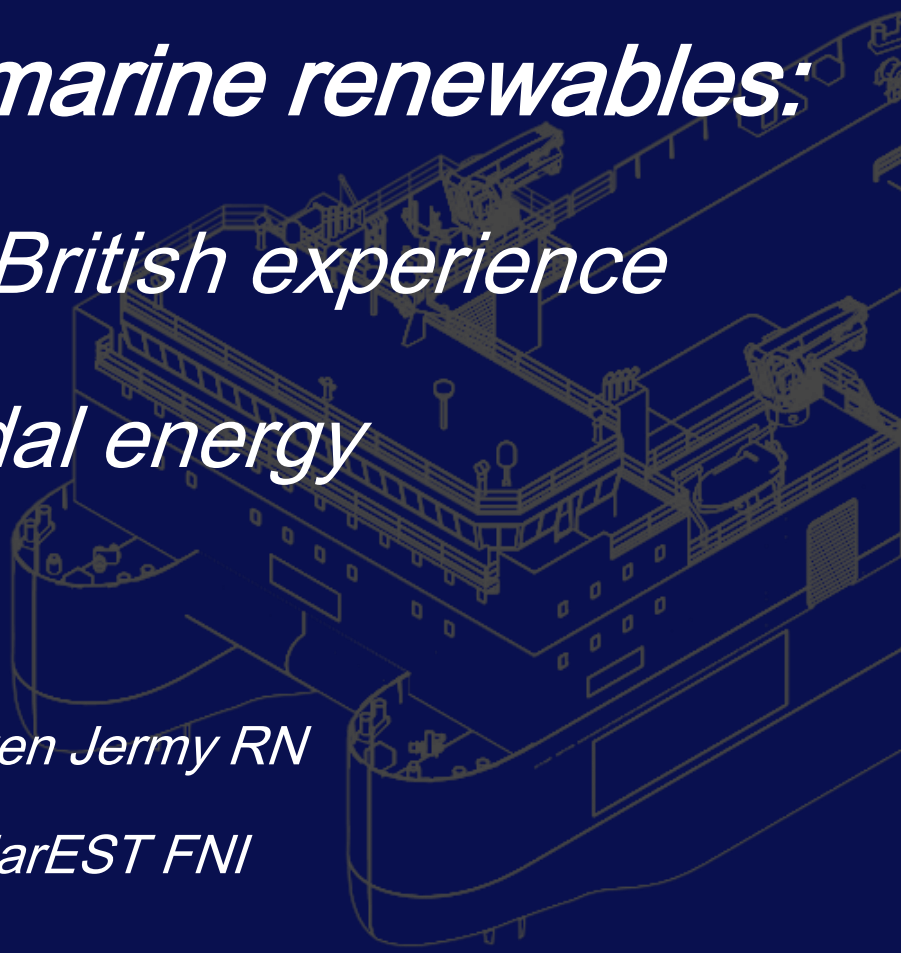
Leading the world in marine renewables:

a decade's worth of British experience

in wave & tidal energy



Commodore Steven Jermy RN

CMarTech FIMarEST FNI

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Structure

- Strategic Context
- Marine Renewables Lessons Learned
- Wave Energy
- Tidal Energy
- South Africa’s Opportunity

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South West UK – Marine Energy Experience

Academic research hotspot

Excellent natural resources

Maritime & industrial heritage

Innovative regional businesses

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THE MOJO MARITIME TIMELINE

Richard Parkinson acquires the business

Formation of Ocean Dynamics Group

Company restructuring
New investment
New Directors

1970's | 2004 | 2006 | 2009 | 2011 | 2012 | TODAY

Local Marine Contracting

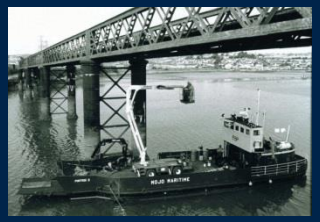
Entry into marine renewables

Success in tidal projects

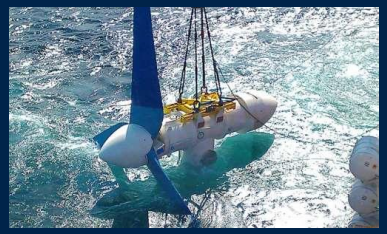
Marine Operations Management

Engineering Consultancy

R&D projects

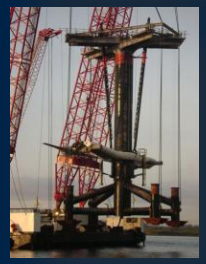


WIND



WAVE

TIDE



Reducing the cost of energy for marine renewables

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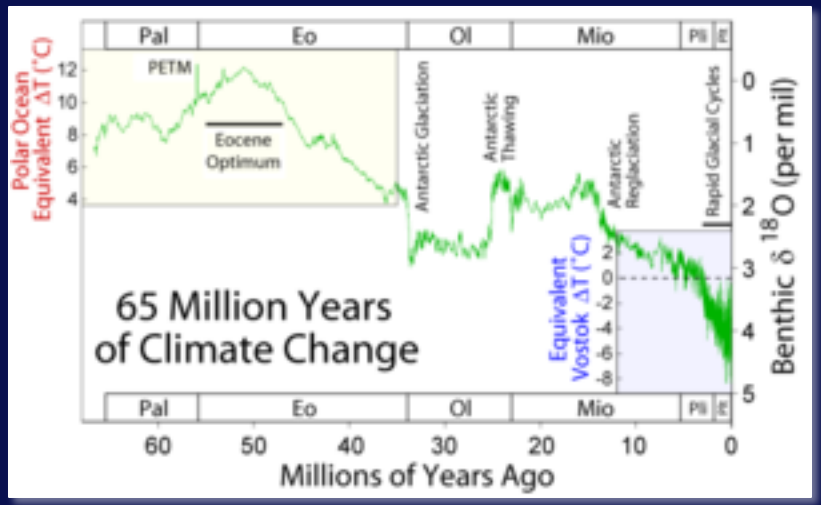
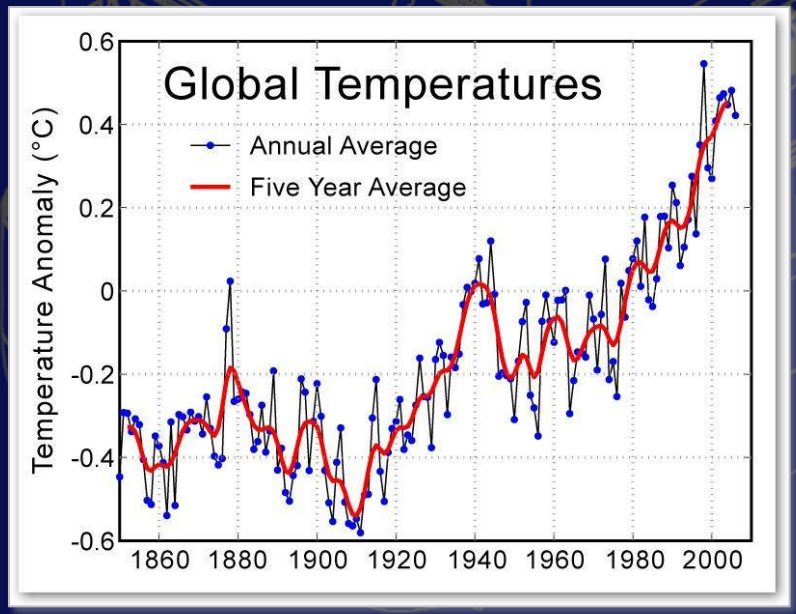
The Strategic Context for Energy

Climate Change

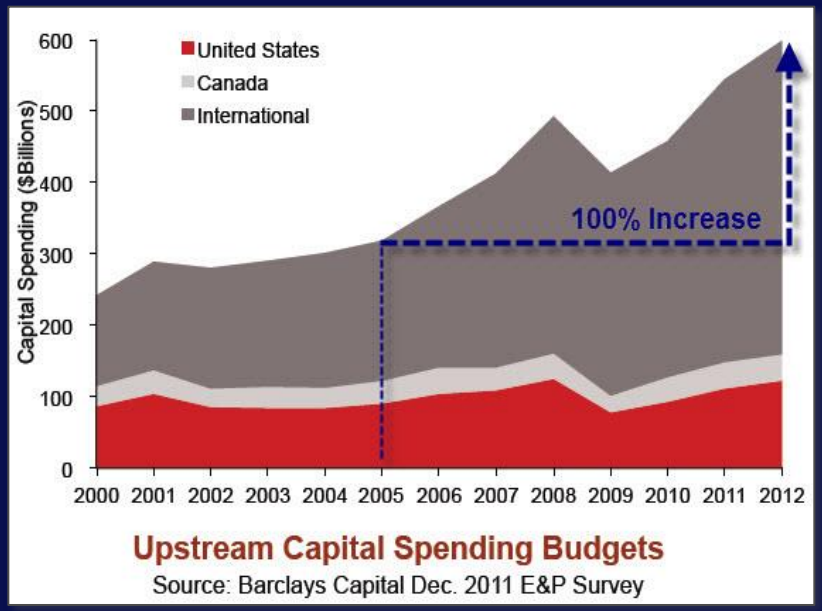


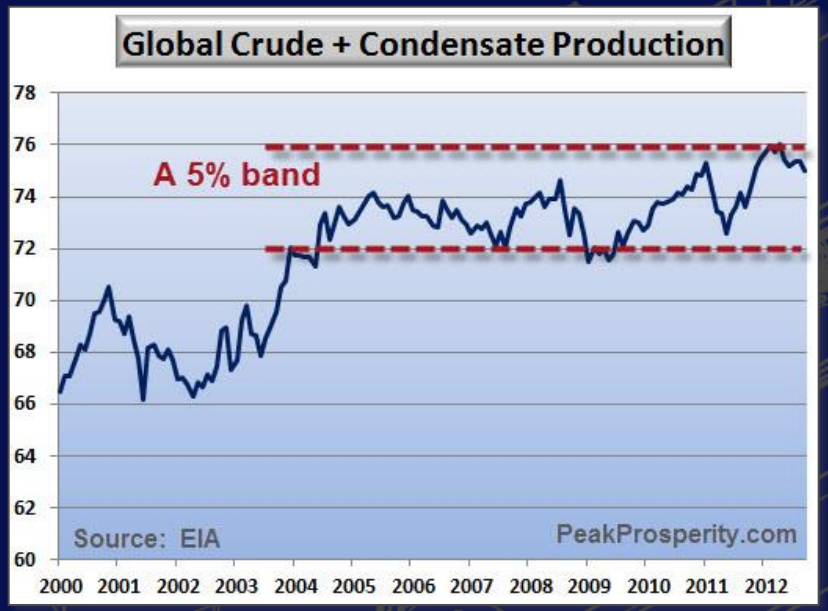
Palaeocene-Eocene Thermal Maximum

Current Trends



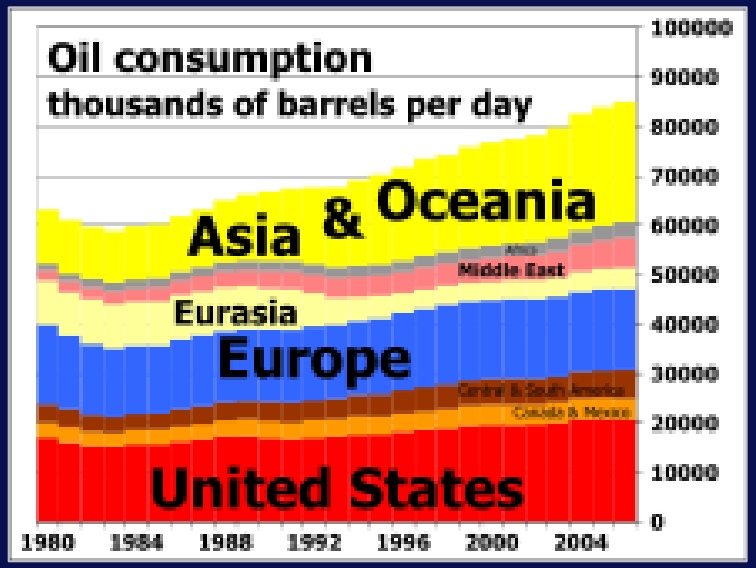
Global Energy Context





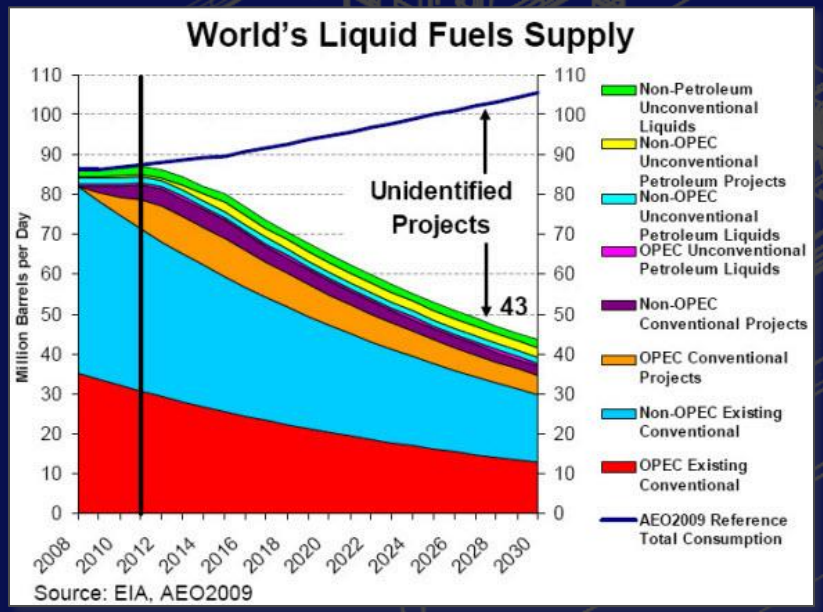
Oil & Gas Industry –
CAPEX v Strategic Yield

