



The University of
Nottingham

UNITED KINGDOM • CHINA • MALAYSIA

Reinventing Offshore Wind

IMechE Rugby Branch Meeting,

Nov 7, 2017

Seamus D. Garvey CEng, PhD, MIET, FIMechE
Neville Rieger Prof. of Dynamics

Contents

- **Offshore Wind as a UK resource.**
- **Generation Integrated Energy Storage (GIES)**
- **The *Wild* : Huge turbines compressing air**
- ***TETRAFLOAT - Child of Wild***
- ***WINDTP – Cousin of Wild***
- **Concluding remarks**

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Offshore Wind as a UK Resource

The Offshore Valuation, 2010.

Total practical resource for offshore renewables

Technology	Currently allocated capacity (GW)	Currently allocated capacity (TWh)	Additional practical resource (TWh)	Total practical resource (TWh)
Fixed wind	47	165	241	406
Floating wind	-	-	1,533	1,533
Tidal stream	0.6	2	114	116
Tidal range	-	-	36	36
Wave	0.6	1	39	40
Total	48.2	168	1,963	2,131

UK electricity consumption currently ~1TWh/day ...

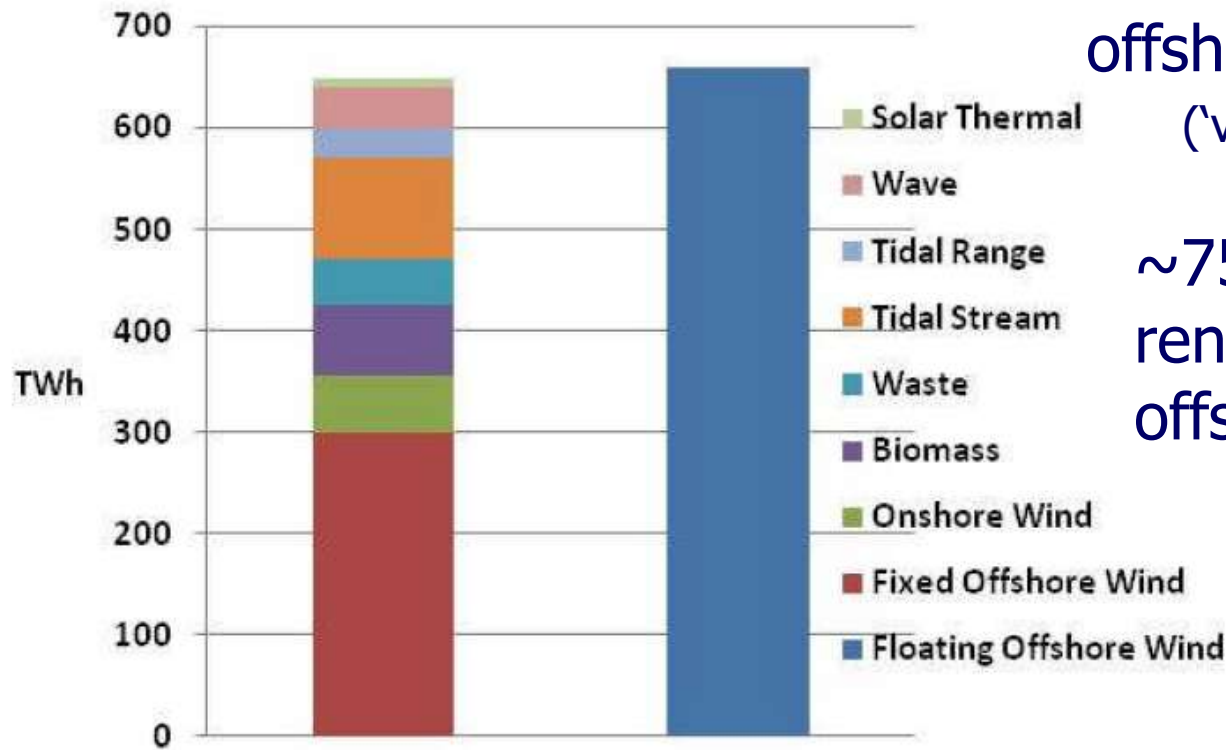
~345TWh/year (2016) – from D.U.K.E.S.

$354 \times 1,000,000 \times 40 = \text{£}15\text{bn}$

Offshore wind is the new *North-Sea Oil* !

Offshore Wind as a UK Resource

UK Renewable Resource Potential



>1000TWh per year
available to UK from
offshore wind alone.

(very conservatively)

~75% of all of our
renewable energy is
offshore wind.

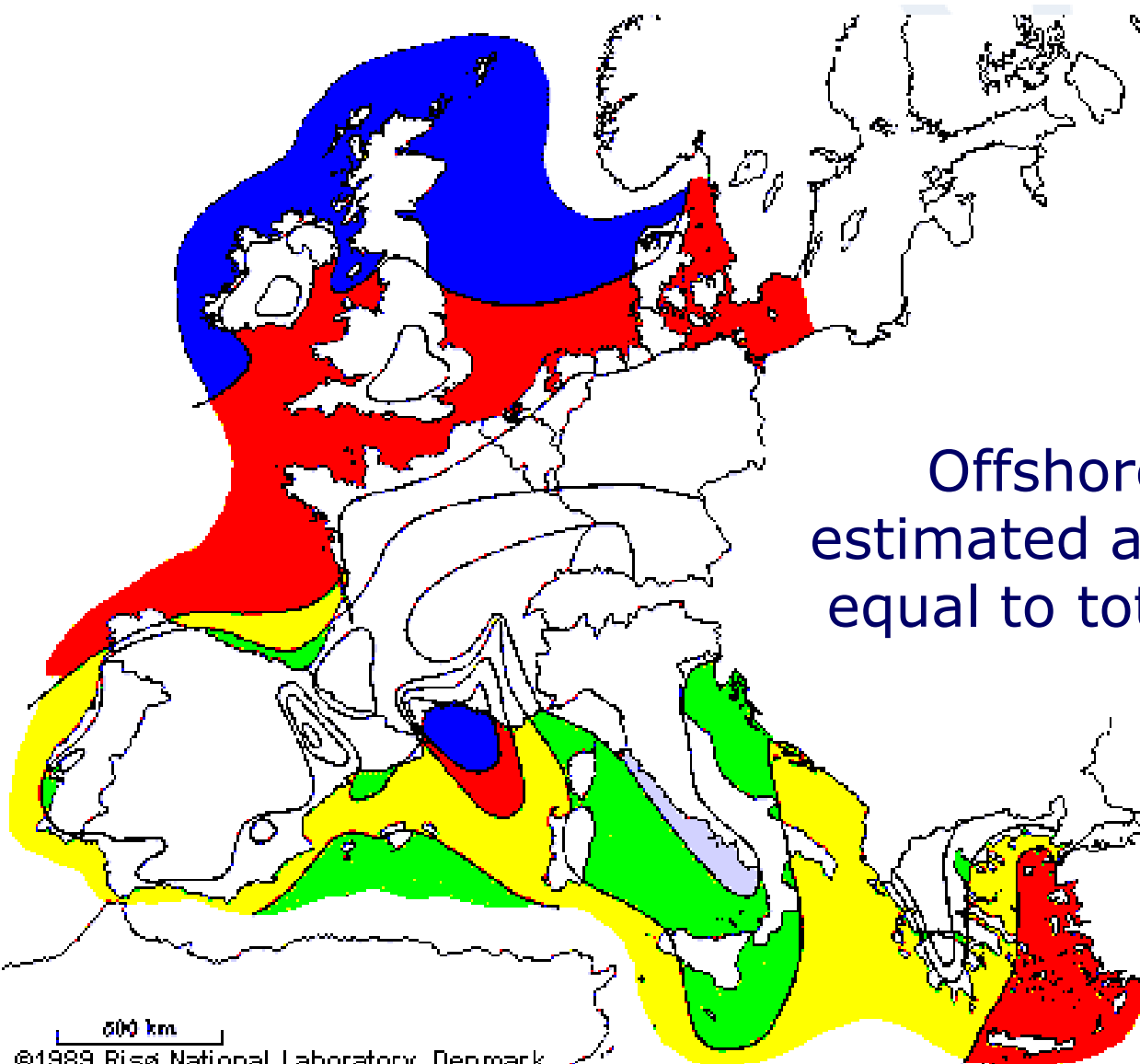
[http://www.all-energy.co.uk/userfiles/
file/andrew-haslett-200510.pdf](http://www.all-energy.co.uk/userfiles/file/andrew-haslett-200510.pdf)

Offshore Wind as a UK Resource

UK & Ireland have,
by far, the best
offshore renewables
resources in Europe.

