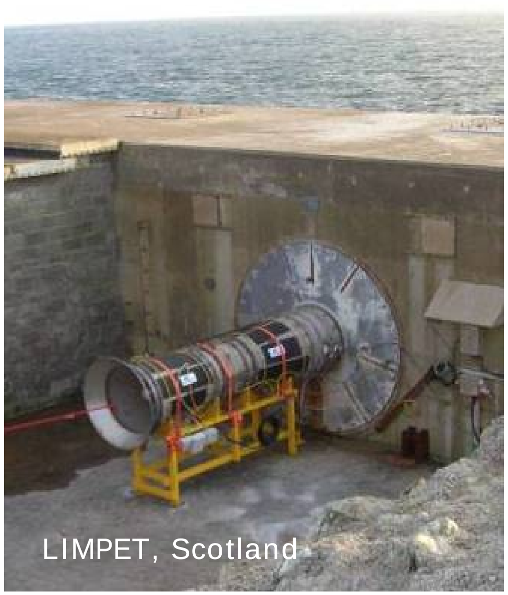
Wave Power Technologies

1. OWC Devices (I): Shore-attached

- Fixed onshore structures
  1. Air-filled chamber with open access to rising and falling waves
  2. Air compression and expansion drive turbine
  3. Turbine/generator resist air movement
  4. Electricity generated by turbine/generator


PICO Plant, Azores, Portugal

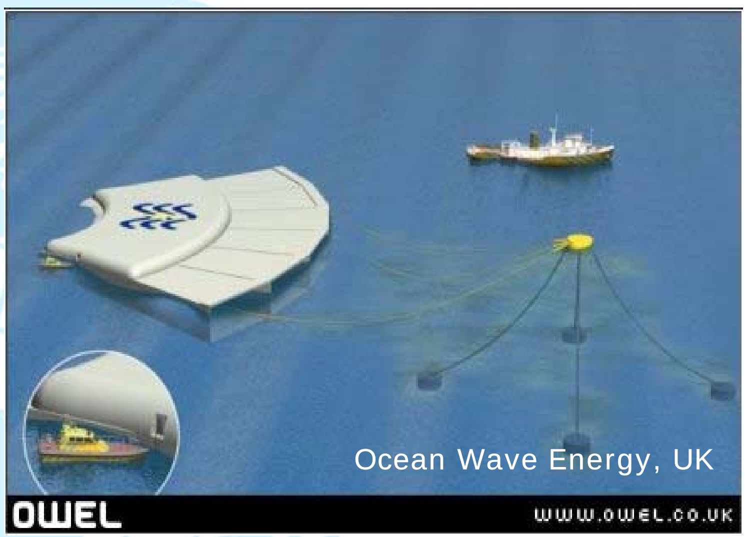

Wavegen OWC: LIMPET


LIMPET, Scotland

Wave Power Converters

1. OWC Devices (II): Floating


OE Buoy, Ireland



Ocean Wave Energy, UK


OceanLinx, Australia

Wave Power Converters

1. OWC Devices (III): Breakwater Designs


Nereida project, Mutriku, Spain


Foz de Douro, Porto, Portugal

1. Breakwaters provides stable platform
2. Can be retro-fitted or installed as part of new breakwater
3. Costs moderated by dual use
4. Developers may be port authorities, rather than electricity utilities

Wave Power Converters

2. Surge Devices


Aquamarine Oyster, Scotland


WaveRoller, Finland


BioWave, Australia

1. Base rests on seabed, flap is buoyant
2. Wave surge causes flap to oscillate
3. Hydraulic pistons resist flapping motion
4. Pressurized seawater drives generator on beach

Wave Power Converters

3. Point-absorber Devices (I)

Wavebob, Galway, Ireland

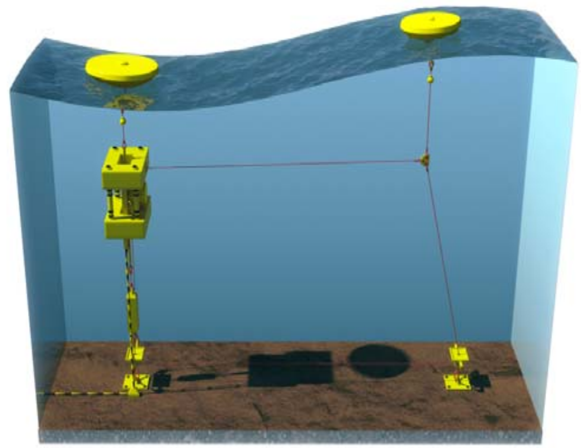

WET-NZ, New Zealand

1. Self-reacting device; spar and float configuration
2. Spar mass ignores waves, float reacts to passing waves, causing differential motion between spar and float
3. Differential motion is resisted by hydraulic pistons (or direct drive)
4. Hydraulic pressure drives turbines / direct drive generates electricity