Global Energy Context

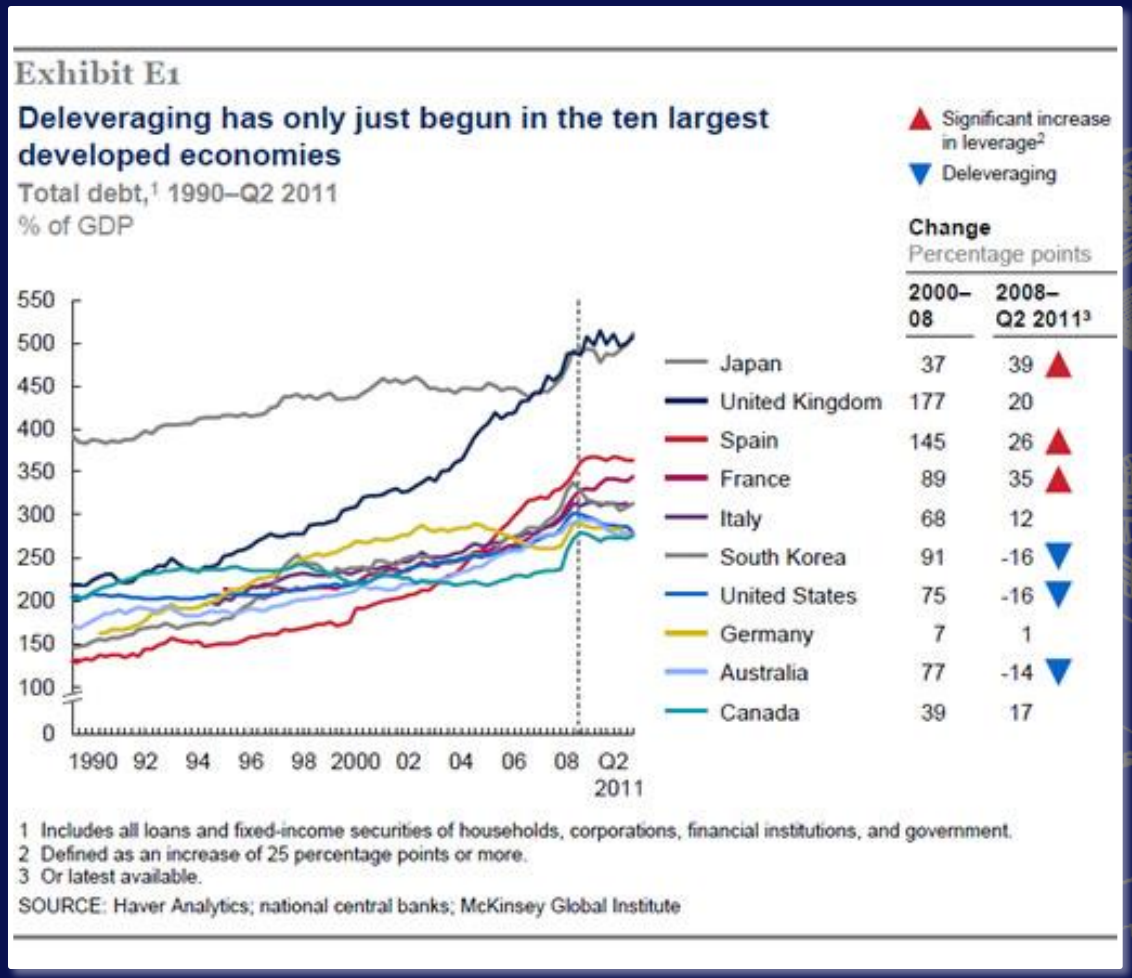


Global Demand

Global Supply



Economics & Debt



G7 Total Debt-to-GDP Ratios

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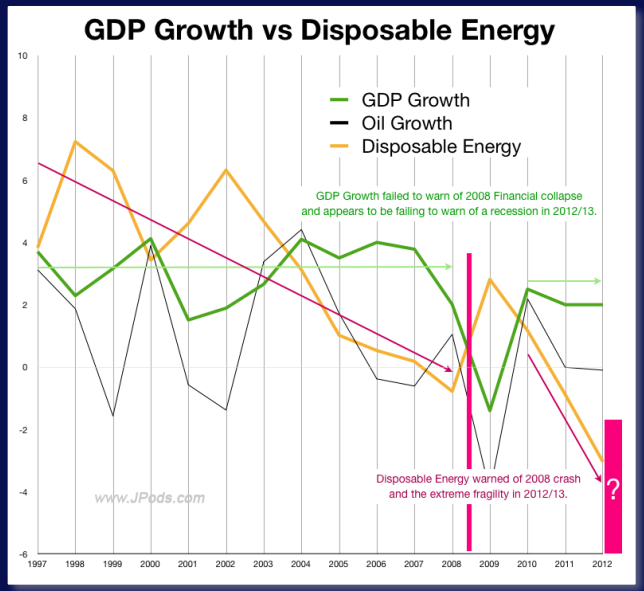
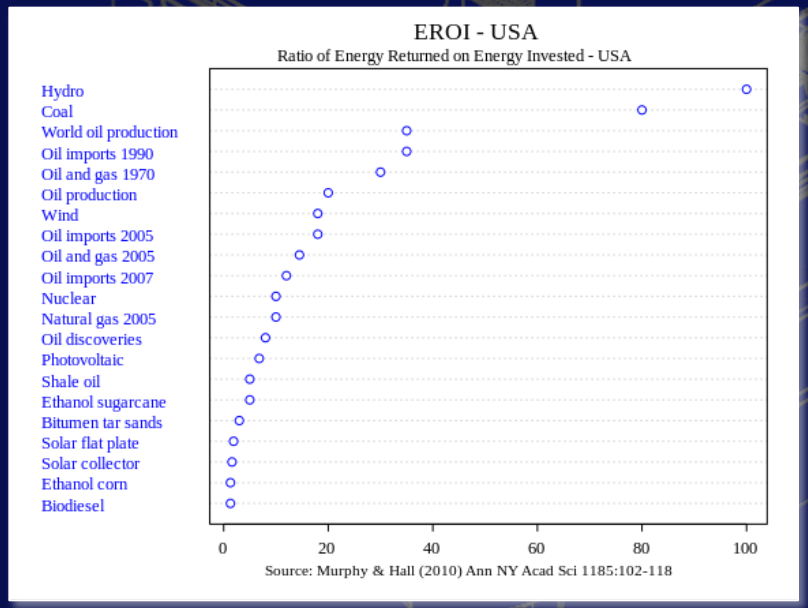
Global Energy Context



Economic Growth & Energy

Energy Return on Energy Invested



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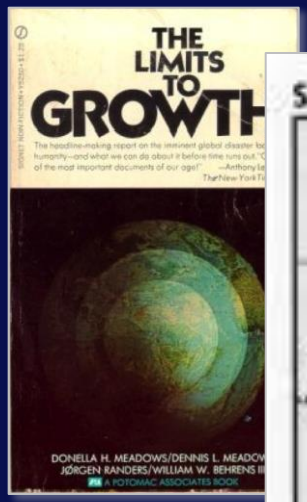
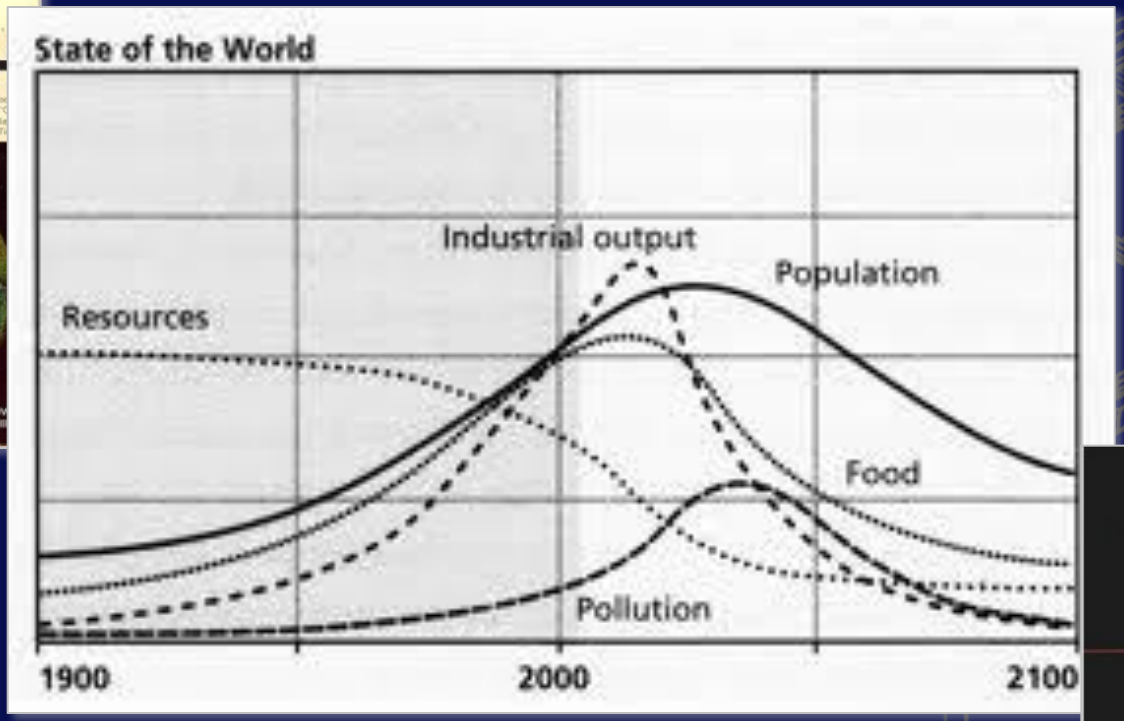
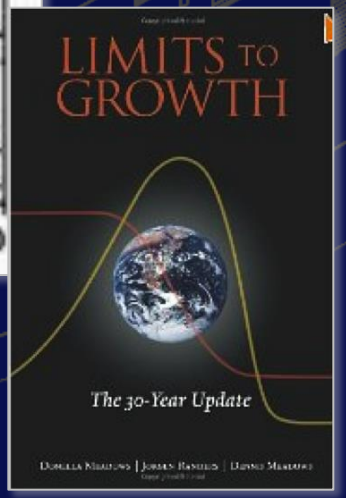
Economic Growth







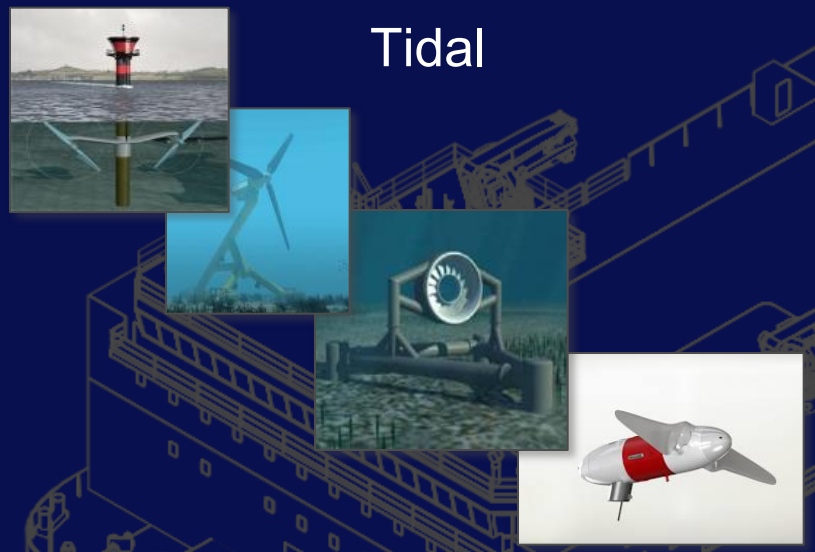
Limits to Growth

Marine Renewable Energy
Lessons Learned

Offshore Renewables

Offshore Wind

Tidal



Wave

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Lessons Learned To Date

Tidal

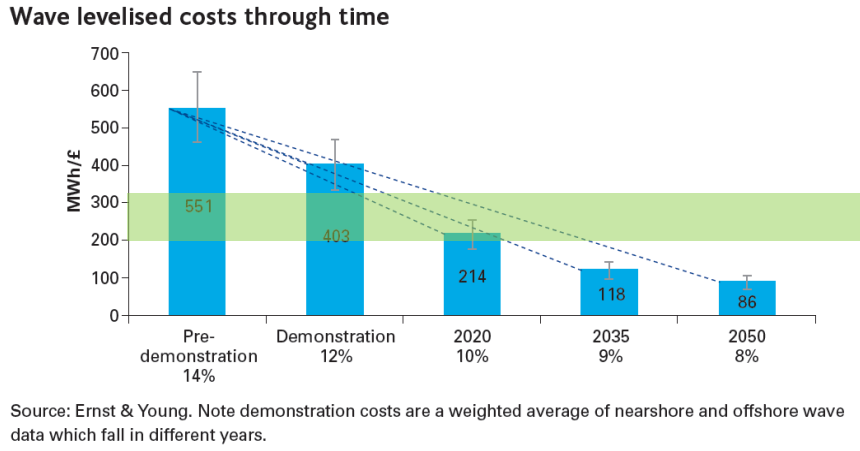
Wave

- Engineering:
  - P_c v yield
  - power density & oceanography
  - array science & oceanography
- Operational:
  - build to install
  - build to survive
  - build to connect
  - build to array
  - build to O&M
- Commercial:
  - Risk capital v return
  - Yield v CAPEX v OPEX
  - LCOE

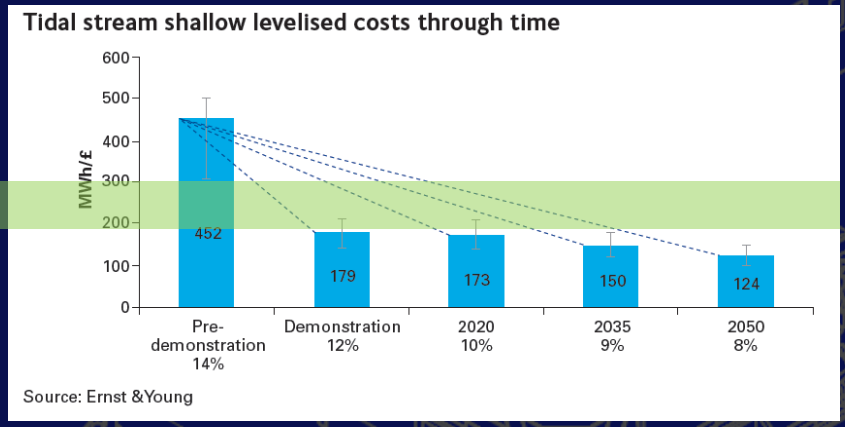
Offshore Energy Supply Cycles

Cycle		Oil & Gas	Offshore Wind	Wave	Tide
Explore		✗ ✗ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
Map		✗ ✗ ✗	✓	✓ ✓	✓ ✓ ✓
Predict	Time	✓ ✓ ✓	✗ ✗	✗ ✗	✓ ✓
	Power	✓ ✓ ✓	✗	✓ ✓	✓ ✓ ✓
	Direction	–	✗	✓ ✗	✓ ✓ ✓
Extract	Technology	✓ ✓ ✓	✓ ✓ ✓	✗	✓
	Balance of Plant	✓ ✓ ✓	✓ ✓	✗	✗ ✗
	Supply Chain	✗ ✗	✓	✓ ✓	✓ ✓
	Cost	✗ ✗	✓ ✓	✗ ✗	✗ ✗ ✗
Field Reserves		✗ ✗ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
Decommission		✗ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓

Wave & Tidal Energy Prospects



Source: Ernst & Young. Note demonstration costs are a weighted average of nearshore and offshore wave data which fall in different years.