Offshore resource in Europe
estimated at 3000 TWh / year –
equal to total Europe Electricity
Consumption.

[http://www.nowireland.ie/pdf/
PDowlingPresentation.pdf](http://www.nowireland.ie/pdf/PDowlingPresentation.pdf)



Offshore Wind as a UK Resource

Renewables are reaching “grid-parity” in terms of LCoE.

- Borssele wind farm, €72.70/MWh[§], July 2016.
- Kriegers Flak wind farm, €49.50/MWh[§], Sept 2016.
- UK CfD auctions: Sept 11, 2017
£74.75/MWh .. for projects delivered in 2021/2022
£57.50/MWh .. for projects delivered in 2022/2023



Booming offshore market lifts
MAKE global wind outlook

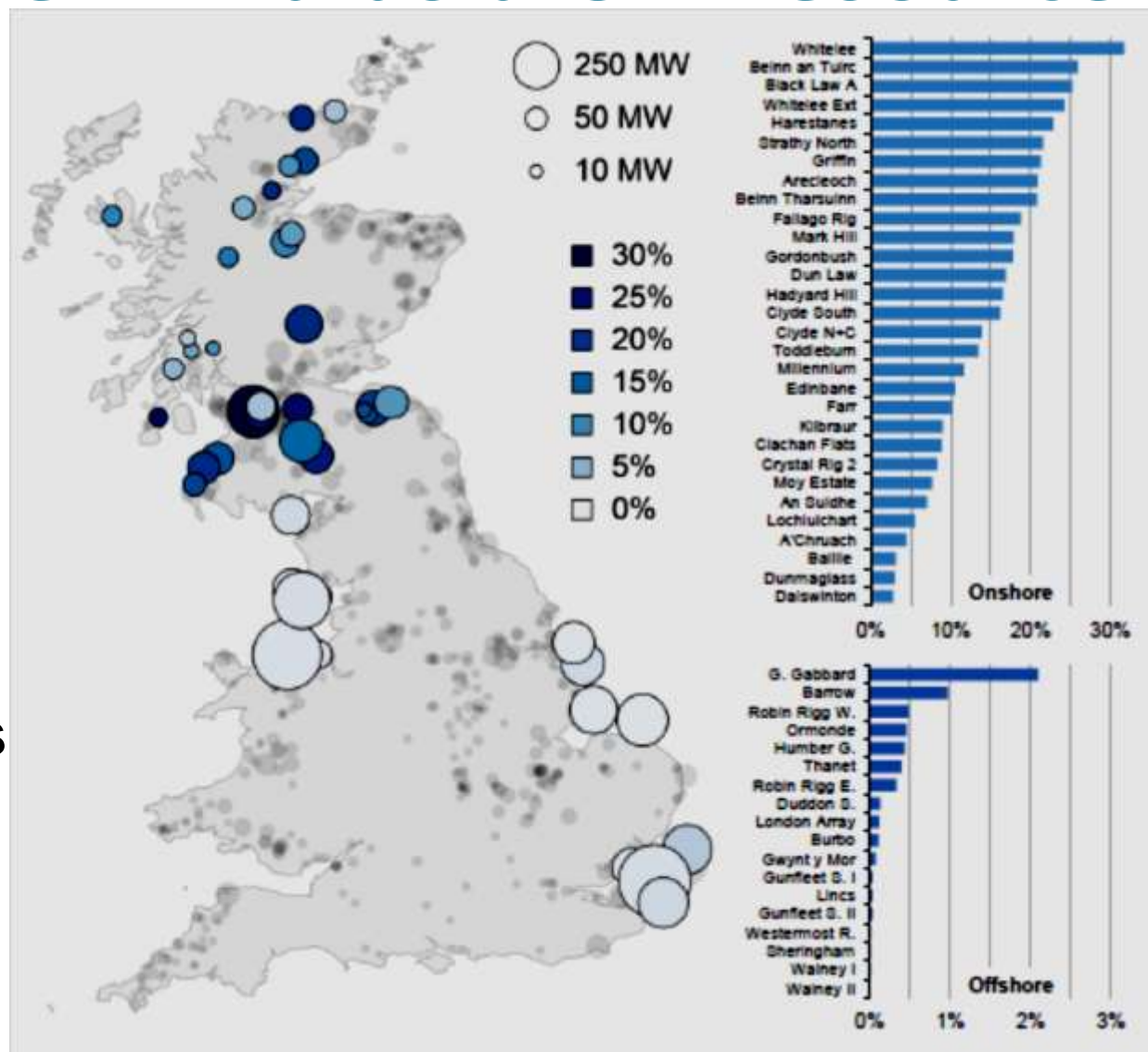
 We expect to see
average auction prices
of €30-40/MWh
over most European
markets by 2025

§ These costs exclude costs of the electrical connection.

Offshore Wind as a UK Resource

Small penetrations of wind (or other inflexible) power in electricity systems dominated by fossil-fuelled generation present no problem.

Larger penetrations ... not so easy.



From: M Joos and I Staffell, *Short term integration costs of variable renewable energy: Wind curtailment and balance in Britain and Germany*. Renewable and Sustainable Energy Reviews, (To Appear)

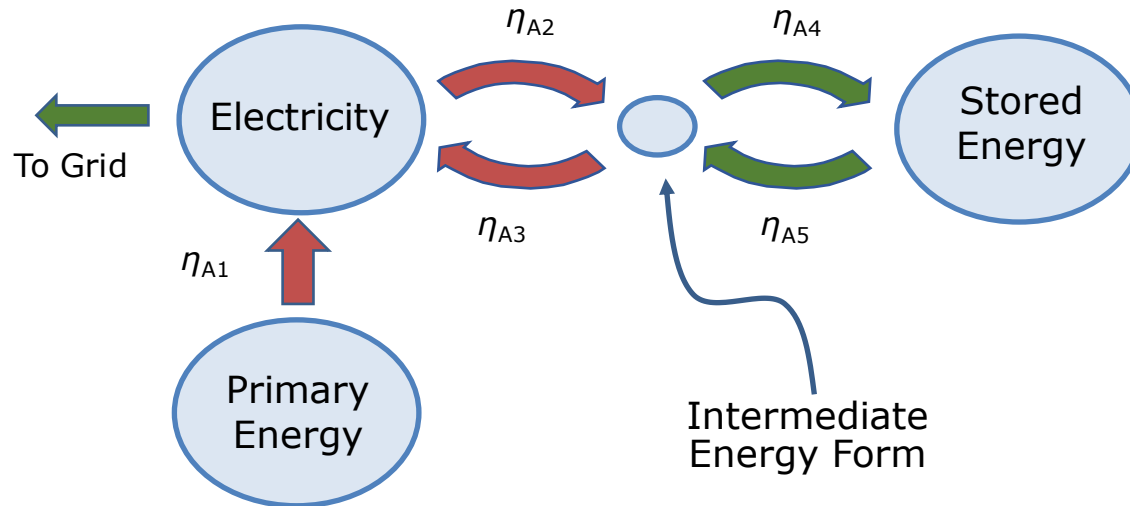
IMechE, Rugby Branch Meeting, Nov. 7, 2017

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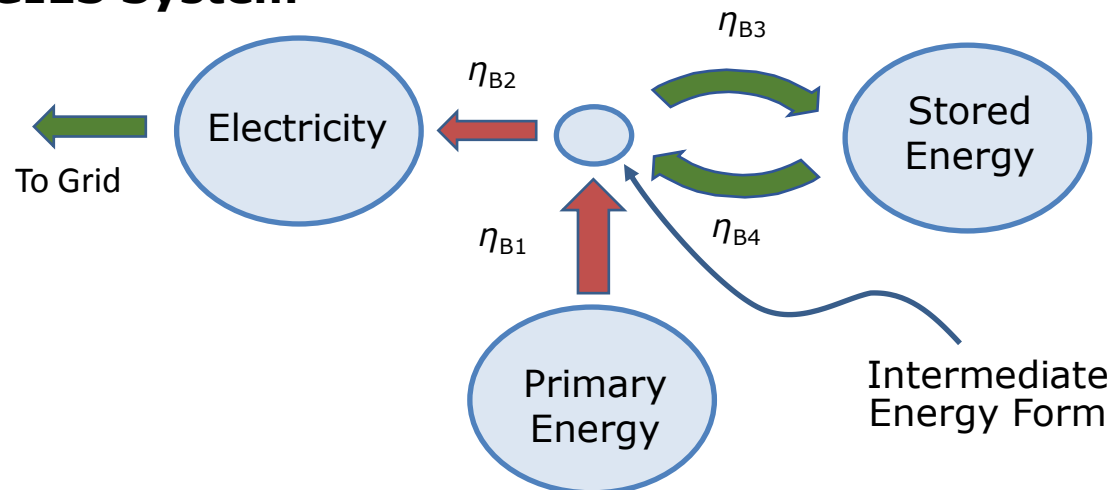
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Generation Integrated E.S.