Wave Power Converters

3. Point-absorber Devices (II)

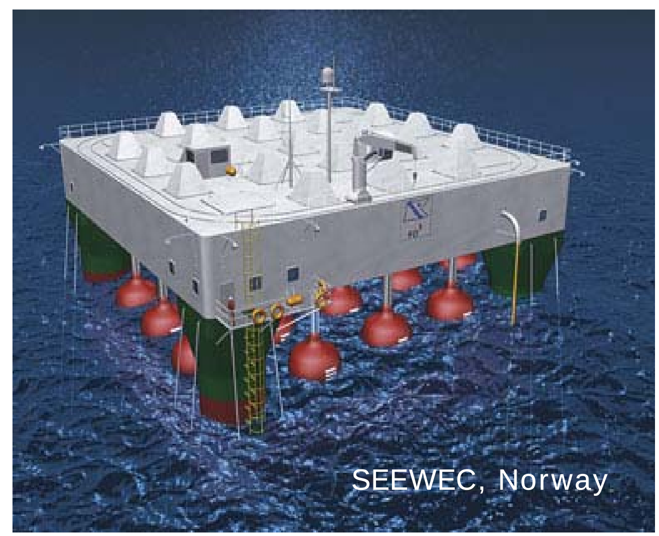
Euro Wave Energy, Norway



Waveberg, USA

OPT PowerBuoy, USA

WaveStar, Denmark



SEEWEC, Norway

Wave Power Converters

4. Attenuators

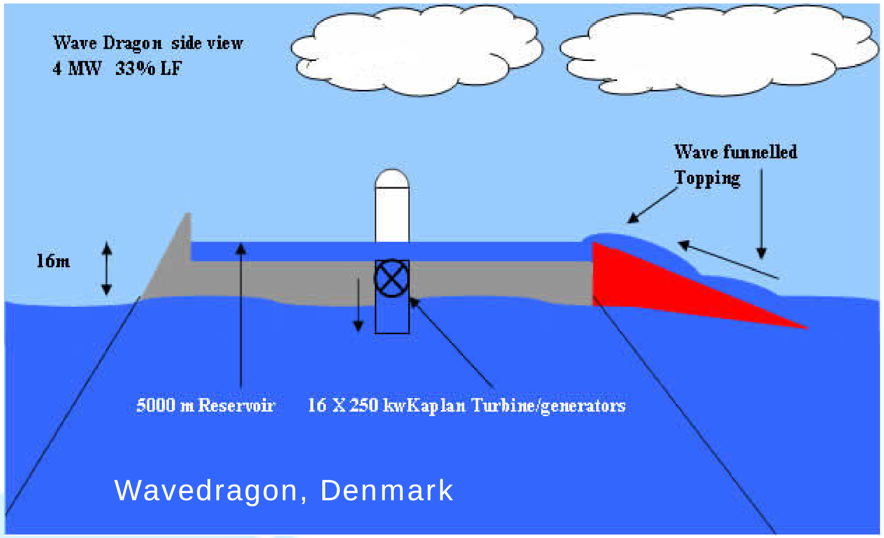
Tank testing model

Prototype testing off Scotland

Pelamis P-2 device

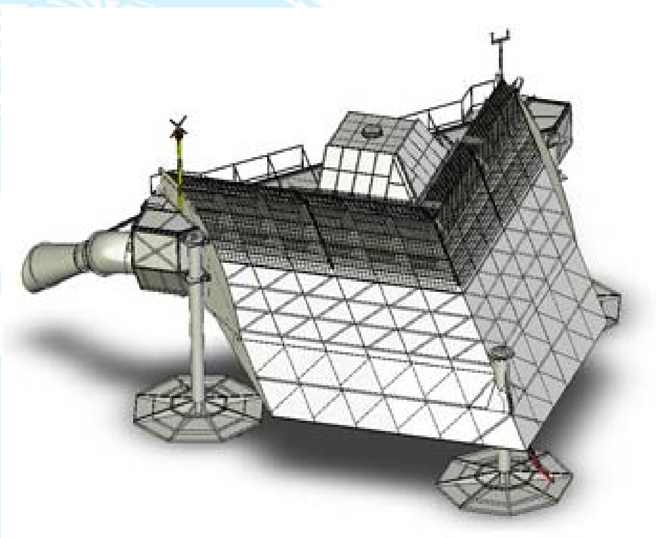
GSIC Snake Device, China

5. Overtopping Devices - Floating (I)



Wavedragon, Denmark


Wavedragon prototype: terminator

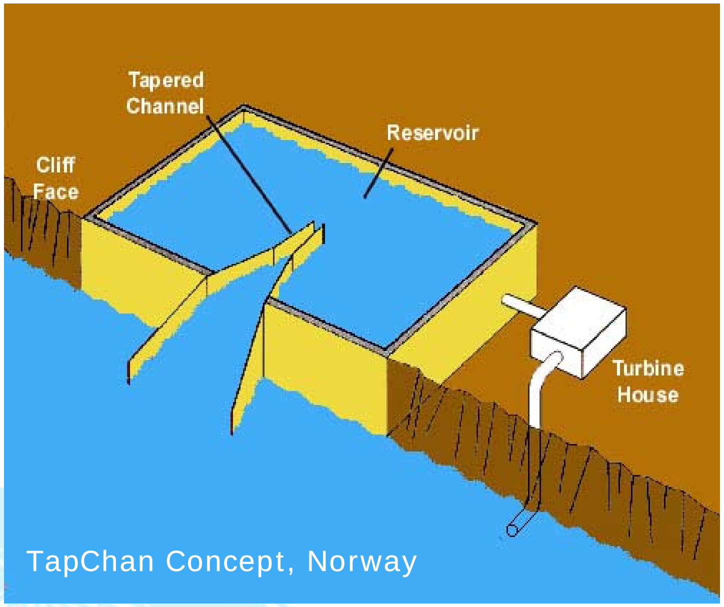

Waveplane, Denmark

Also known as 'terminator' devices

1. Elevated reservoir traps rising waves
2. Reservoir has vertical drains with low-head hydro turbines
3. Turbines resist seawater drainage from reservoir
4. Seawater drainage rotates generator to produce electricity

Wave Power Converters

5. Overtopping Devices (II): Breakwaters



TapChan Concept, Norway

SSG @ Kvitsoy Island, Norway

Also known as 'terminator' devices