Source: Ernst &Young

- Cost reduction step change opportunity more obvious in tidal
- An opportunity to drive down the cost per MW through innovation in:
  - Foundation Optimisation
  - Installation methodology and vessel selection
  - Cable connection (current elephant in the room)
  - Cable Installation – current poor relation
  - O&M methodology

Wave Energy

WAVE POWER

Wave power available to a wave energy converter is calculated by:

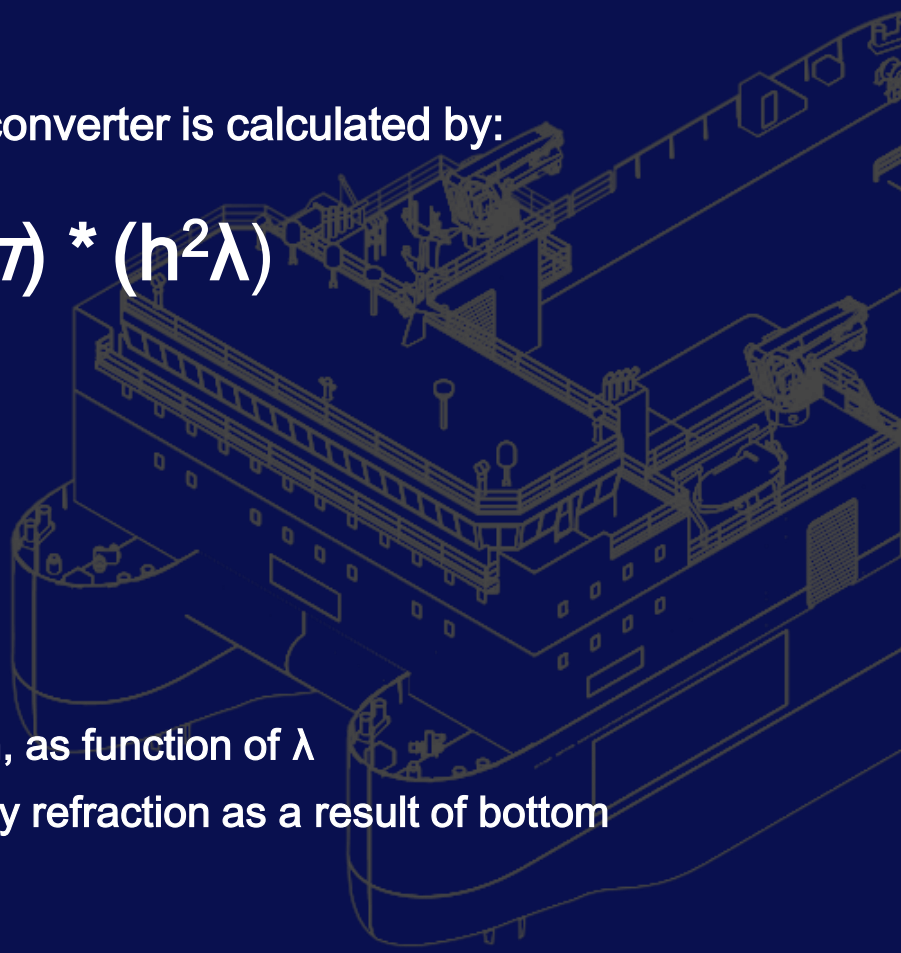
$$P = (\rho g/64\pi) * (h^2\lambda)$$

Where:

- ρ = water density
- g = gravity
- h = wave height
- λ = wave period

Key Points:

- wave power decays quickly with depth, as function of λ
- wave power is enhanced or reduced by refraction as a result of bottom topography



WAVE POWER

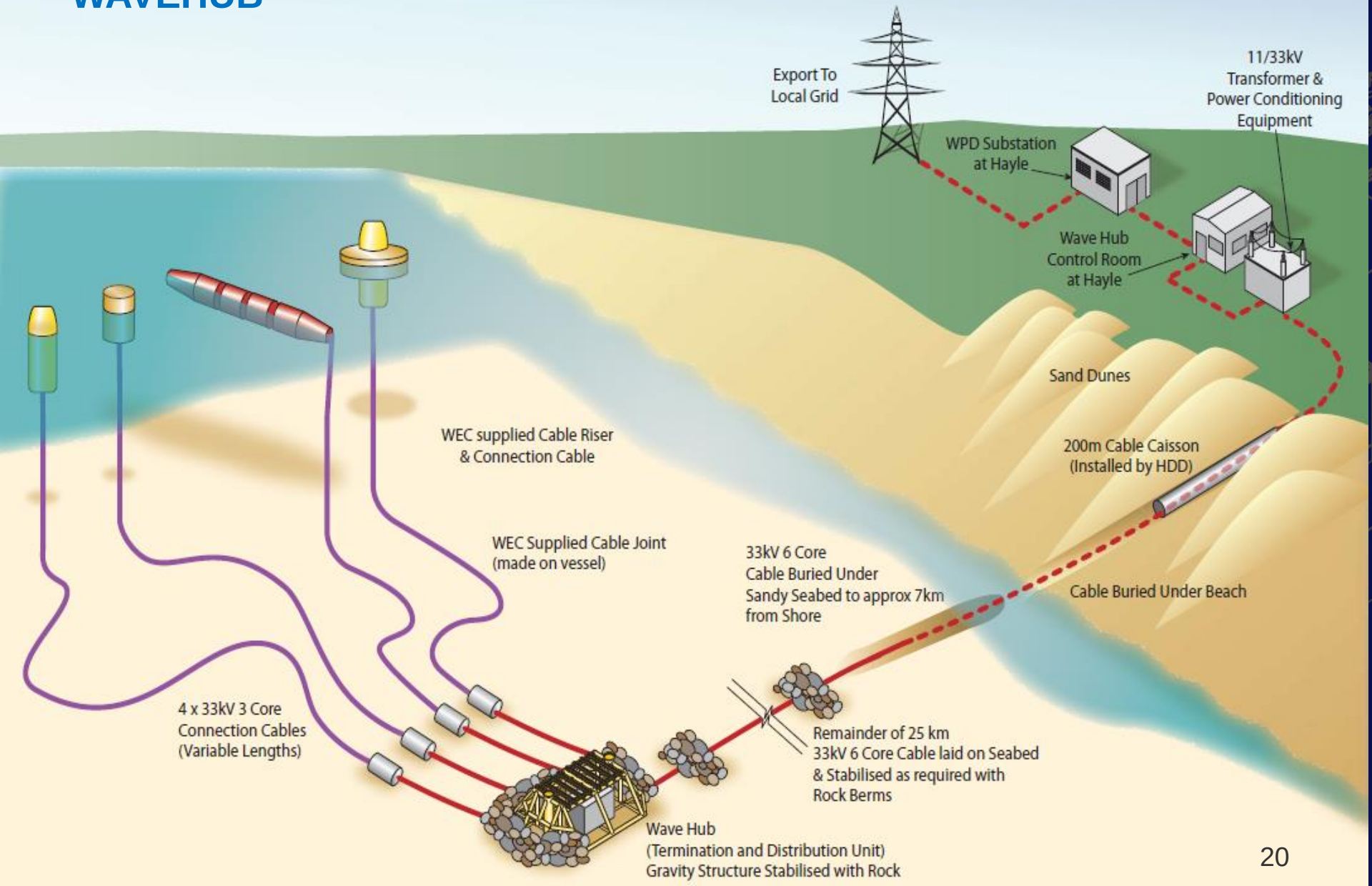
Pelamis

Carnegie

Wello

Anaconda

WAVEHUB


Export To
Local Grid
11/33kV
Transformer &
Power Conditioning
Equipment
WPD Substation
at Hayle
Wave Hub
Control Room
at Hayle
Sand Dunes
WEC supplied Cable Riser
& Connection Cable
200m Cable Caisson
(Installed by HDD)
WEC Supplied Cable Joint
(made on vessel)
33kV 6 Core
Cable Buried Under
Sandy Seabed to approx 7km
from Shore
Cable Buried Under Beach
4 x 33kV 3 Core
Connection Cables
(Variable Lengths)
Remainder of 25 km
33kV 6 Core Cable laid on Seabed
& Stabilised as required with
Rock Berms
Wave Hub
(Termination and Distribution Unit)
Gravity Structure Stabilised with Rock

WaveHub

In the water and open for business

Tidal Energy

Tidal Stream Power

Offshore (and onshore) wind and tidal power available from a horizontal axis turbine is calculated from:

$$P = \tfrac{1}{2} \rho e \pi r^2 u^3$$

Where:

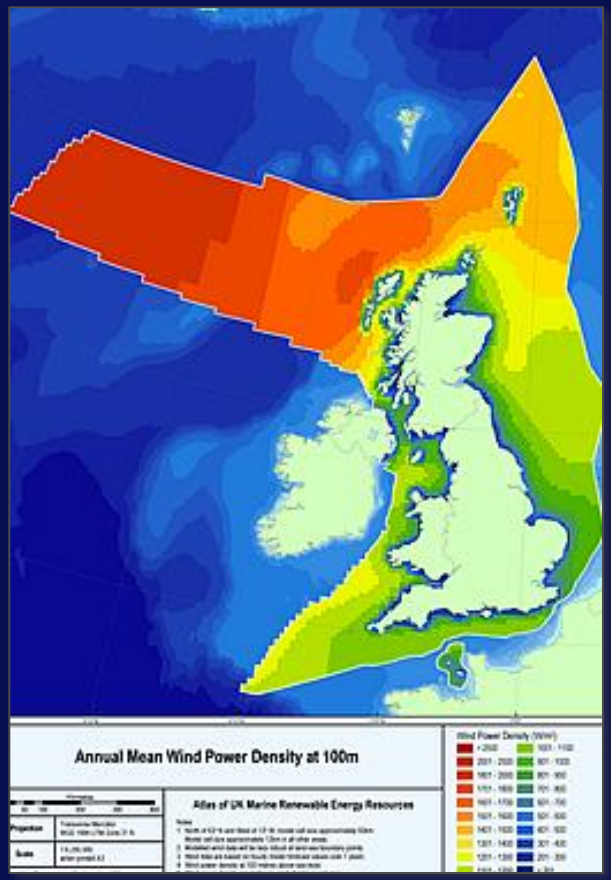
- ρ = water density
- *e* = turbine power coefficient
- r = blade radius
- u = tidal stream velocity

Key Points:

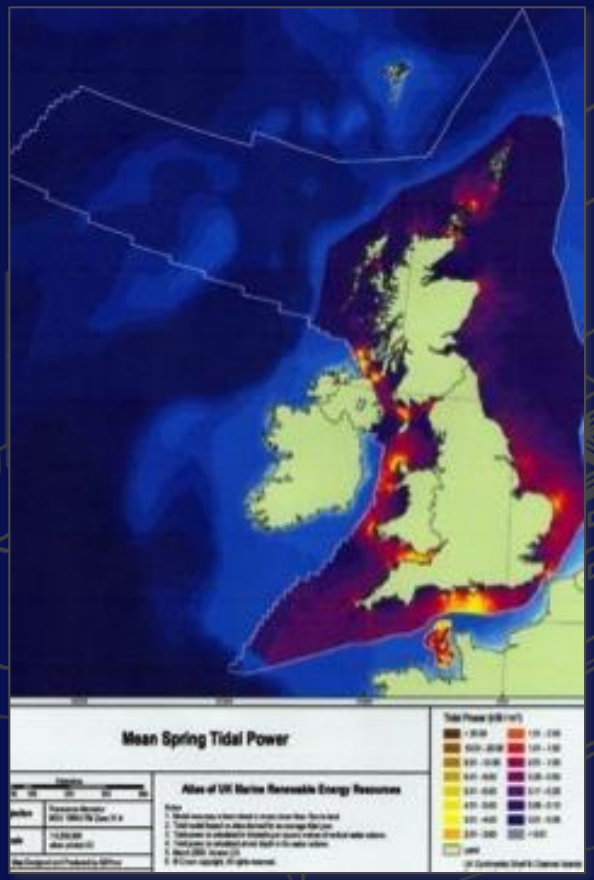
- u^3 matters more than πr^2
- $1/7^{th}$ power law for power loss with depth
- losses of speed in the wake limit on overall yield
- turbine arrays are typically be spaced at 8-10D