A) Non-GIES System



B) GIES System



GLIES – examples

SLIDE-SNATCH ... from Keith MacLean, ERP.
(From Scoping workshop for *Barriers to E.S.*)



1 Wh

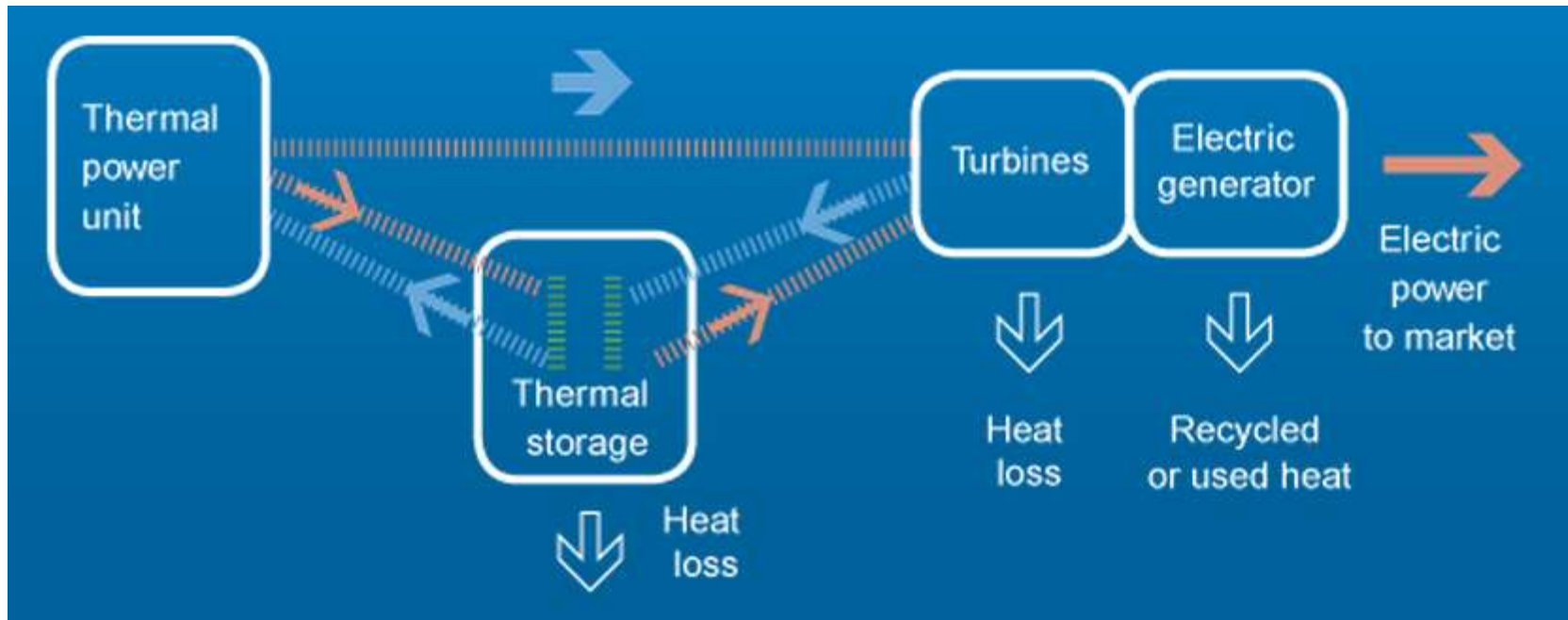
OR



1,000,000,000,000 Wh

GIES – examples

Integrated energy storage being developed for thermal power stations



www.energy-nest.com

GIES – examples

Integrated energy storage is a feature of ALL natural hydro-power.



Itaipu Dam
Brazil / Paraguay
12.6 GW

GIES – examples

Generation Integrated Energy Storage already exists
for Concentrated Solar Power (CSP)



Andasol III (Spain)
50 MW, 7.5 hrs storage



GIES – examples

Bio-mass is a form of GIES.



Miscanthus
(from SEWTHA)



Wood pellets.

(<http://www.thegreenage.co.uk/tech/biomass-boiler/>)

GIES – examples

This open-access paper says all the general stuff !

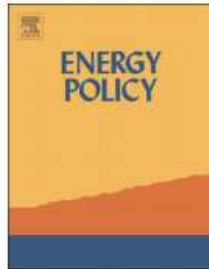
Energy Policy 86 (2015) 544–551



Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol



On generation-integrated energy storage



S.D. Garvey^{a,*}, P.C. Eames^b, J.H. Wang^c, A.J. Pimm^a, M. Waterson^c, R.S. MacKay^c,
M. Giulietti^c, L.C. Flatley^c, M. Thomson^b, J. Barton^b, D.J. Evans^d, J. Busby^d, J.E. Garvey^e

^a University of Nottingham, United Kingdom

^b Loughborough University, United Kingdom

^c University of Warwick, United Kingdom

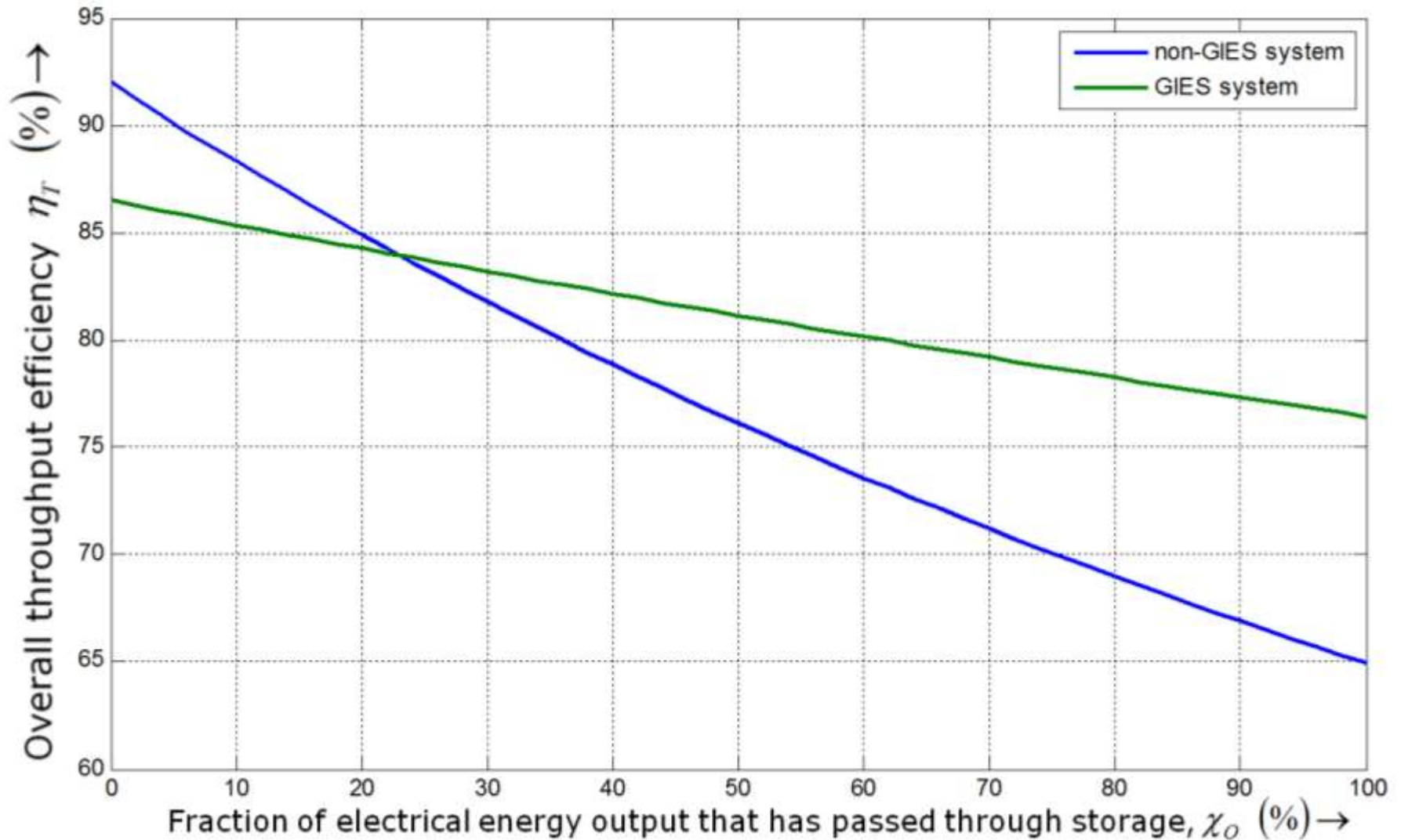
^d British Geological Survey, United Kingdom