1. TapChan was early development in Norway
2. SSG utilizes multiple stacked chambers

Slot-cone generator, Wave Energy AS

Current Power Technologies

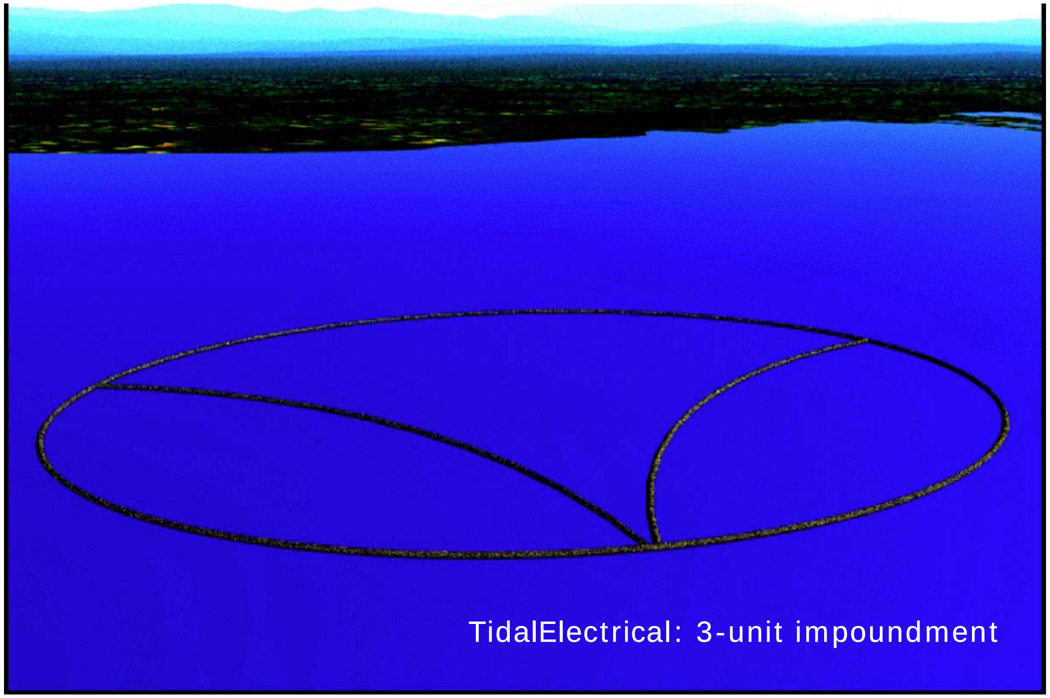
- Tidal Rise and Fall
  - Potential energy, arising from long period waves (tides)
  - Utilize conventional hydro dam technologies (+ tidal fences)
- Tidal Current Energy
  - Bi-directional kinetic energy, arising from water body movement caused by tides (1-8 m/sec); single extraction method but multiple technologies
  - High level of R & D activity and deployments
- Ocean Current Energy
  - Uni-directional kinetic energy, arising from tidal rise and fall
  - Slow-moving currents (1 m/sec) may require different technologies
- Convergence of Tidal Current Technologies?
  - There are at least 5 distinct ways to convert tidal energy
  - Tidal current technologies are currently converging on HAT models
- Scale and Arrays
  - Tidal devices will be deployed in multi-unit arrays (units >1 MW already)