Power Density

Offshore Wind



Tidal



Tidal v Wind – Similarities & Differences

- Well known tidal advantages:
  - chronological predictability
  - sub-surface

- Less well known tidal advantages:
  - directional predictability
  - power density
  - fluid depth v turbine diameter

Tidal Energy Challenge

Pentland Firth, Inner Sound, Scotland – 10kts = 5 ms^{-1}

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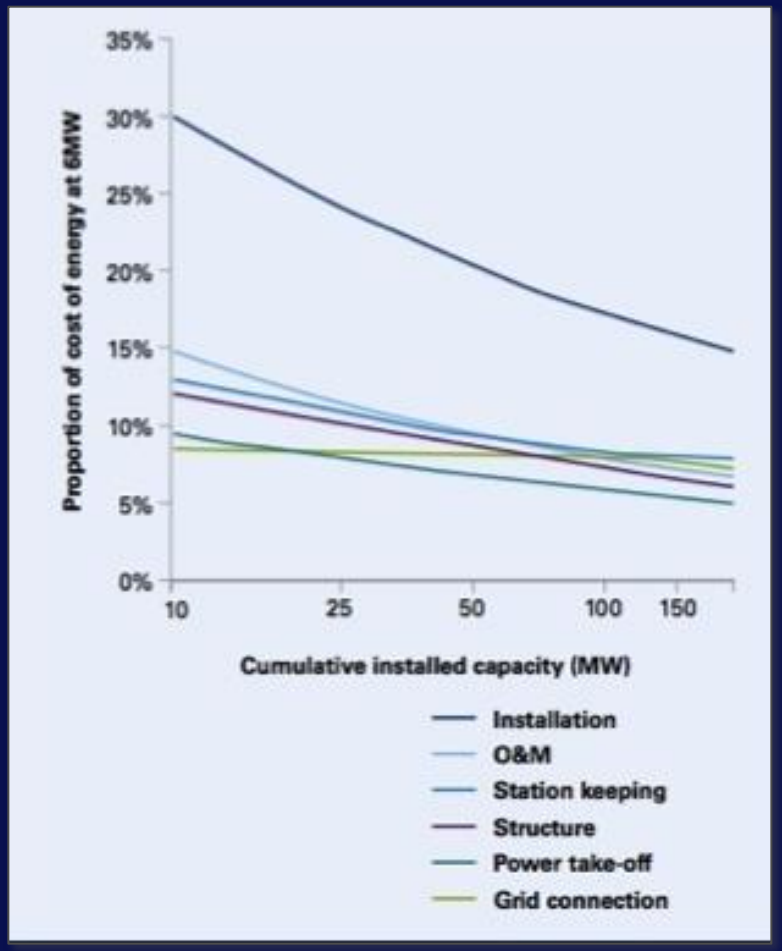
The Sector Focus

- Deployment, installation, and O&M account for 50% of a typical marine energy deployment.
- The industry focus is turning:
  - *from* turbines.
  - *to* foundations & multiple turbine arrays.
  - *seeking* cost reduction, through rapid innovation.
- The science to maximise yield revenue also needs to be developed.



Technological focus – foundations & installation methods

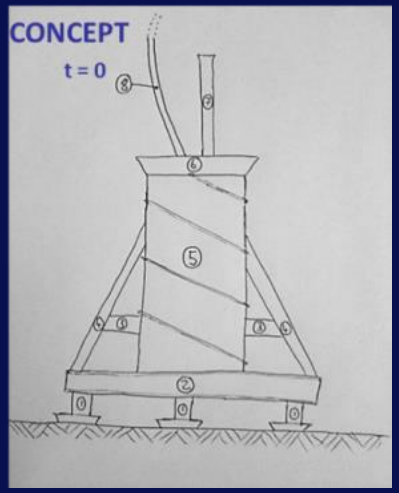
Gravity Base Foundations

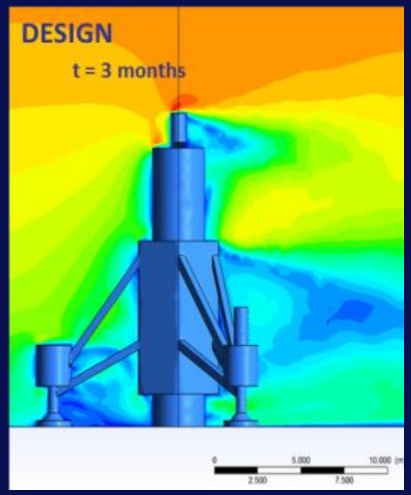
'Jack Up' Barges &
Dynamic Positioning Vessels

Pile Foundations

I – Tidal Energy Innovation - Foundations

- **Tidal Turbine Foundation:**
  - **Gravity base – approx 1000 tonne per iMW – expensive – difficult to install**
  - **Pile – 100 tonne per iMW – topside drilling required -**





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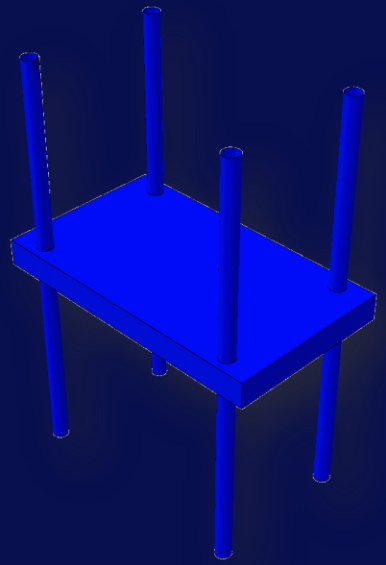
II – Tidal Energy Innovation - Vessels

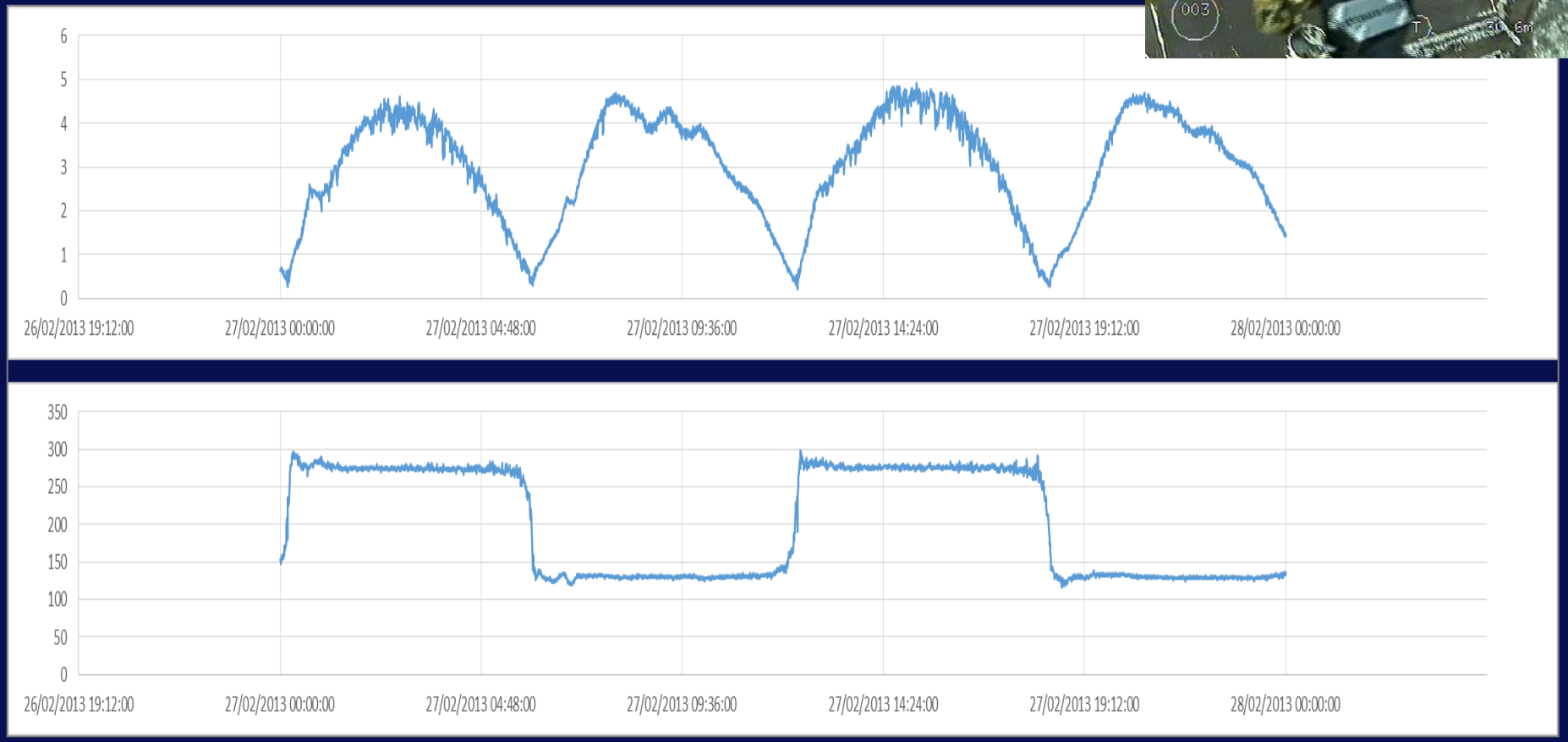
- Jack Up Barges:
  - Possible stability/VIV issues
  - Susceptible to weather downtime
  - Depth limited
  - Expensive day rates
  - Restricted availability



- DP Vessels:
  - Expensive Day Rates
  - Limited DP performance

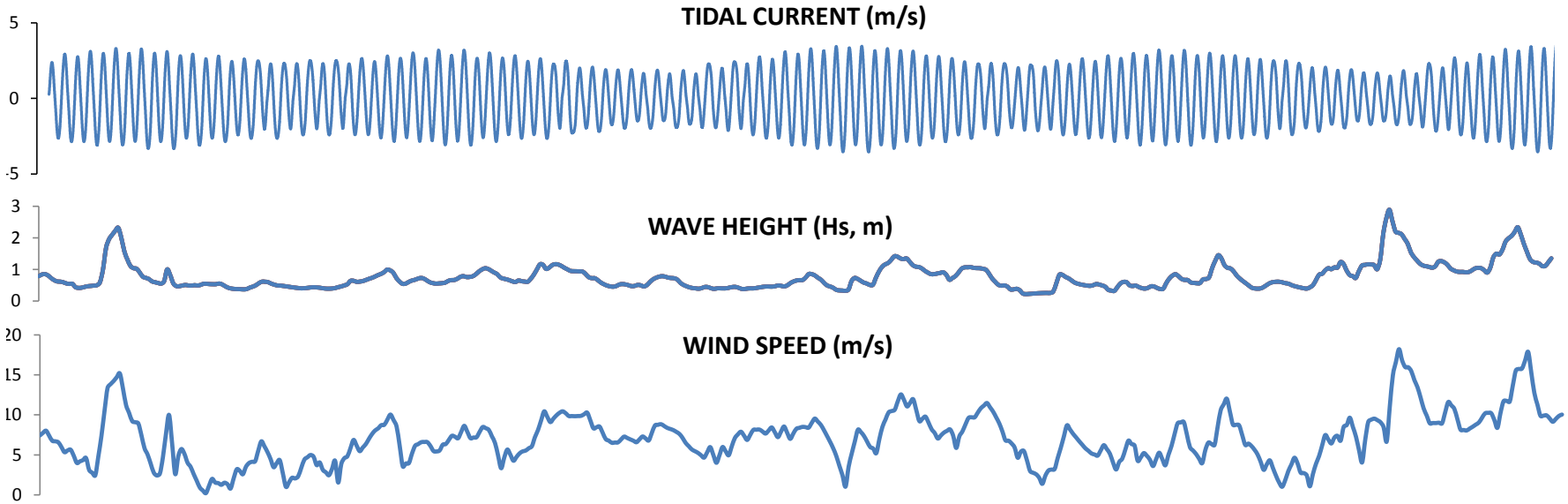
Environment Data

- 24hr (Feb 2013)