^e University of Leeds, United Kingdom



<http://www.sciencedirect.com/science/article/pii/S0301421515300458>

GIES – performance



$$\eta_T = \eta_X \times [1 - \chi_I] + \chi_I \times \eta_S$$

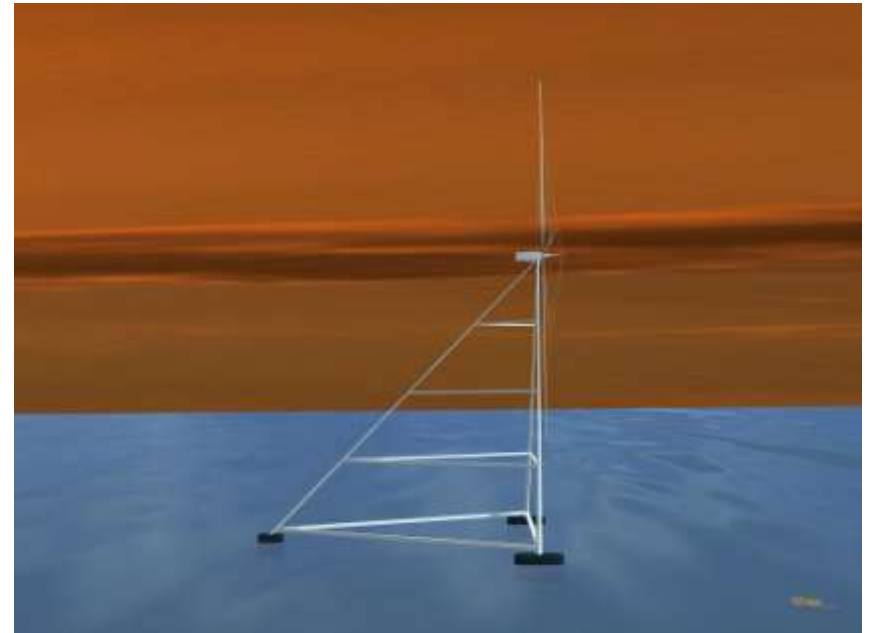
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Wild concept – the ICWTs.

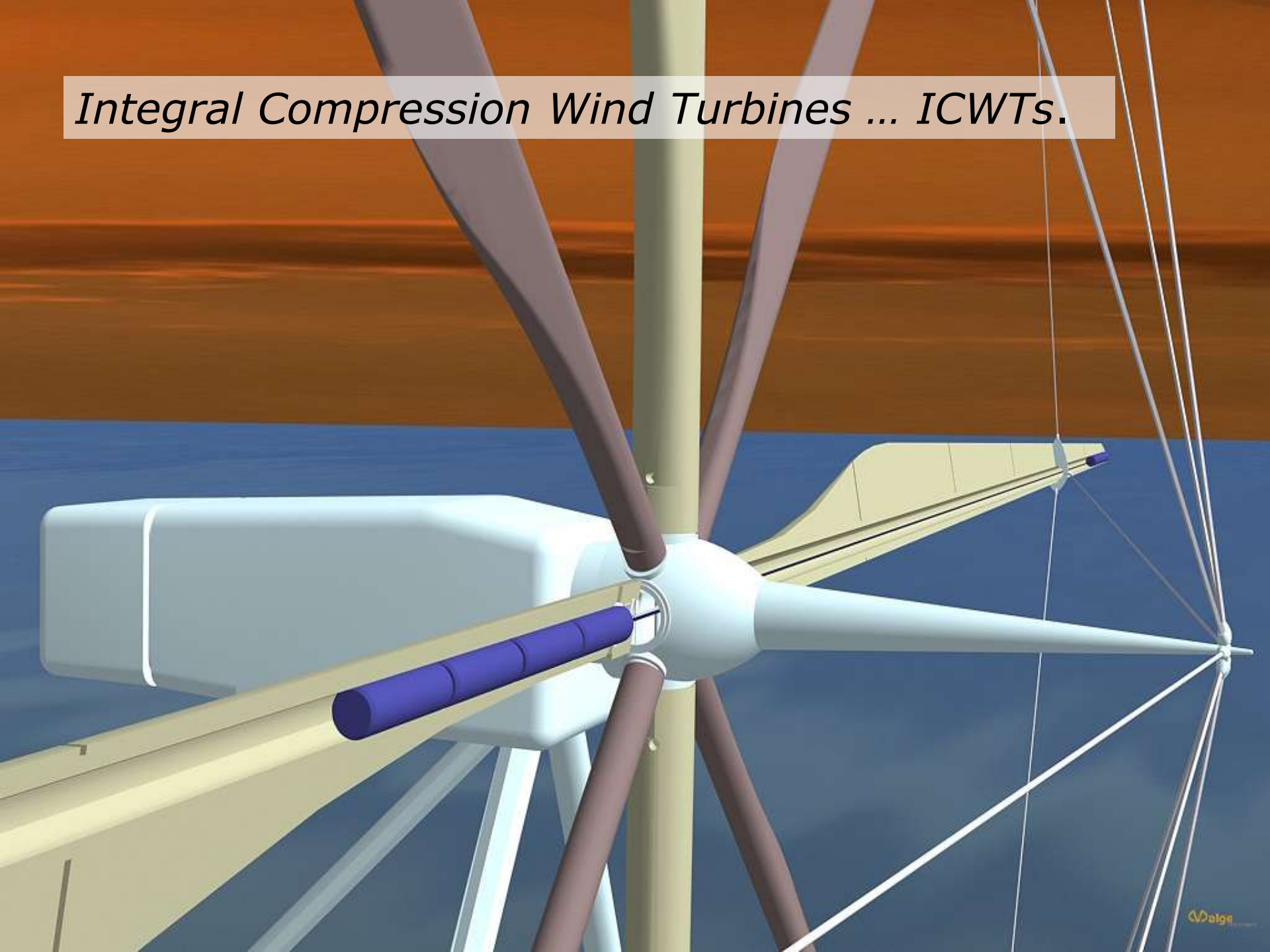
ICWTs = Integral Compression Wind Turbines.