Current Power Technologies

1. Barrages and Impoundments


Sihwa Barrage, Korea

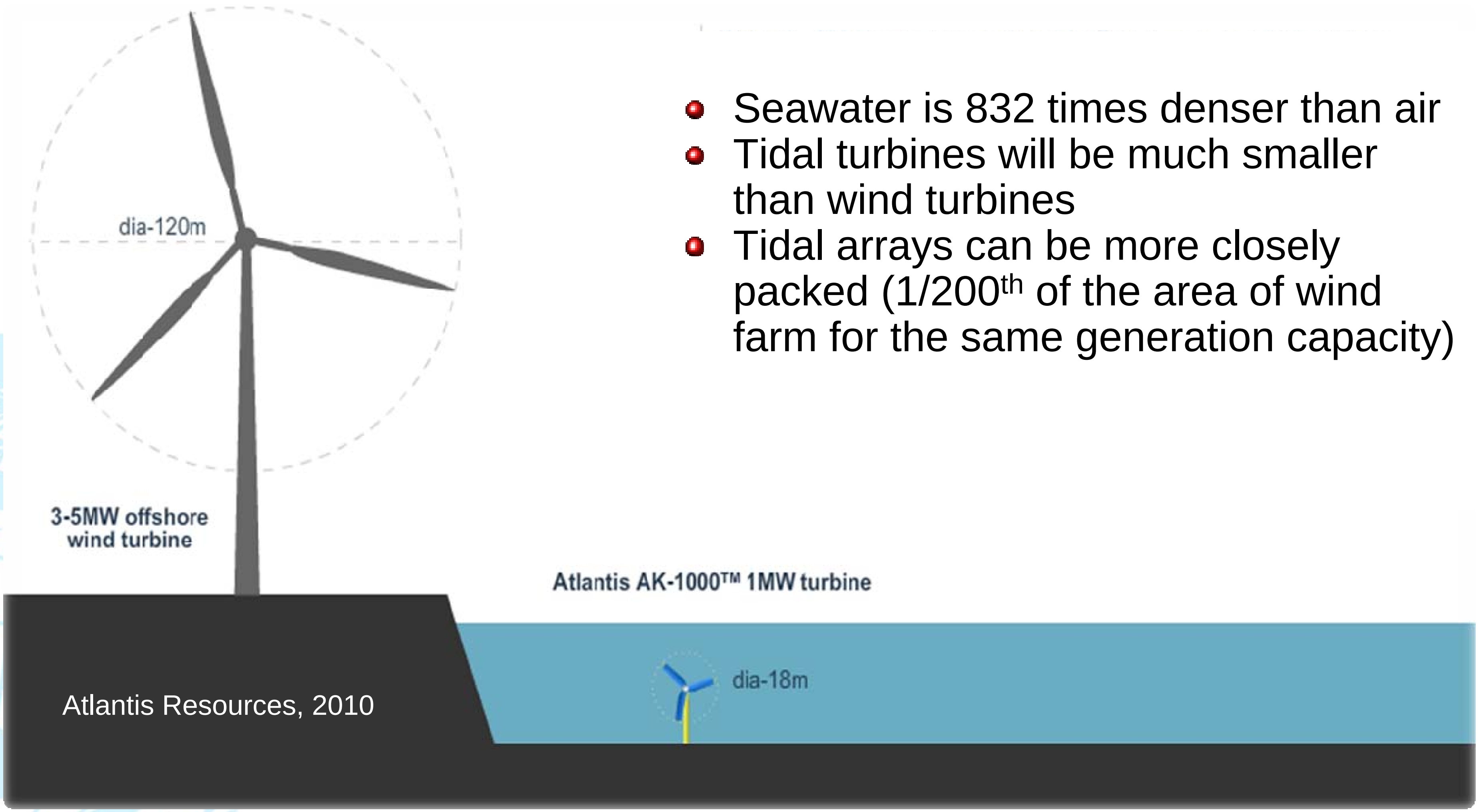

La Rance, France


TidalElectrical: 3-unit impoundment

Tidal Current Devices

2. Horizontal Axis Devices

- Seawater is 832 times denser than air
- Tidal turbines will be much smaller than wind turbines
- Tidal arrays can be more closely packed (1/200th of the area of wind farm for the same generation capacity)



Atlantis Resources, 2010

Tidal Currents

2. Horizontal Axis Devices (II)


Atlantis Resources,Singapore


Marine Current Turbines, UK


Statkraft, Norway

3. Open-ring & Vertical Axis Designs

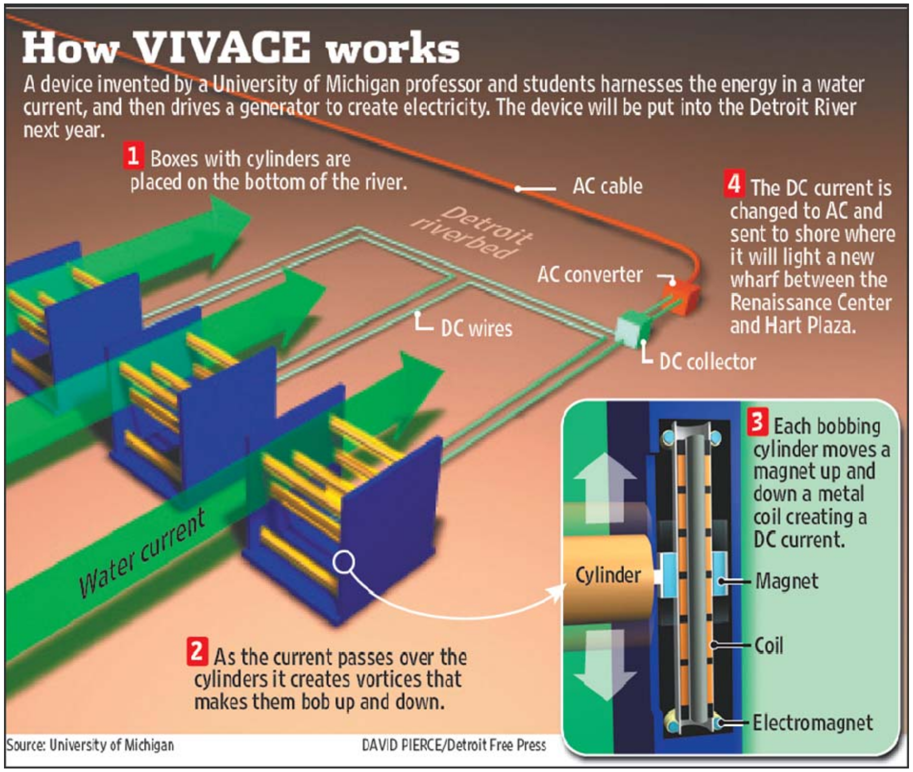
OpenHydro: open-ring turbine @ EMEC, May 2007