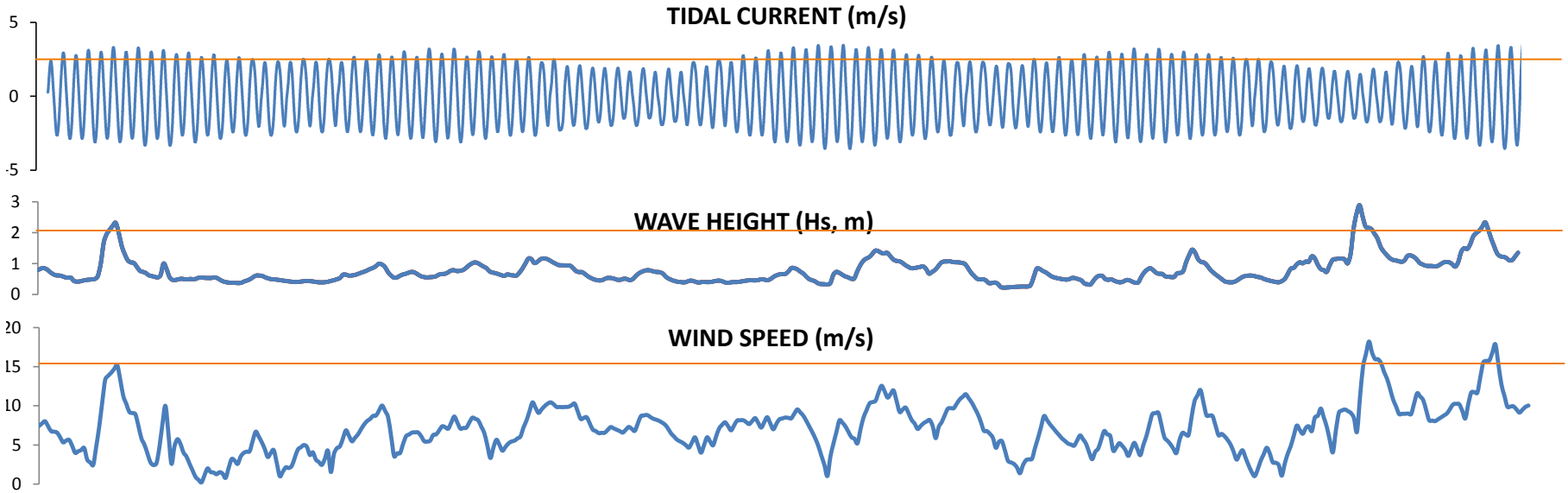
Tidal Energy Challenge

- Environmental Conditions



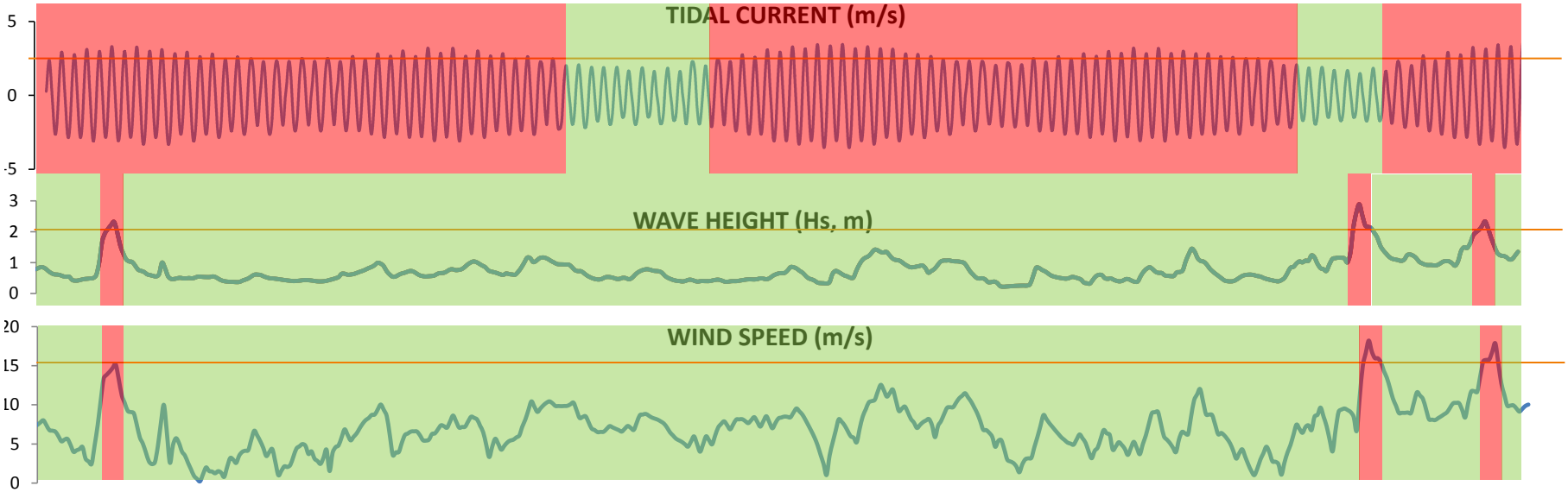
Tidal Energy Challenge

- Environmental Conditions



Tidal Energy Challenge

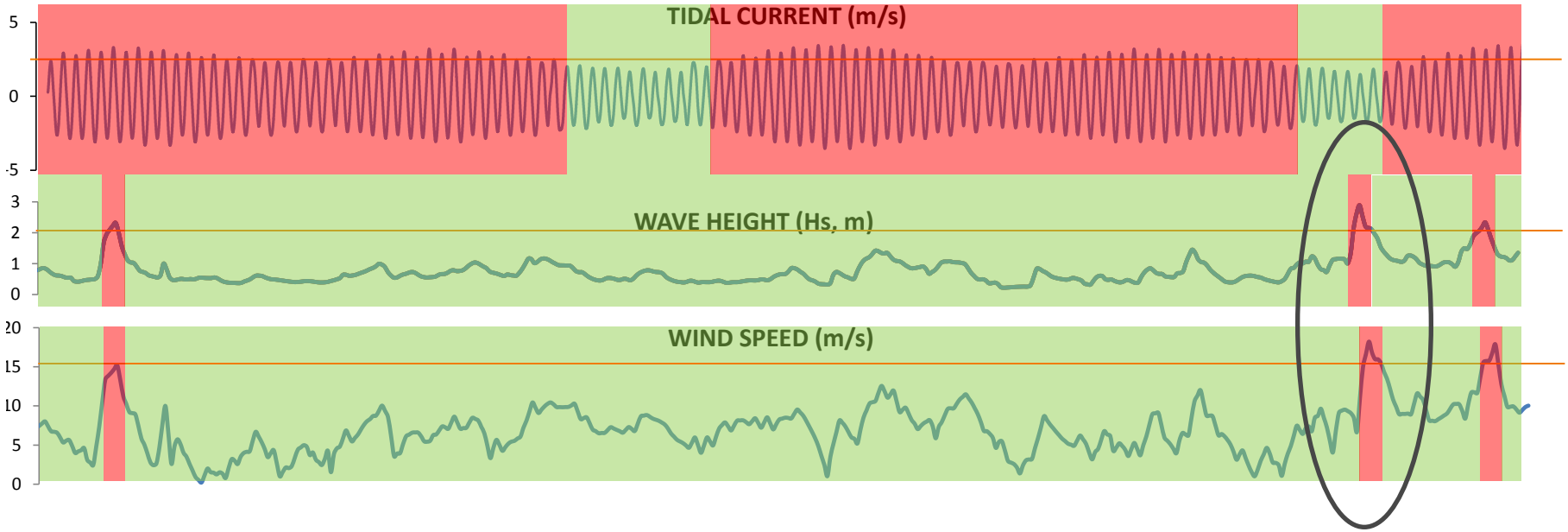
- Environmental Conditions



  - Vessel utilisation 10~15%

Tidal Energy Challenge

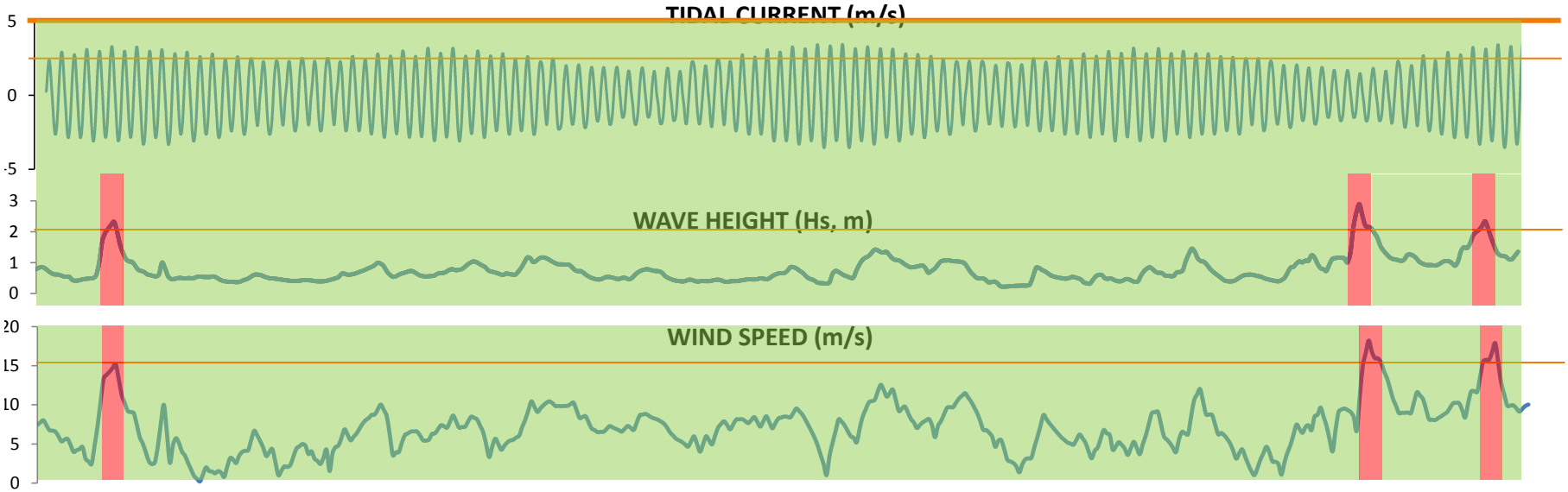
- Environmental Conditions



  - Vessel utilisation 10~15%
  - Very sensitive to weather risk

Tidal Energy Challenge

- Environmental Conditions



  - Vessel utilisation 90~95%

Tidal Energy – Systems Approach

Stage 1 – use Bauer sub-sea drill to deploy a mono-pile.

Stage 2 – deploy turbine onto the mono-pile.

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II – Tidal Energy Innovation - Vessels

- Main Characteristics:
  - Catamaran Hull of 4000 tonnes
  - 6m Draft
  - 4 Voith Schneider powered by 8DGs
  - Dynamic Positioning up to 10 knots
  - Crew of 12 – Accommodation to 25
- Key Design Parameters:
  - operate for 90% of the tidal cycle.
  - giving 4 times the daily working capability in a tidal race when compared to a conventional DP vessel.
  - and at highly competitive rates, when compared to larger offshore construction vessels.