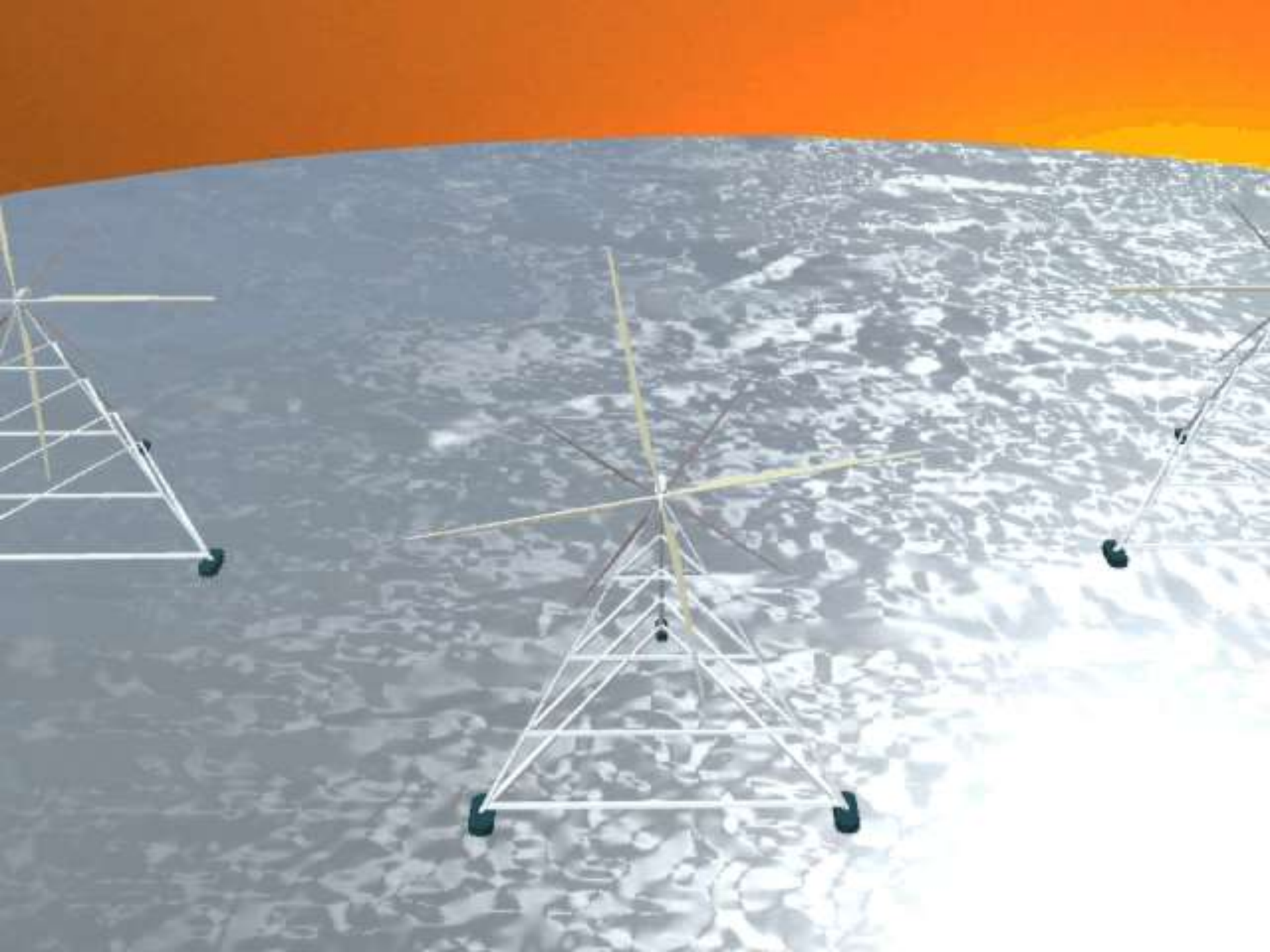
(Offshore only) One can engineer floating wind turbines that compress air directly and are relatively inexpensive^[1] per kWh(e) ultimately produced.



[1] Garvey, S.D.. *Structural Capacity and the 20MW Wind Turbine*, IMechE Jrnl. of Power & Energy, Dec 2010. Vol 224 pp1083-1115. (Arthur Charles Main Prize, 2011).

Integral Compression Wind Turbines ... ICWTs.

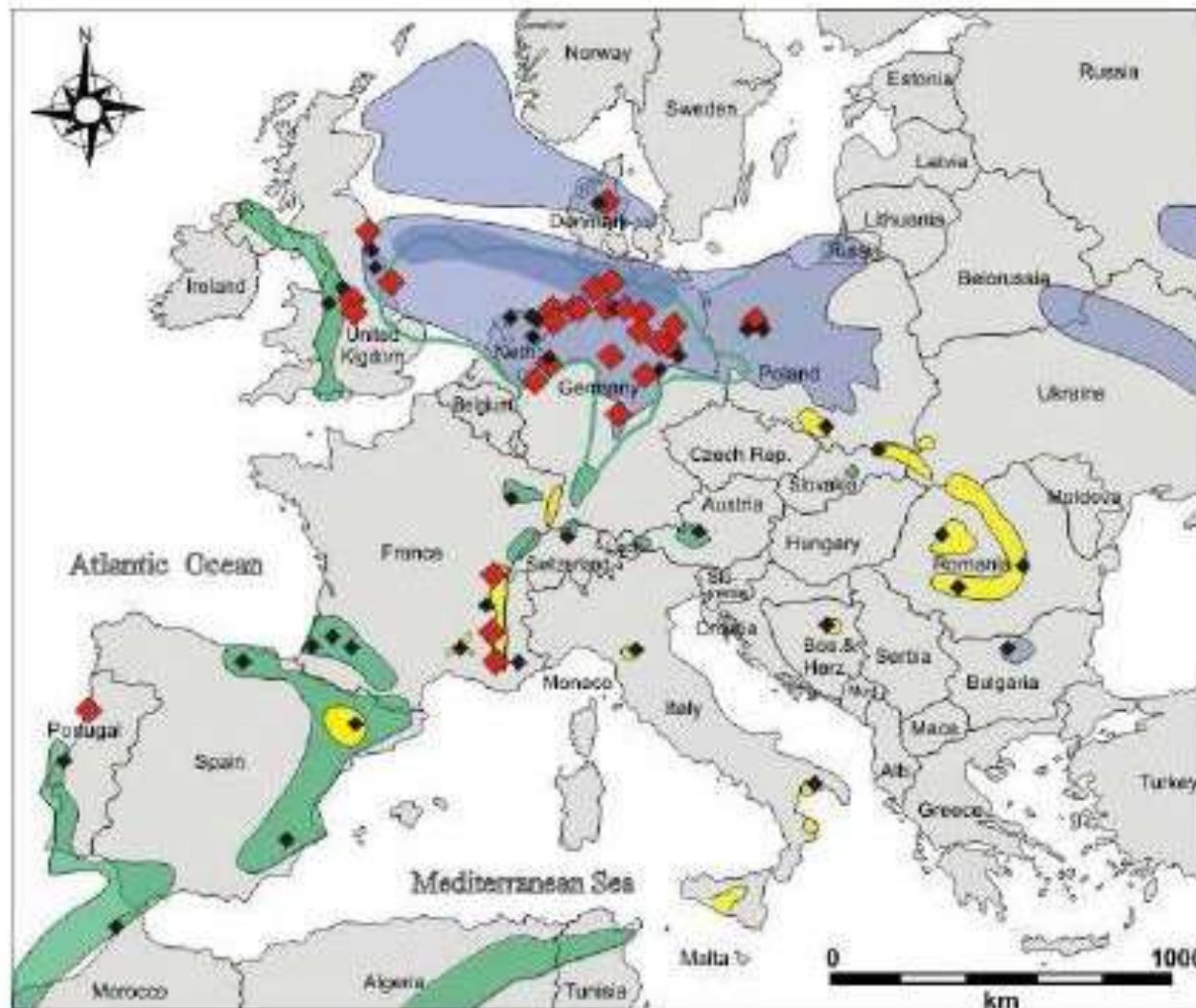




HP air storage for the ICWTs

Where might one store pressurised air offshore ... ?