Enermar’s Kobold turbine, Straits of Messina, 2007

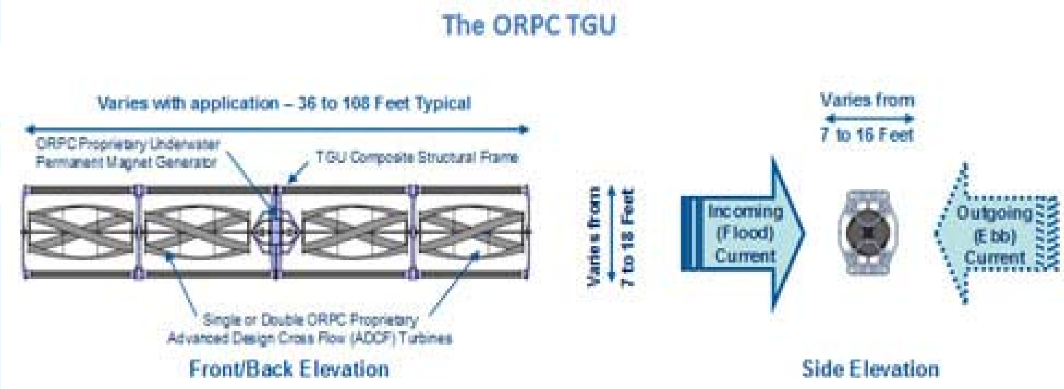
Tidal Currents

4. Cross-flow Devices

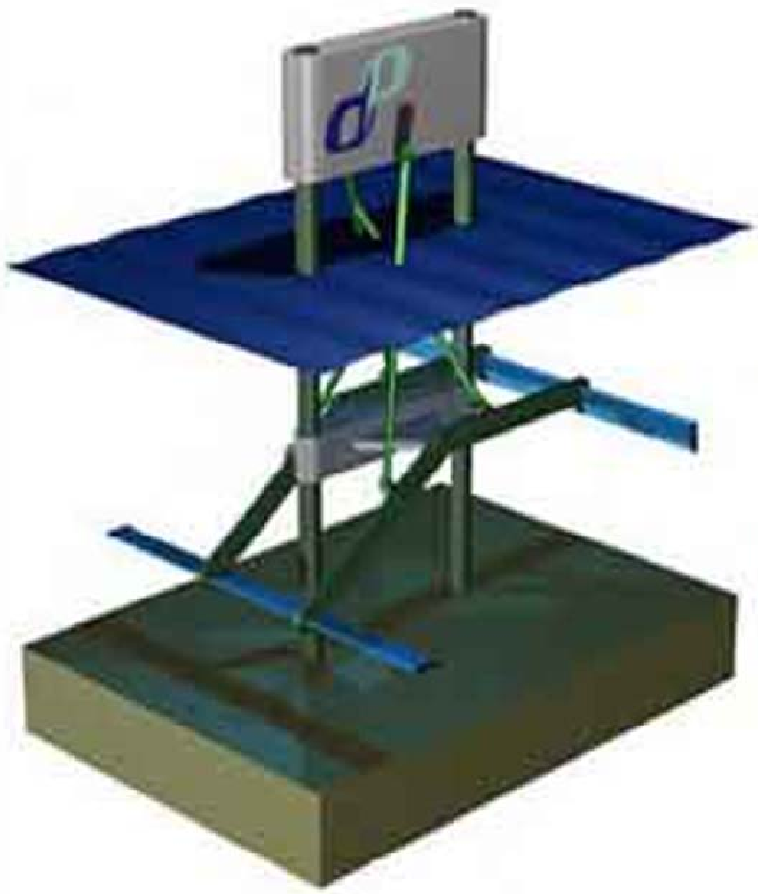
ORPC, USA – cross-flow turbine



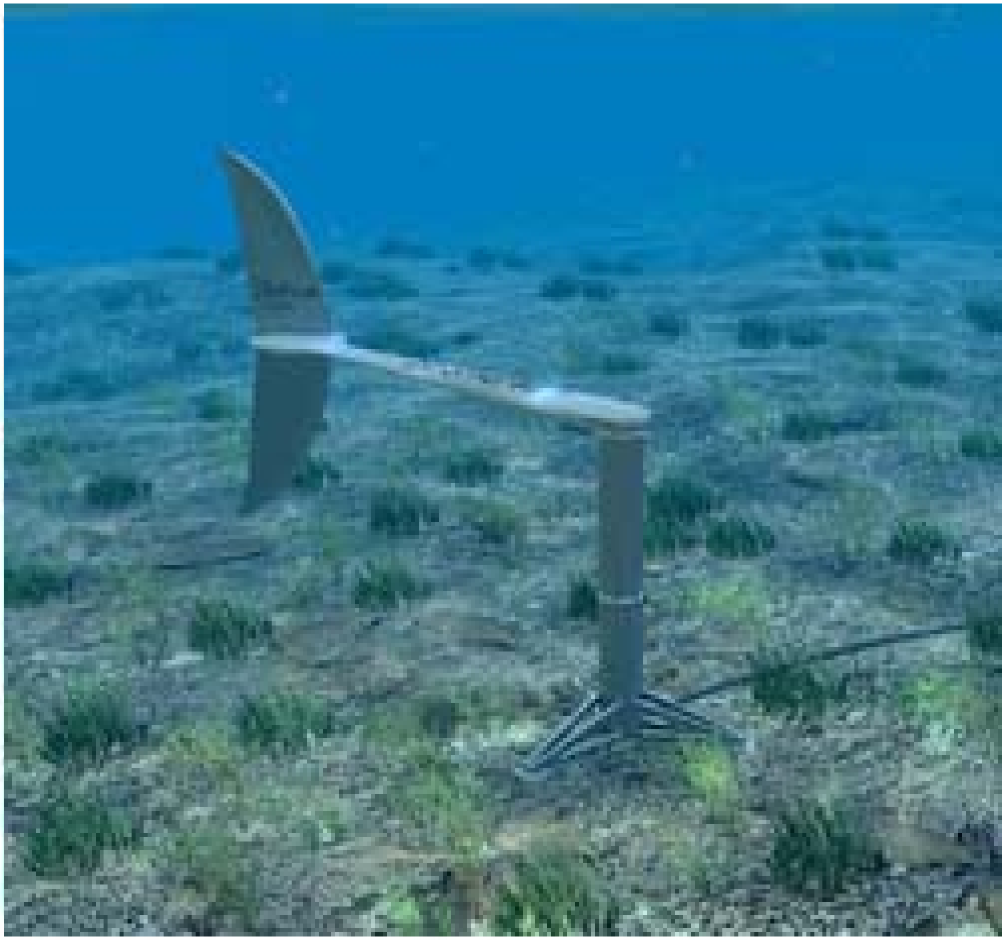
VIVACE, USA – oscillating cylinder device



5. Reciprocating Devices



Pulse Tidal, UK – reciprocatinghydrofoils



BioStream, Australia – bio-mimetic hydrofoil

Other OE Technologies

- Ocean Thermal Energy Conversion
  - Long history of R &D; first pilot in 1929
  - US, Japan, China, Korea and Mexico undertaking R & D
  - Significant progress on ‘cold water pipe’ issues
  - Potential in Indonesia and Malaysia under investigation
- Submarine Geothermal
  - Mexico and New Zealand undertaking R & D
  - Early stage R & D only
  - May develop from mid-ocean ridge metals mining projects
- Salinity Gradient Power
  - Multiple electrochemical processes being investigated
  - First pressurized reverse osmosis prototype operational in Norway
  - R & D in Netherlands, China and Korea
- Hybrid Systems
  - Wave/wind systems – sharing moorings and shore connections
  - Tidal/wind systems – may be less likely due to moorings
  - Multi-use platforms – wind, wave and tidal currents

Ocean Thermal Energy Conversion

Resource and Test Facility

Temperature Diff. (Surface – WD 1,000m)