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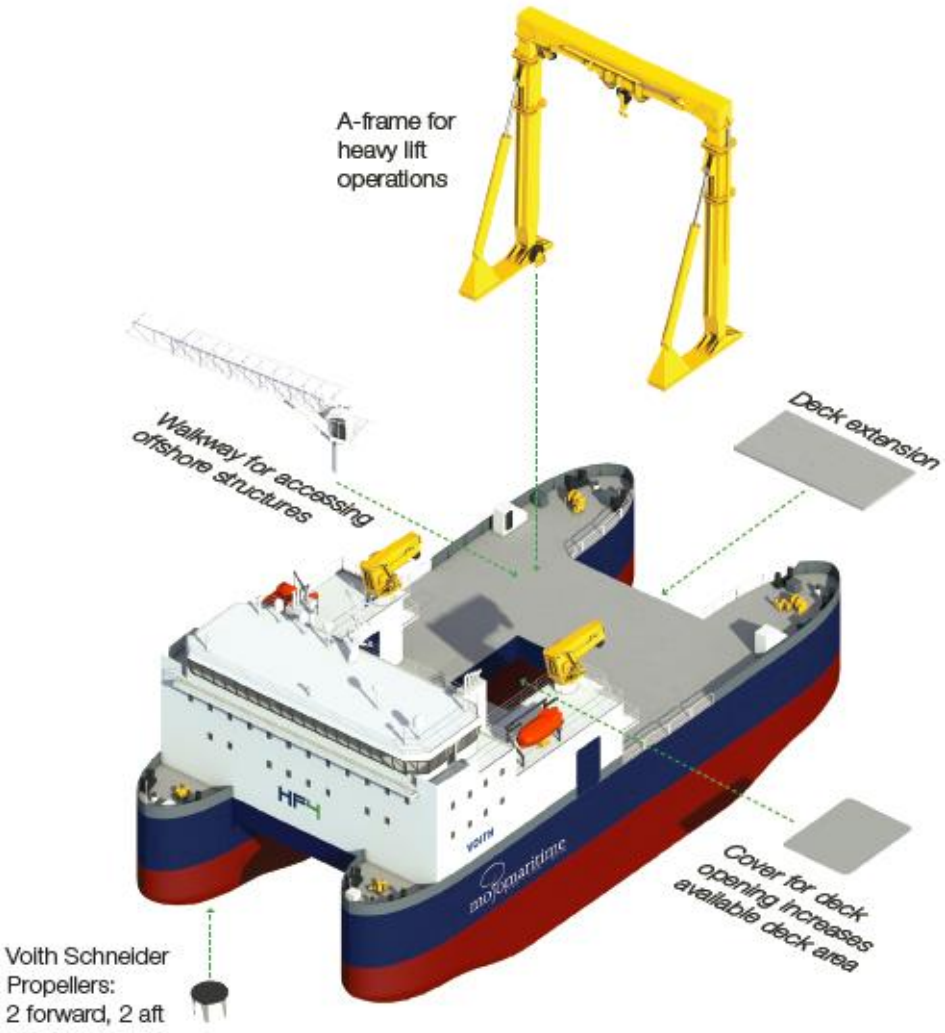
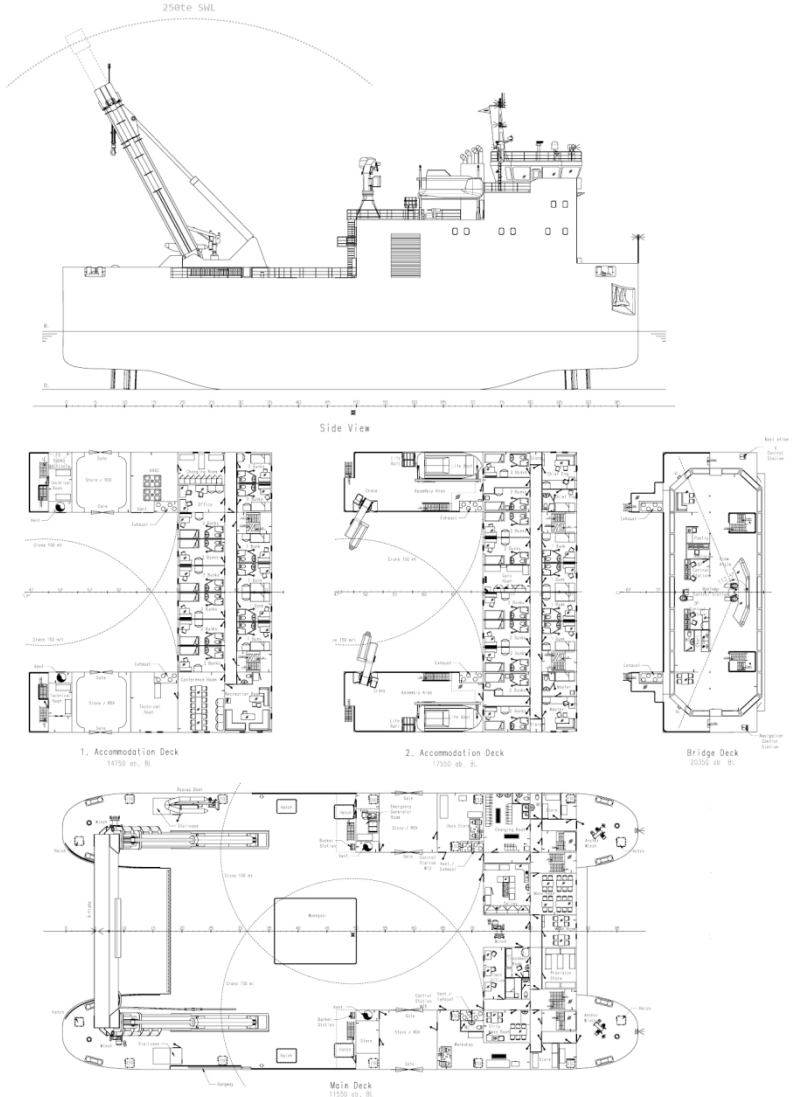
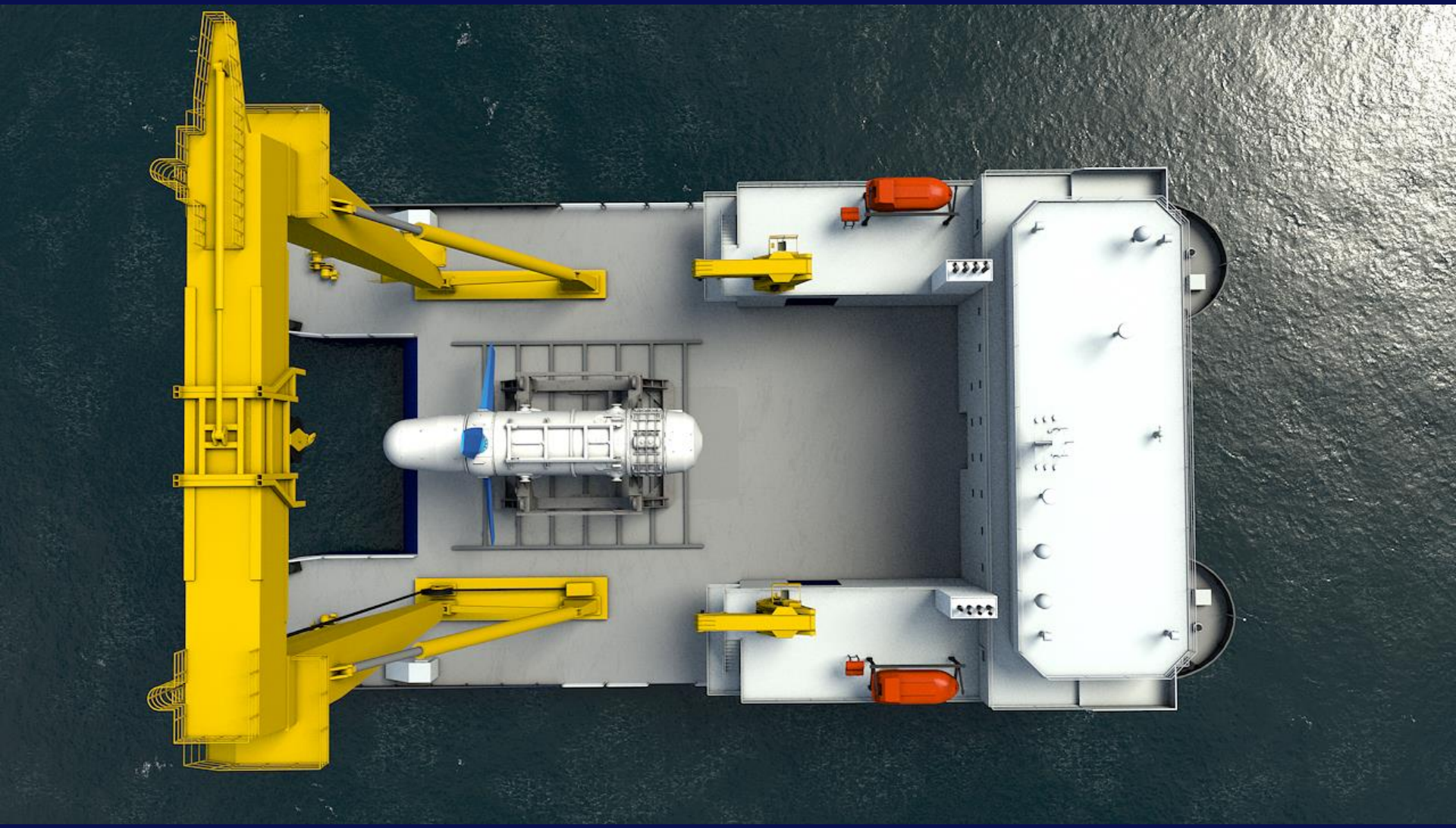
General Arrangement





Deck Layout – Tidal Energy Turbine Installation - Single Turbine



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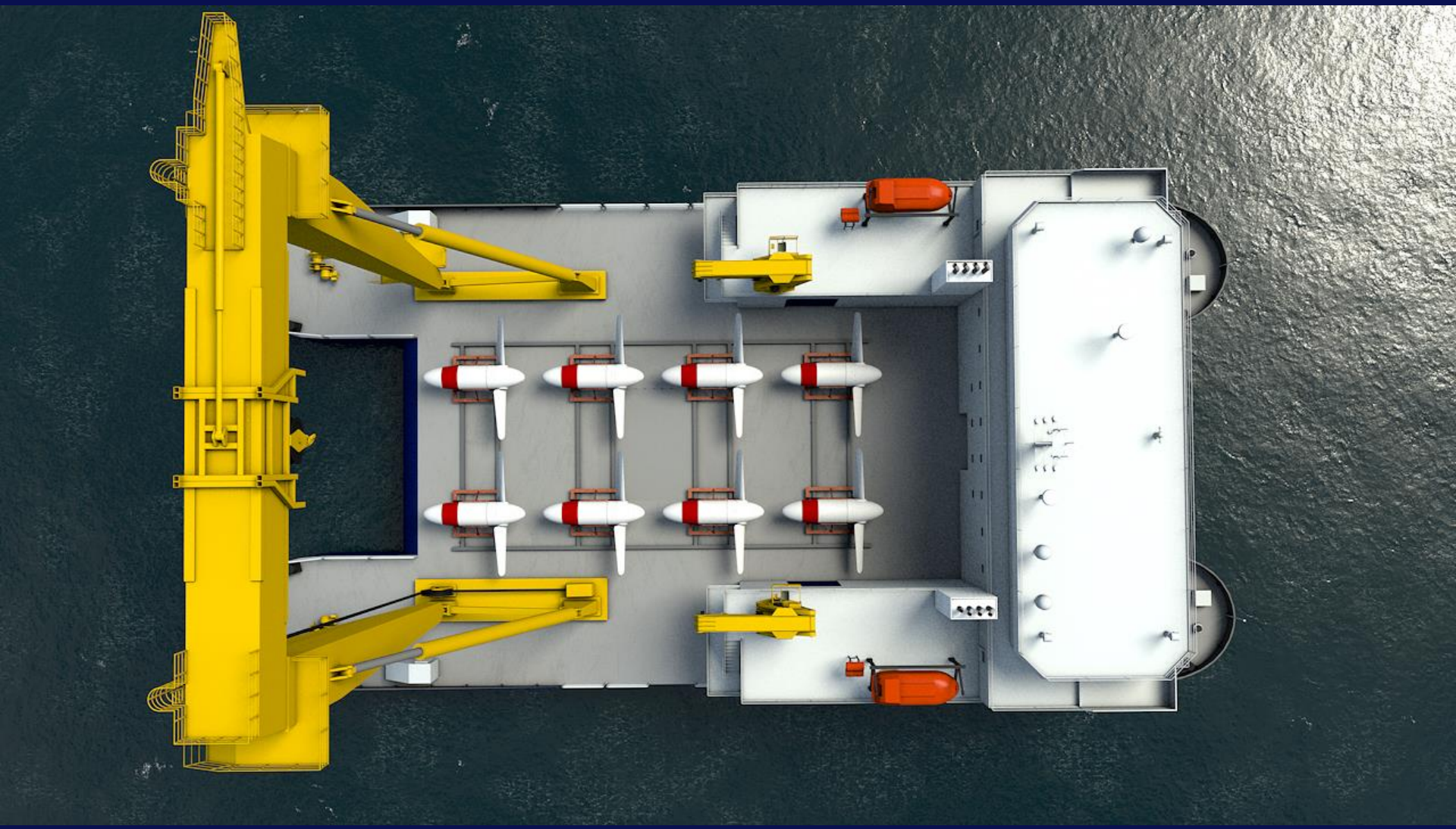
Deck Layout – Tidal Energy Turbine Installation - Multiple Small Turbines



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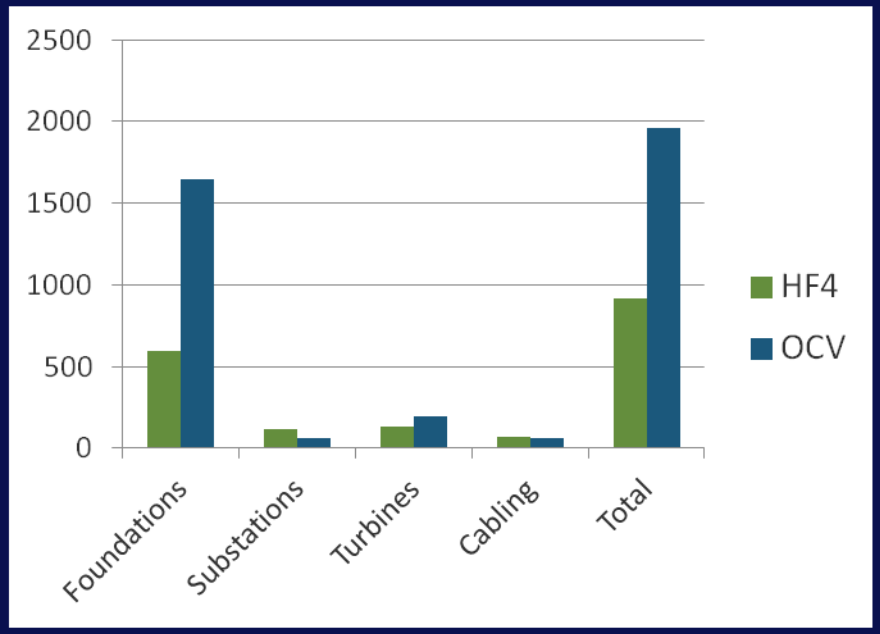
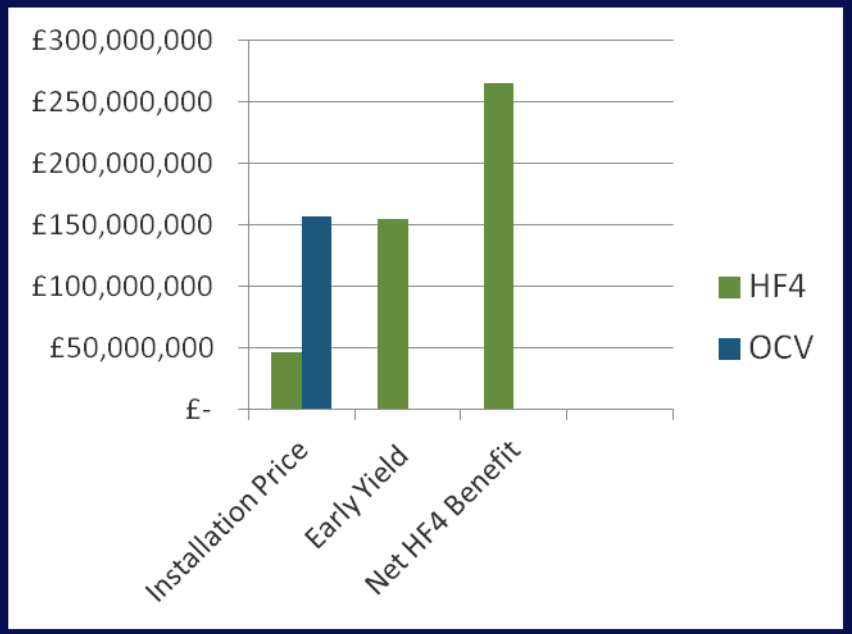
II – Tidal Energy Innovation - Vessels

HF4 v OCV – Installation Days



HF4 v OCV – Net Financial Benefits



HF4 v OCV install 100MW array:
•time – 2.3 years v 5.4 OCV years = 3.1 years saved.
•cost – £55K day rate + 3.1 year early = £111M saved.

HF4 v OCV yield & net benefits:
•yield – 3.1 years at UK strike prices = £154M gained.
•net benefit = installation savings & early yield = £265M.