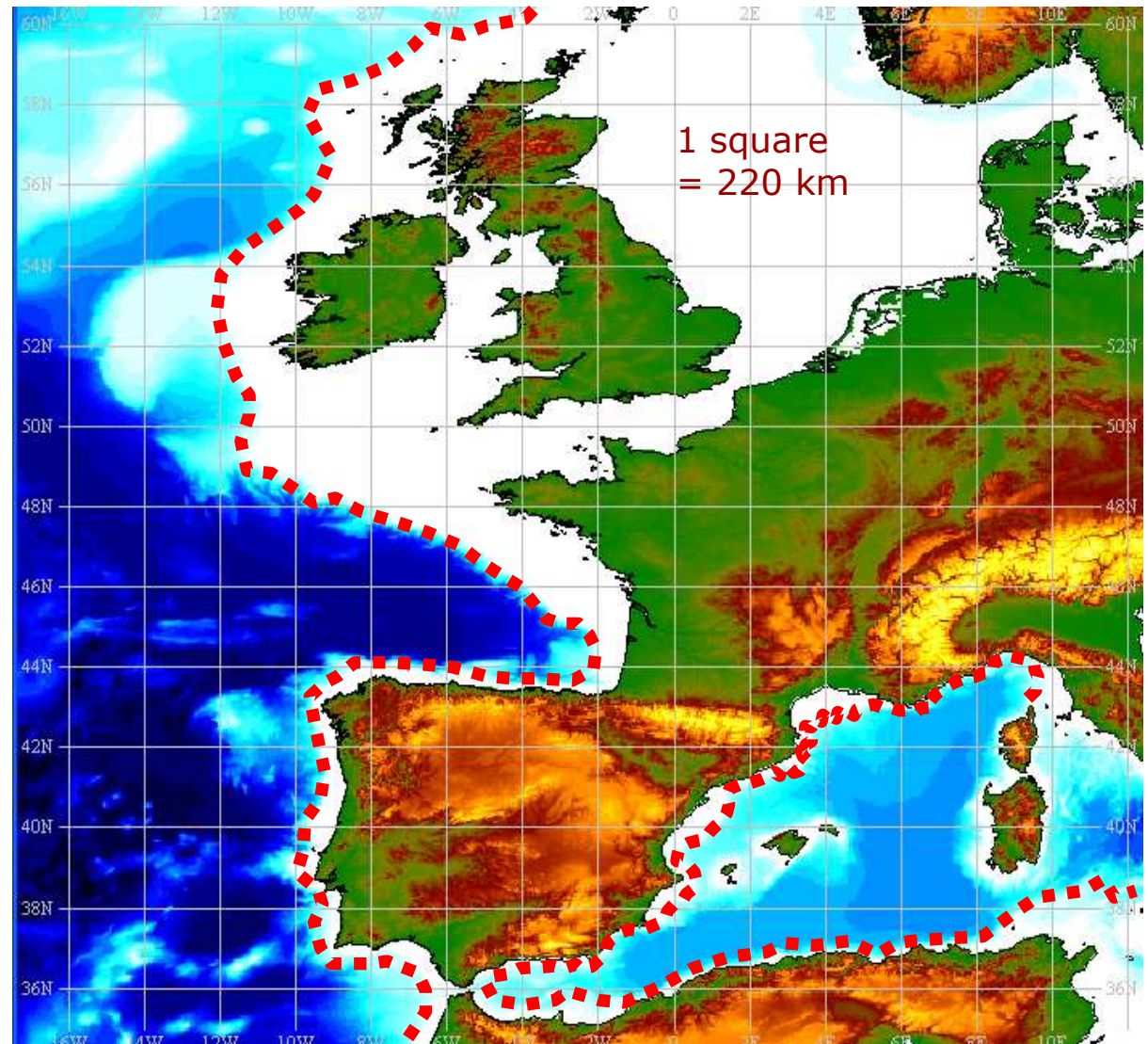
The North Sea has salt deposits



Salt cavern fields

- ◆ Gas Storage
- ◆ Storage of Crude Oil & LPG, Brine Production
- Tertiary salt deposit
- Mesozoic salt deposit
- Range of Mesozoic salt above Permian
- Paleozoic salt deposit, Permian
- Paleozoic salt deposit, Rotliegend below Permian

Much more can be said about where and how HP air can be stored underwater.



The ICWTs + Energy Bags

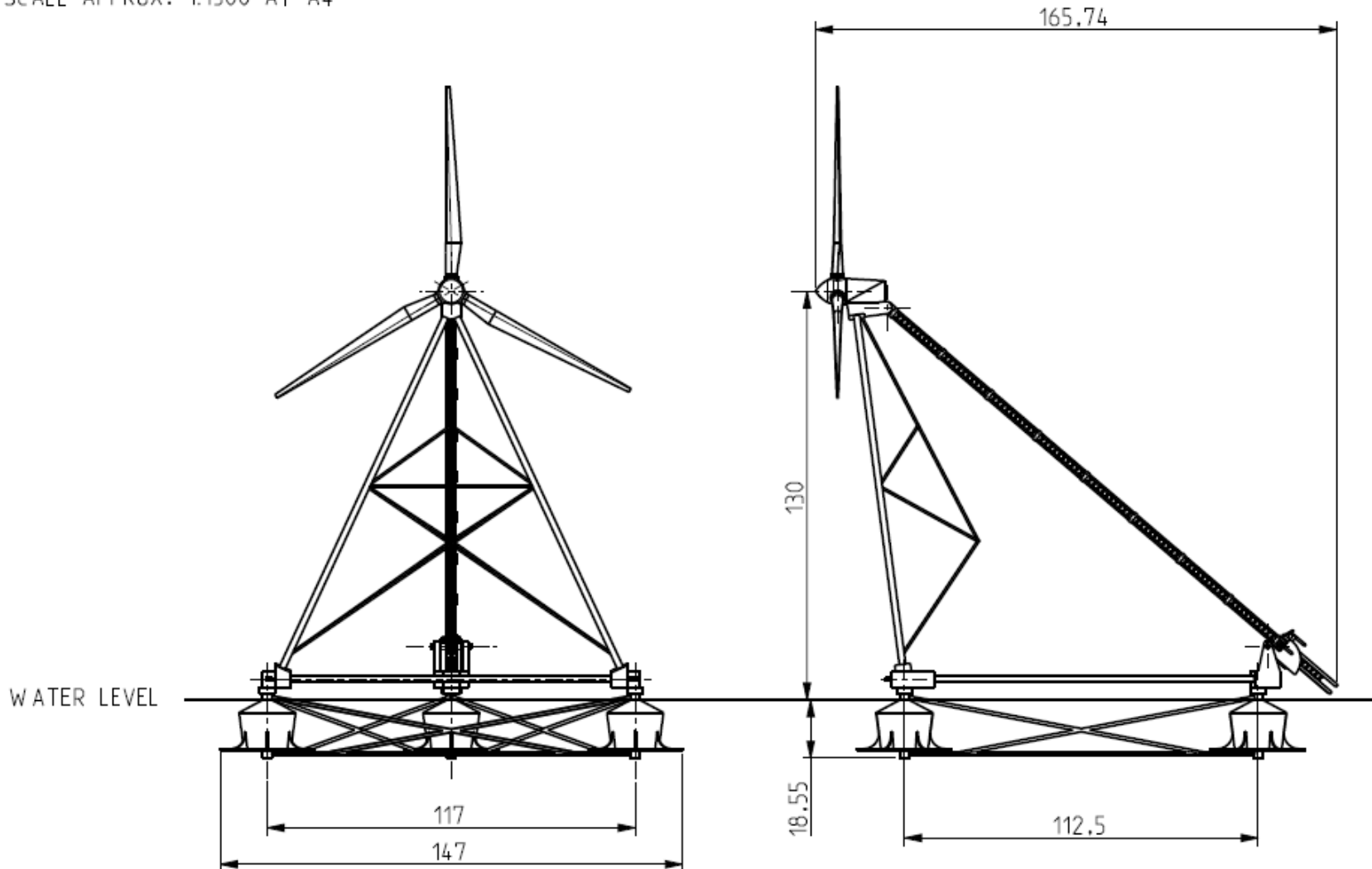
- In ~2007, the UK looked set to install possibly ~35GW of offshore wind by 2035 at £3M/MW \Rightarrow >£100Bn.
- The *Structural Capacity* ... paper explains why the ICWTs demand substantially less (<50%) structural material than their direct-generating counterparts.
- >20MW wind turbines seemed unthinkably large then ...
- EPSRC proposal in mid 2011 sought ~£1M to explore. Proposal scored 6H, 6H, 3M but came bottom of the pile. “Too risky” ($(£1\text{M} / £50\text{Bn}) = 0.002\%$).
- Realistically: total redesign of offshore wind turbines was never going to be an easy sell!