- Most of northern Japan too cold
- Areas of S. Japan have potential for OTEC

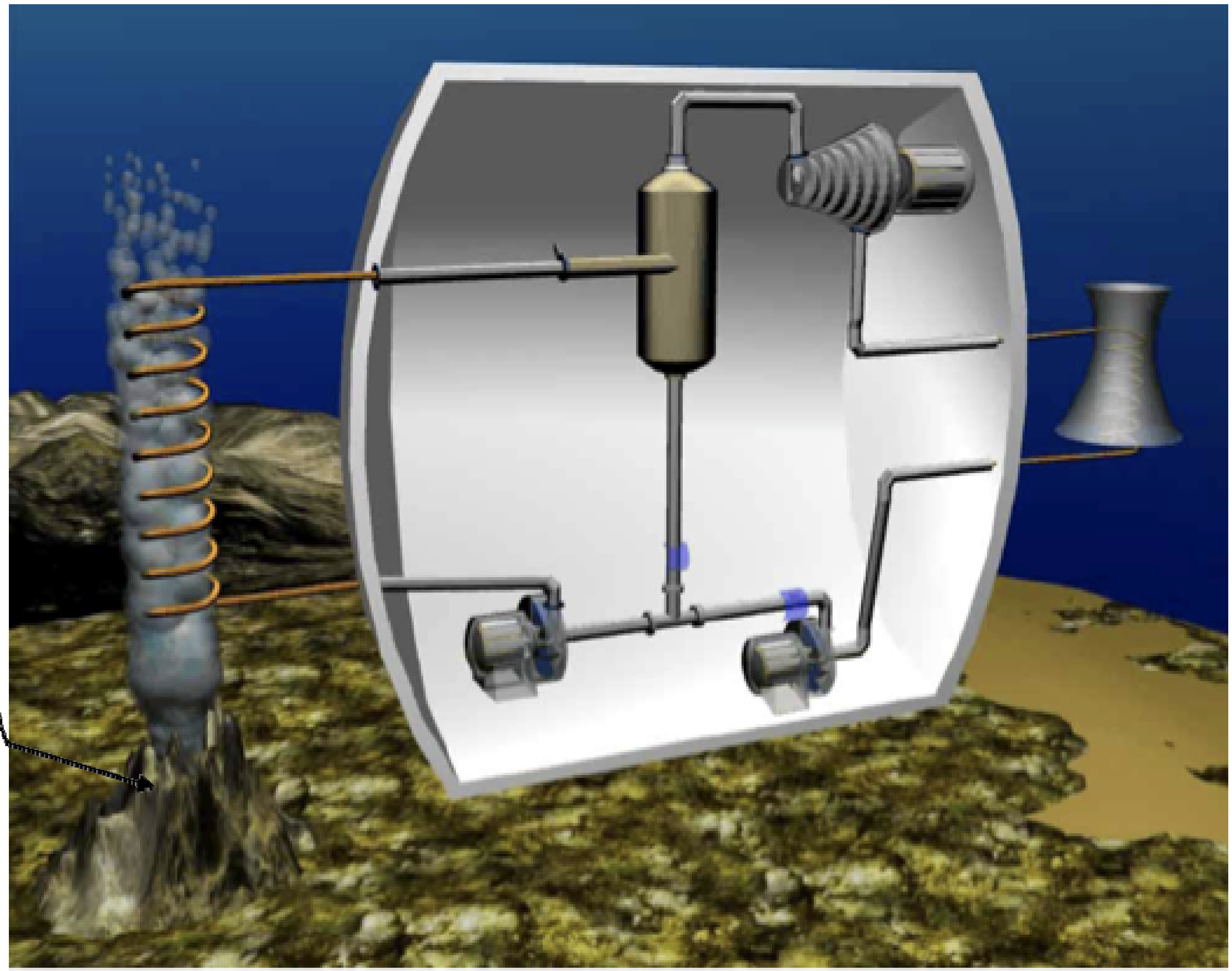
SAGA University – 30 kW Pilot OTEC

- Ammonia – water system
- Still under development

SubmarineGeothermal

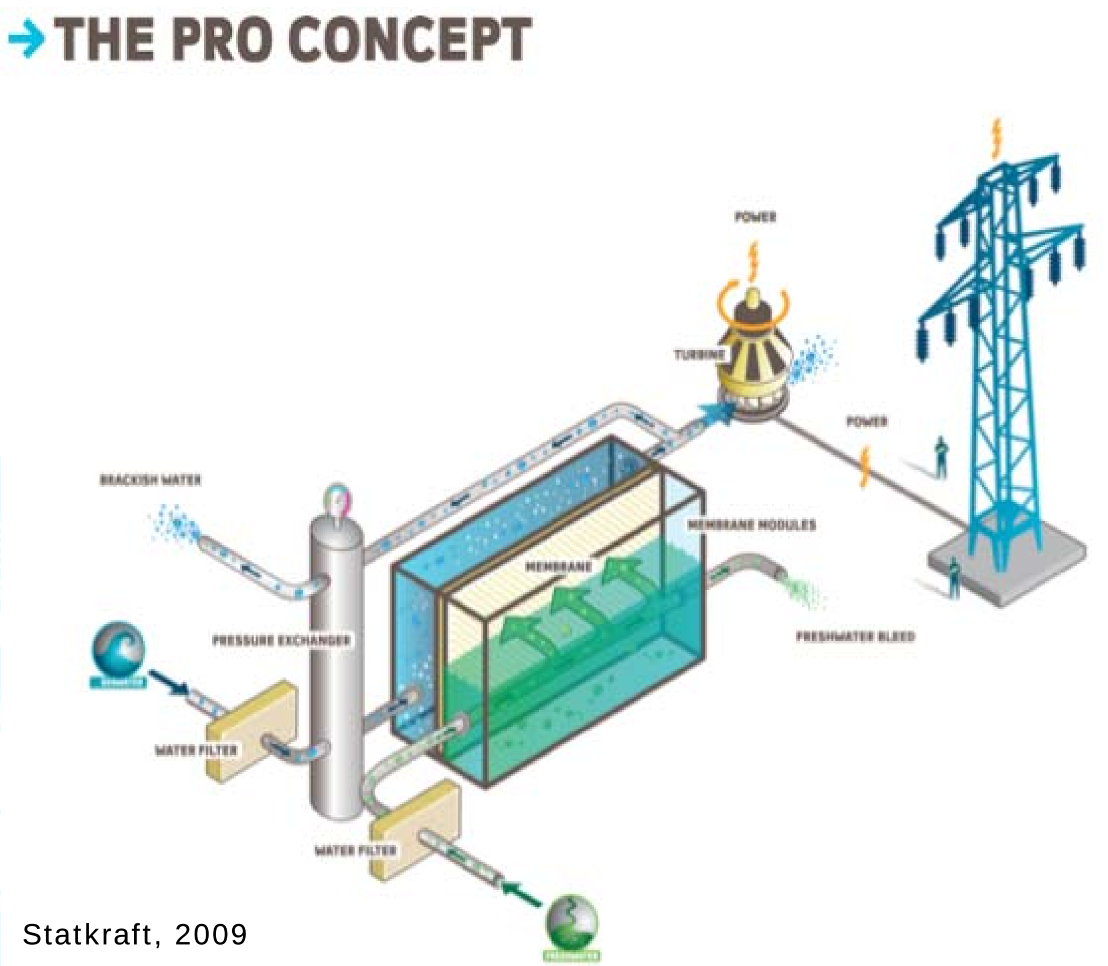
Conceptual Design

350° C water from hydrothermal vent on seafloor

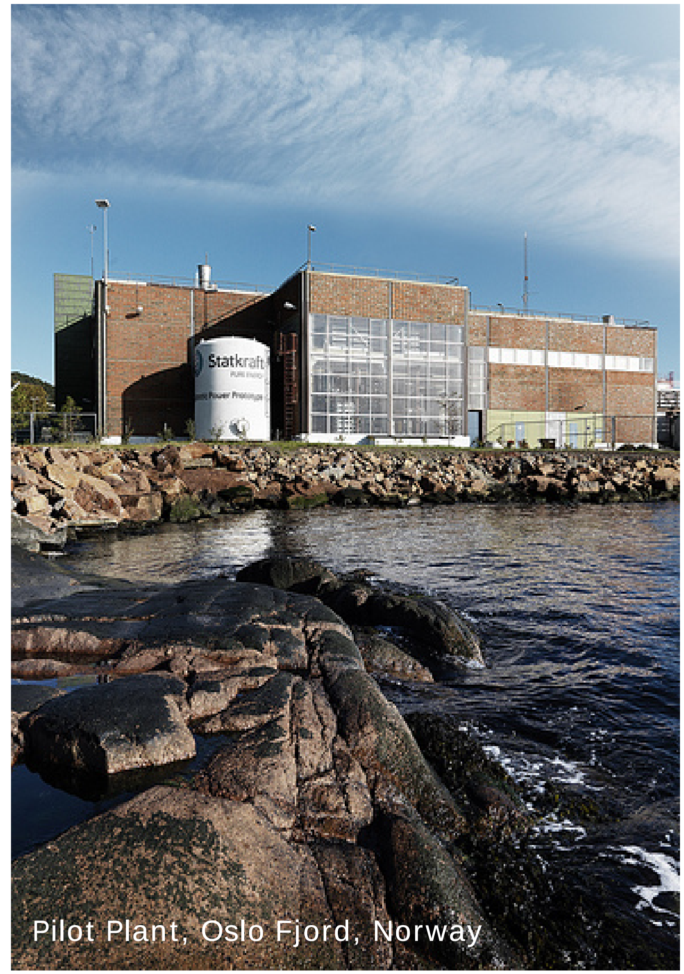


UNAM, Mexico (Hiriart, 2009)

PressurizedReverseOsmosisConcept&PilotPlant



Statkraft, 2009



Pilot Plant, Oslo Fjord, Norway

Marine Energy - Markets

Grid-connected electricity for utility-scale applications

Off-grid communities will utilize small-scale, stand-alone applications

Drinking water may be an important product of ocean energy

Environmental Dividend

- Wave and tidal energy
  - Installed in high-energy environments, often devoid of biota and essentially restorative
  - Potential issues with scouring/sediment accumulation will be manageable
  - Very limited visual impact
  - Submarine noise may be limited
  - Interaction with marine biota may be limited and not damaging
- Tidal barrages
  - Essentially permanent
  - Potential problems with siltation
  - Usually built with secondary uses, e.g., causeways/barriers
  - More limited applications except in remote settings
- Other forms
  - OTEC and salinity gradient power may produce large volumes of exotic/brackish water





Marine Energy – Key Messages

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  - Marine energy resources have no other uses
  - **Competition for space**for other uses should be **manageable**
- Markets for Marine Energy
  - **Utility-scale** electricity generation
  - Integration with **desalination/drinking water** production
  - **Remote**/island/indigenous community**supplies**

OES ExecutiveCommittee

If you have been, thank you for listening!

www.ocean-energy-systems.org

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