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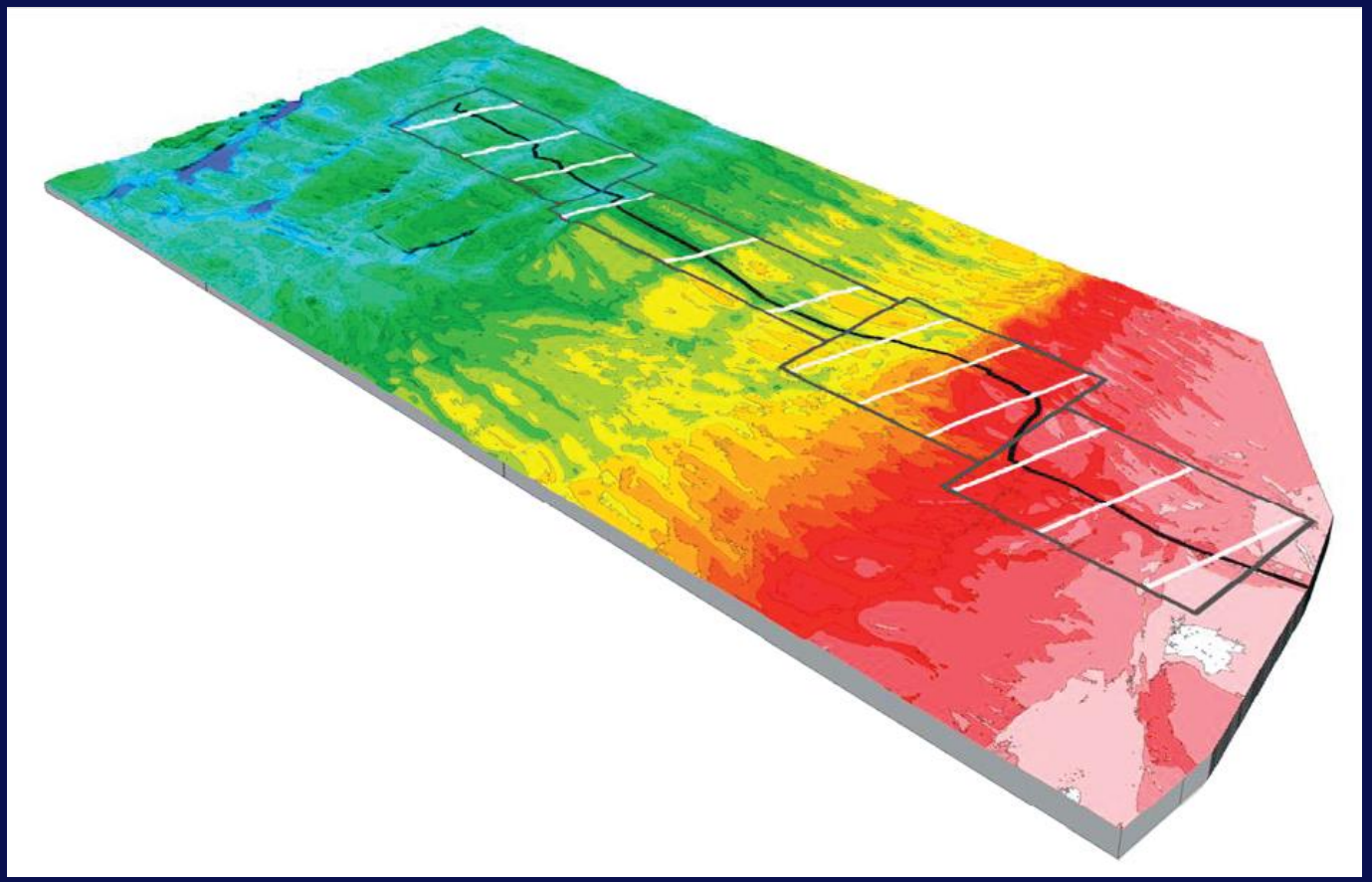
III – Tidal Energy Innovation - Cables



MeyGen – Export Cable Stability Analysis

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IV – Tidal Energy Innovation – O&M

Mojo performing Blade Change 2010, and Powertrain Change 2011

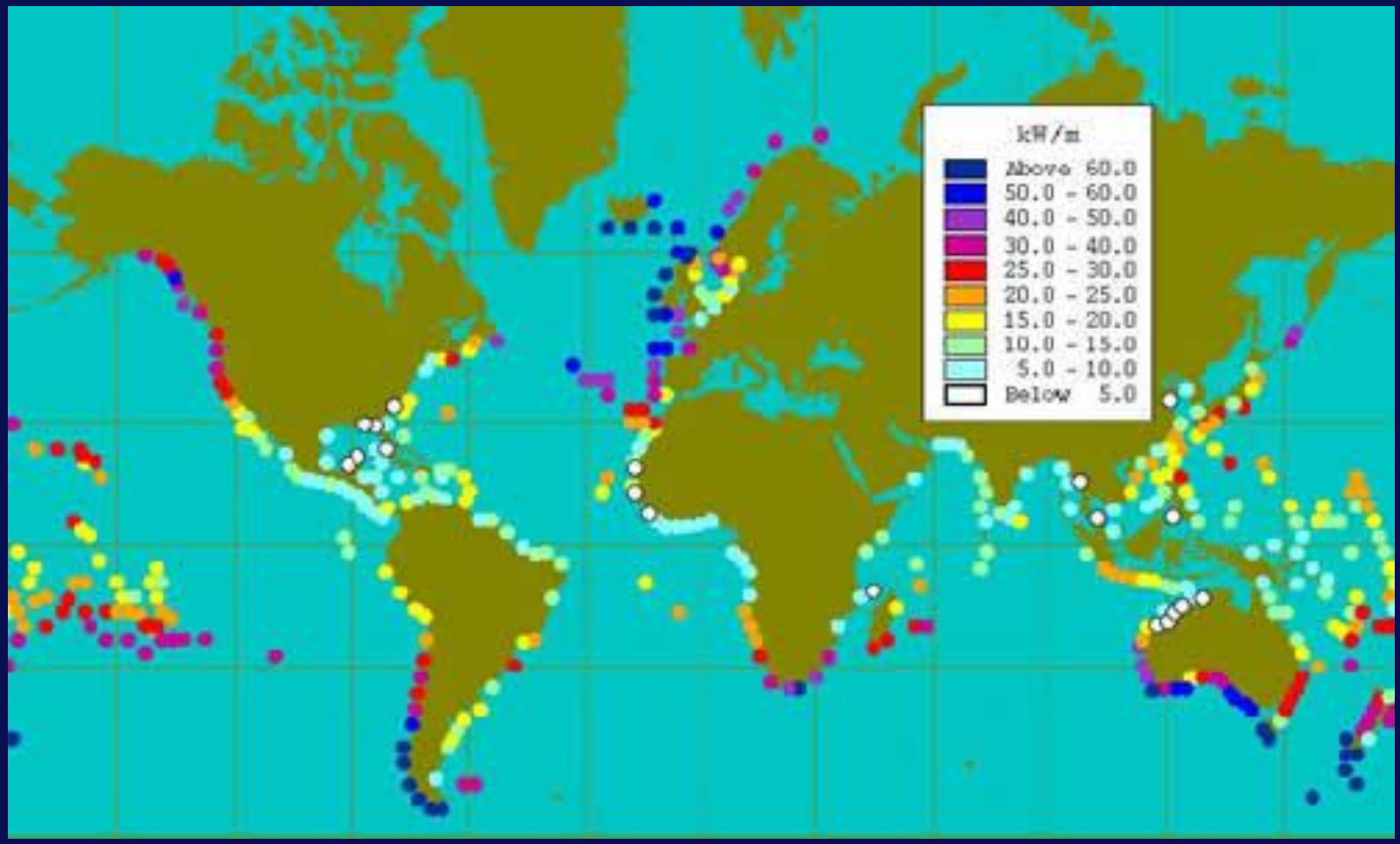
V – Tidal Energy Innovation

Turbine Interaction

Critical to array design & electrical yield

South Africa's Opportunities

South African Wave Energy Opportunity



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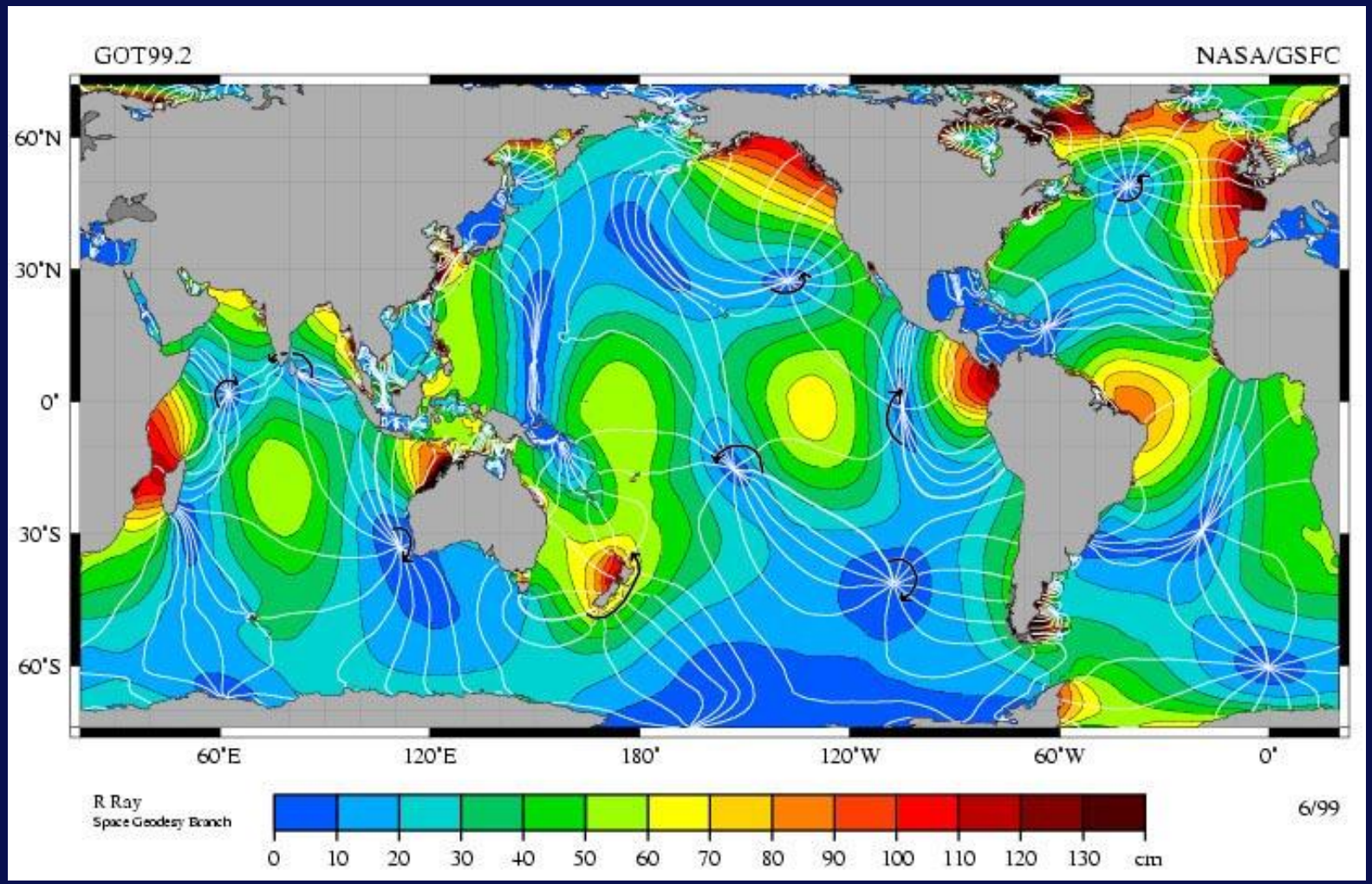
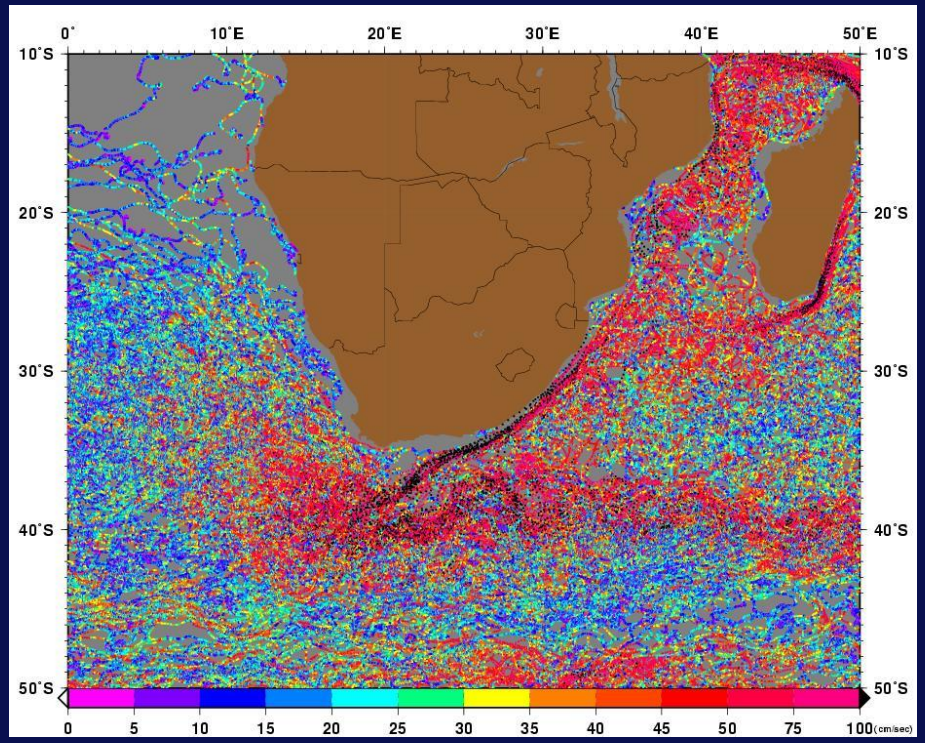
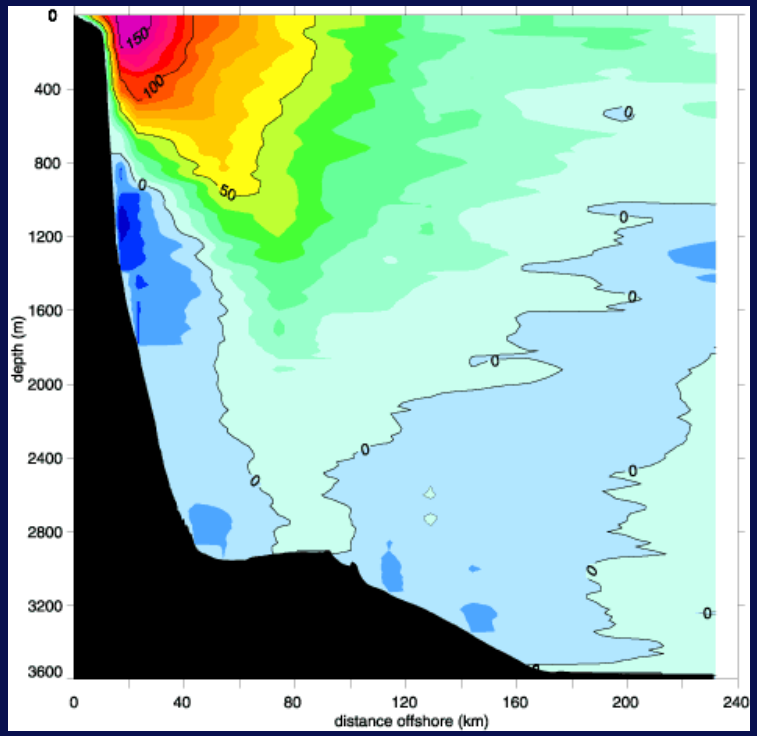
South African Tidal Energy Opportunity