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TETRAFLOAT: Floating Platform

SCALE APPROX. 1:1500 AT A4



TETRAFLOAT: Floating Platform

TETRAFLOAT is a floating support structure for upwind offshore wind turbines that ...

- * Uses material optimally.

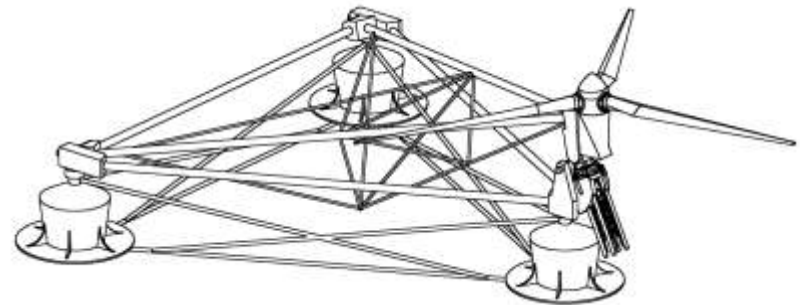
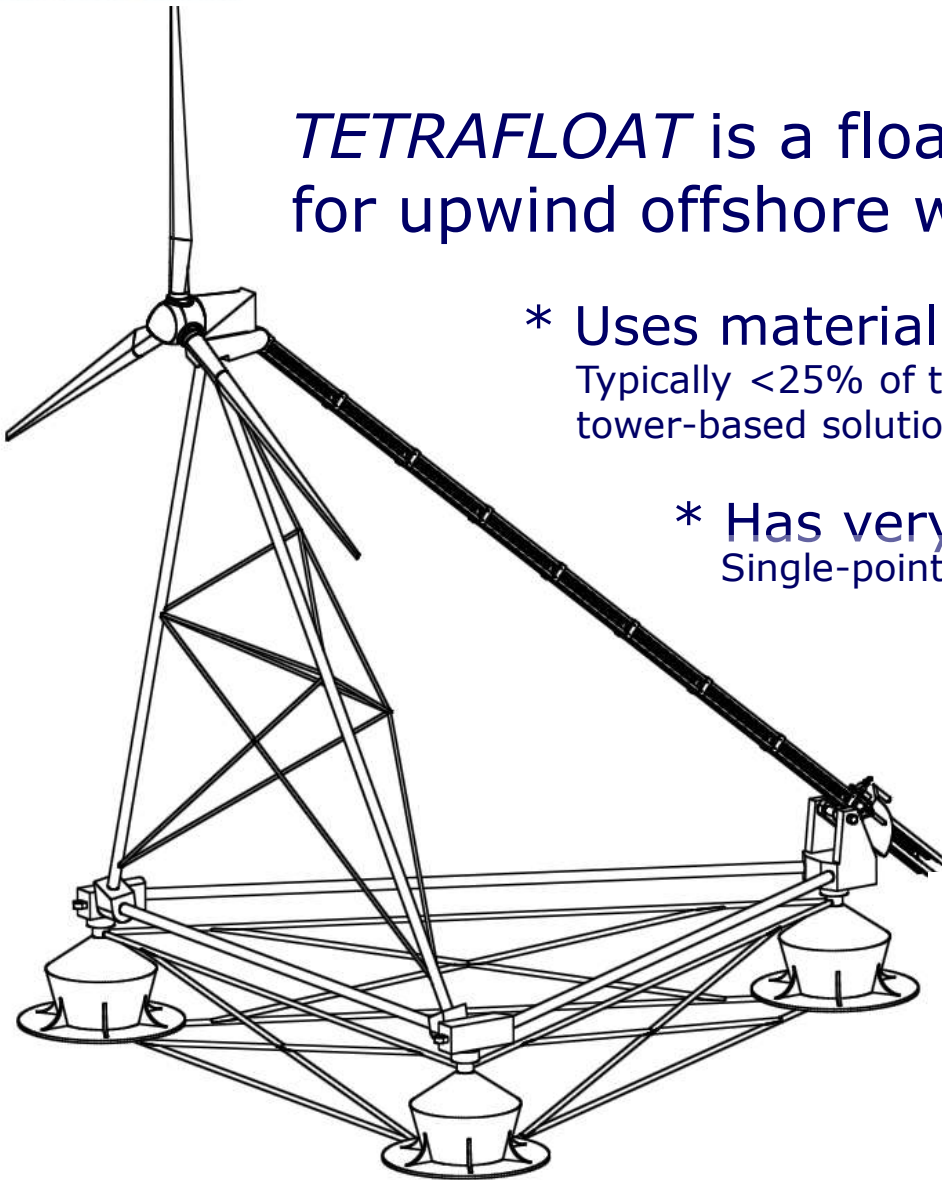
Typically <25% of the material needed for any tower-based solution (including other floaters).

- * Has very simple seabed fixing

Single-point mooring – with no turning moments.

- * Facilitates O&M

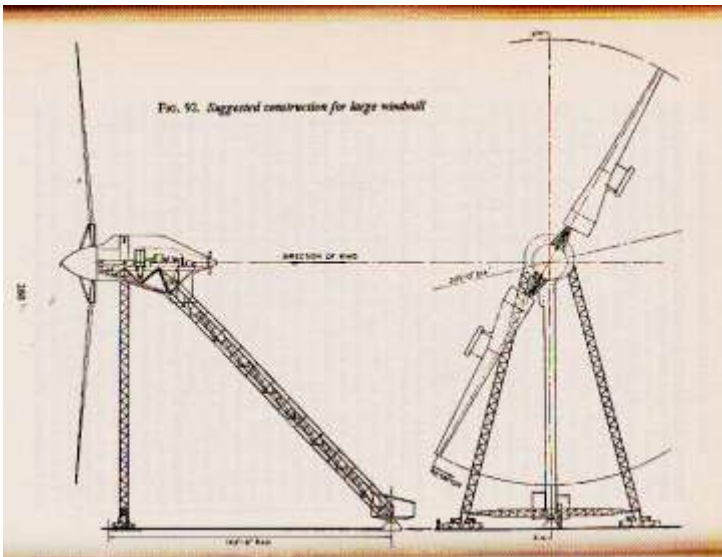
No crane needed to lower/raise the turbine head.



TETRAFLOAT: Floating Platform



The tetrahedron is the simplest and most material-efficient structure.



TETRAFLOAT: Floating Platform



TETRAFLOAT Ltd.

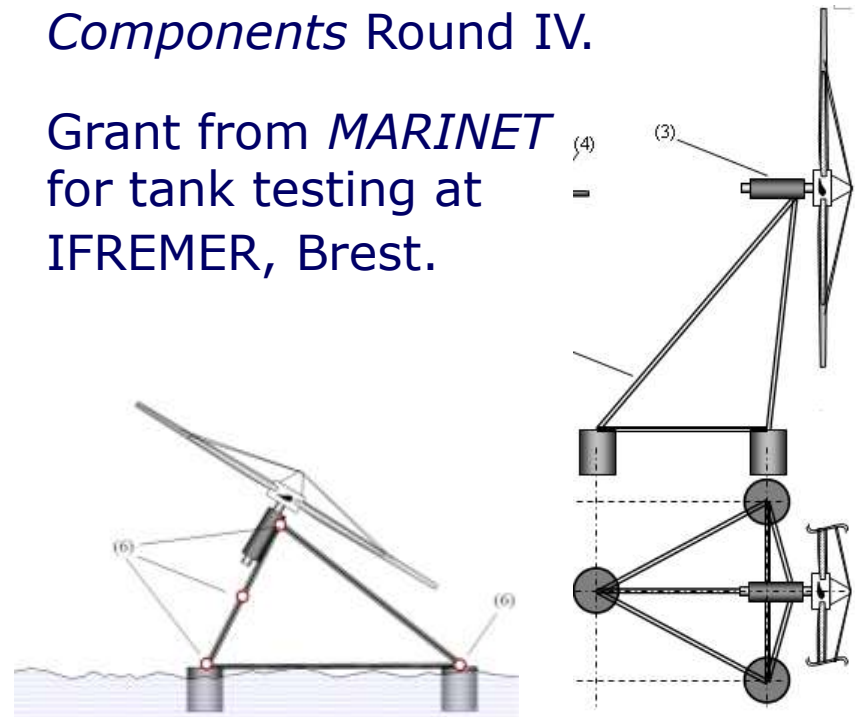
Sir Colin Campbell Building

Triumph Road, Nott'm NG7 2TU

Holds a granted UK patent on the
main concept: **GB2466477**
applied for in Nov. 2008

Grant from *DECC Offshore Wind
Components* Round IV.