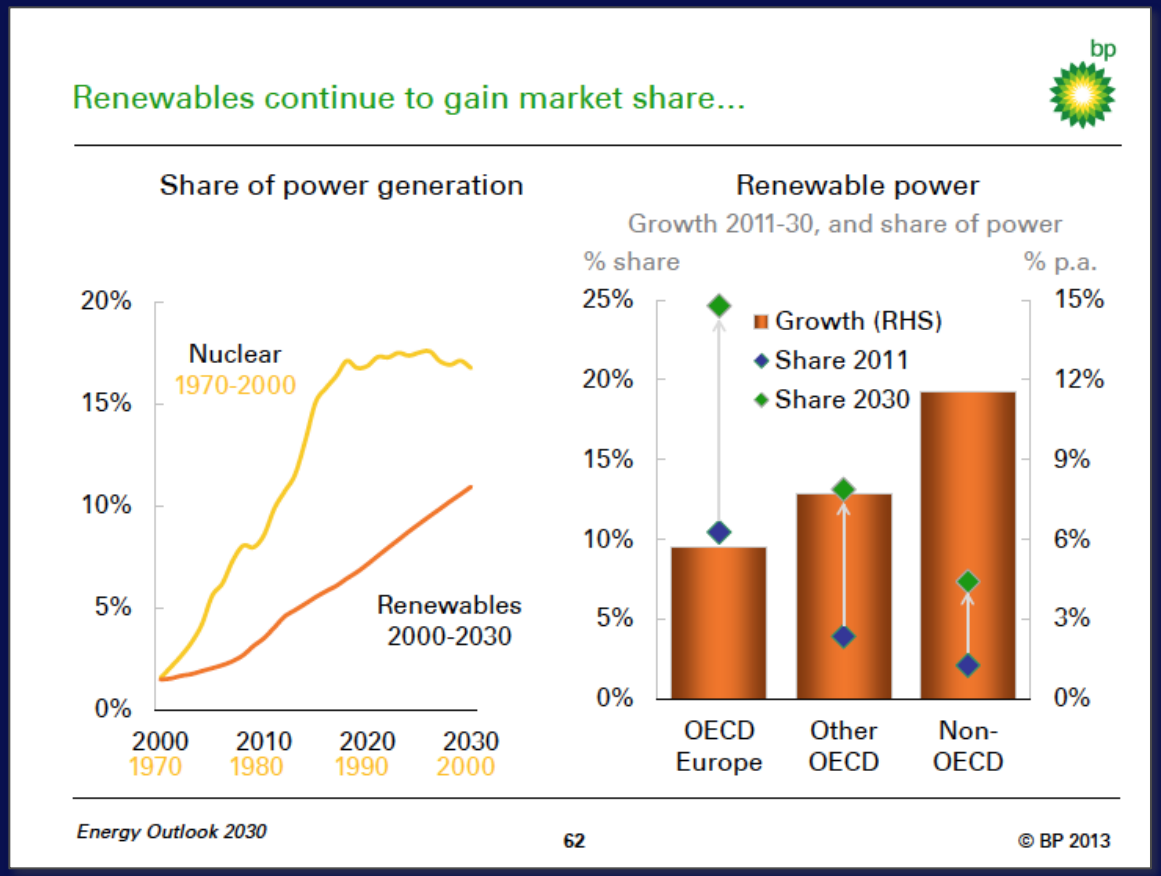
South African Ocean Current Opportunity





South African Business Opportunity

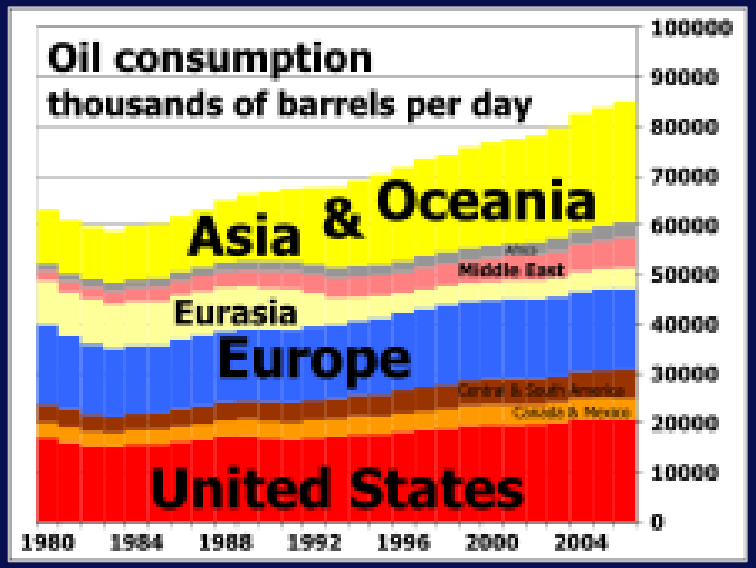
Renewables grow at 8.2% per annum to 2030



Tidal & Wave Energy grow at 64% per annum to 2025

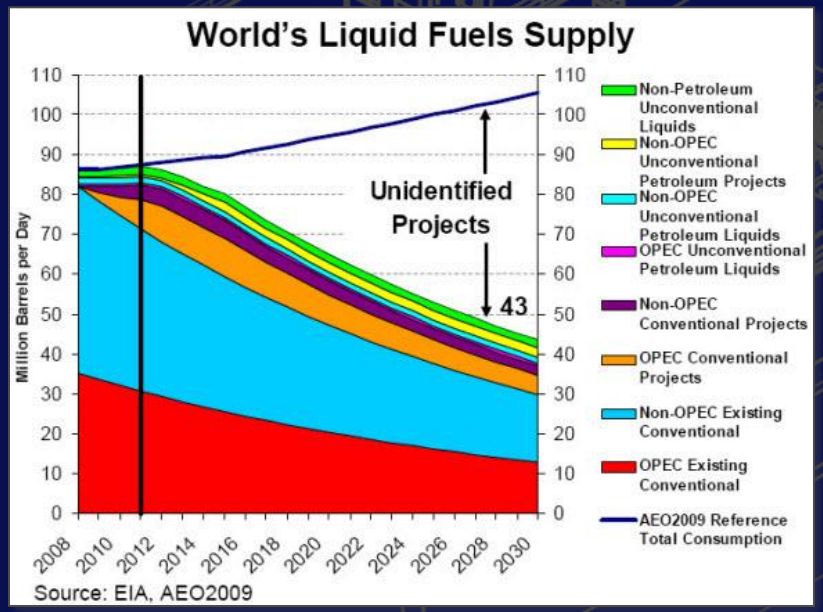
Conclusions

Global Energy Context



Global Demand

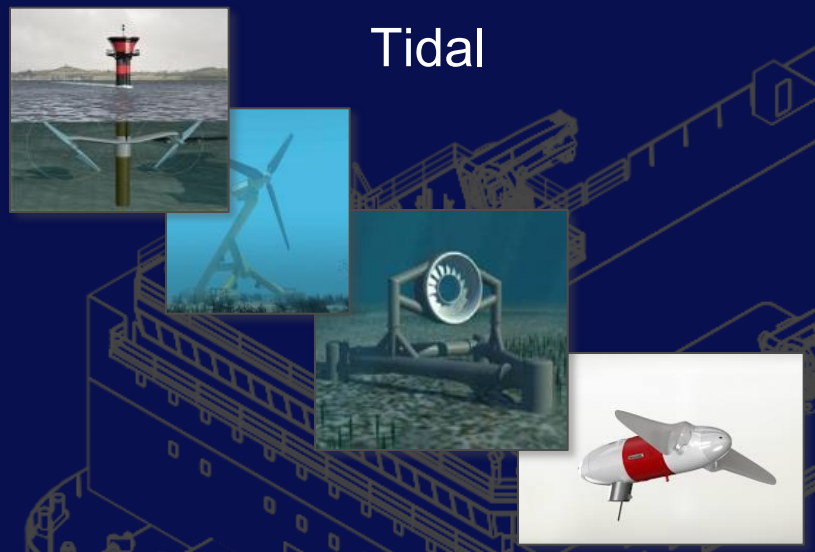
Global Supply



Offshore Renewables

Offshore Wind

Tidal



Wave

HF4

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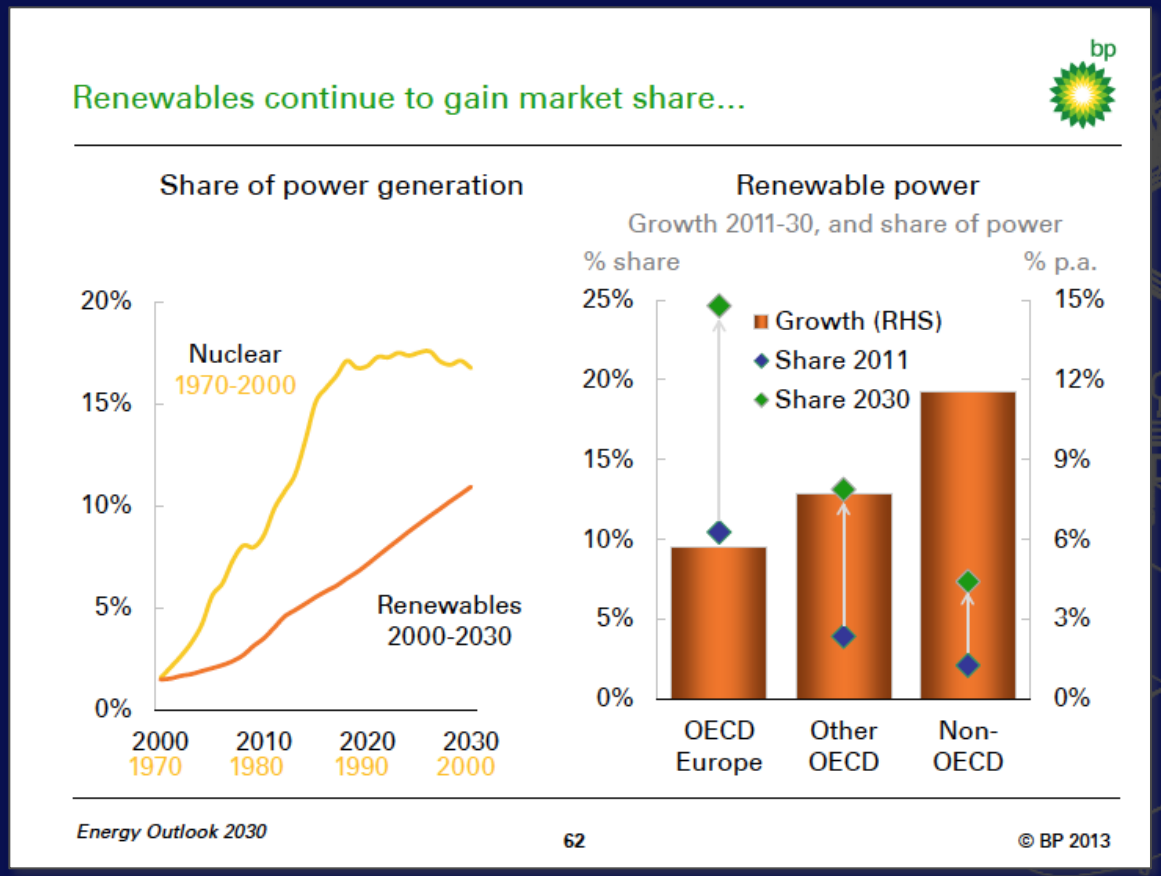
Offshore Energy Supply Cycles

Cycle		Oil & Gas	Offshore Wind	Wave	Tide
Explore		✗ ✗ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
Map		✗ ✗ ✗	✓	✓ ✓	✓ ✓ ✓
Predict	Time	✓ ✓ ✓	✗ ✗	✗ ✗	✓ ✓
	Power	✓ ✓ ✓	✗	✓ ✓	✓ ✓ ✓
	Direction	–	✗	✓ ✗	✓ ✓ ✓
Extract	Technology	✓ ✓ ✓	✓ ✓ ✓	✗	✓
	Balance of Plant	✓ ✓ ✓	✓ ✓	✗	✗ ✗
	Supply Chain	✗ ✗	✓	✓ ✓	✓ ✓
	Cost	✗ ✗	✓ ✓	✗ ✗	✗ ✗ ✗
Field Reserves		✗ ✗ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓
Decommission		✗ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓

The Renewable Energy Outlook

Renewables grow at 8.2% per annum to 2030



Tidal & Wave Energy grow at 64% per annum to 2025

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