Grant from *MARINET*
for tank testing at
IFREMER, Brest.



TETRAFLOAT: Floating Platform

CAPEX	£000s/MW
Project Consenting and Development to FID	150
Project management from FID to WCD	35
Construction phase insurance	40
Turbine (exc. Tower)	1,148
Support structure (inc. tower)	616
Array cables	79
Installation	406
Transmission build	380
Construction contingency	270
Total CAPEX	3,125

OPEX	£000s/MW/yr
Operations & maintenance (planned & unplanned, figures relate to post-warranty cost)	65
Operating phase insurance	16
Transmission charges (G-TNUoS)	8
Total OPEX	89

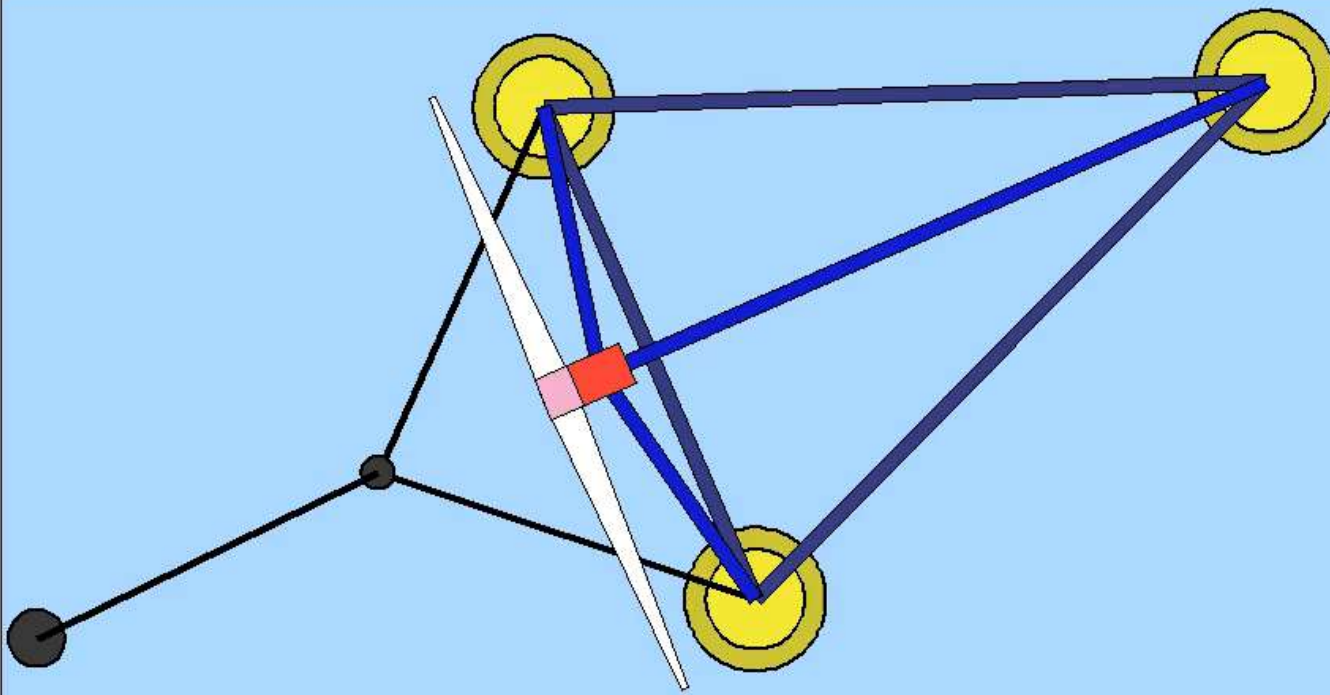
TetraFloat can potentially account for

~13% reduction on LCoE
(*Levelised Cost of Energy*)
overall for UK offshore wind.

TetraFloat changes these costs ...

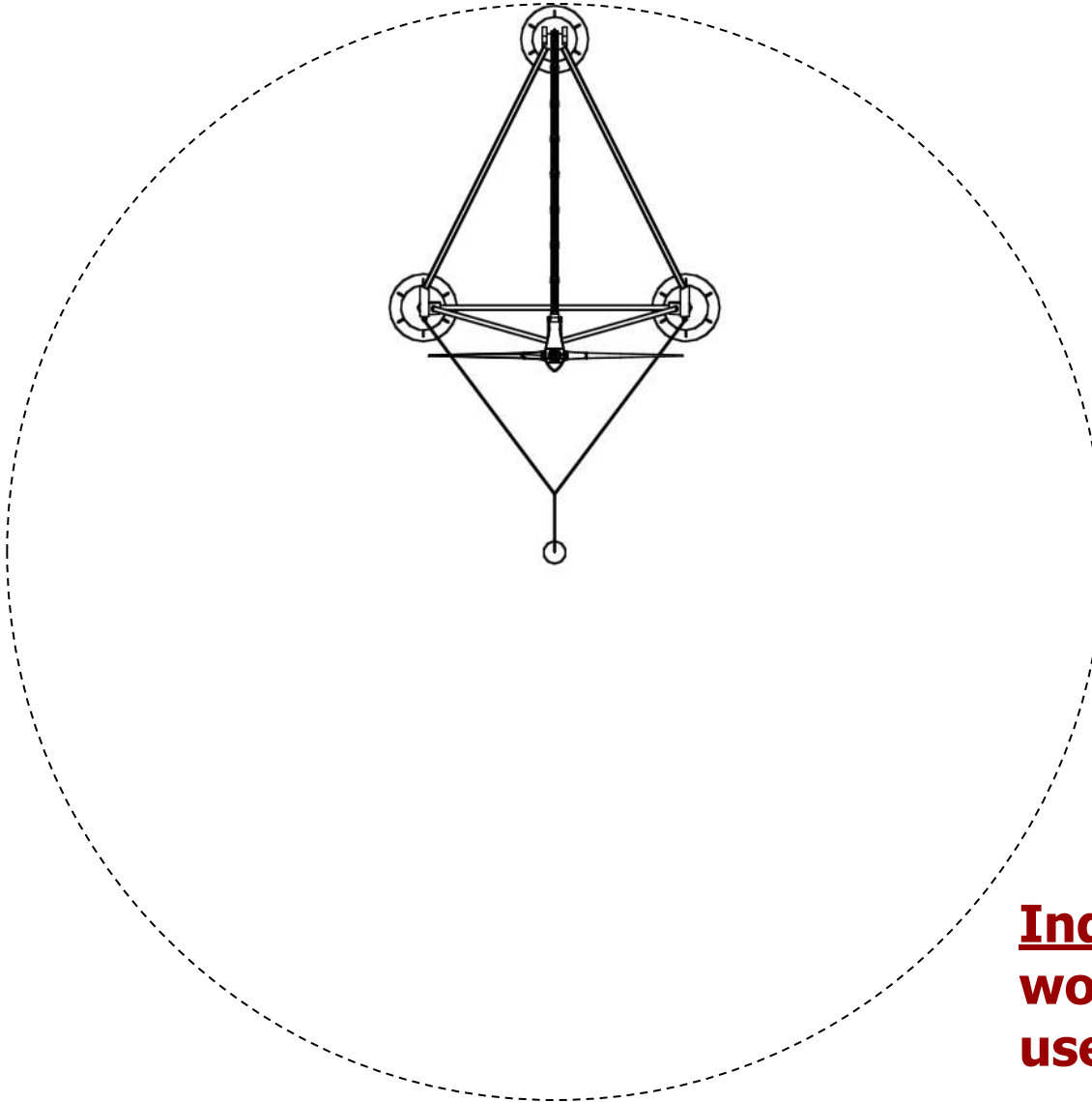
Support Structure	... ↘ 50%
Installation	... ↘ 25%
Construction contingency	... ↘ 25%
Operations & Maintenance	... ↘ 20%
Decommissioning costs	... ↘ 50%

**DECC/Crown-Estate Calculator for
Levelised Cost of Energy for Offshore Wind.**



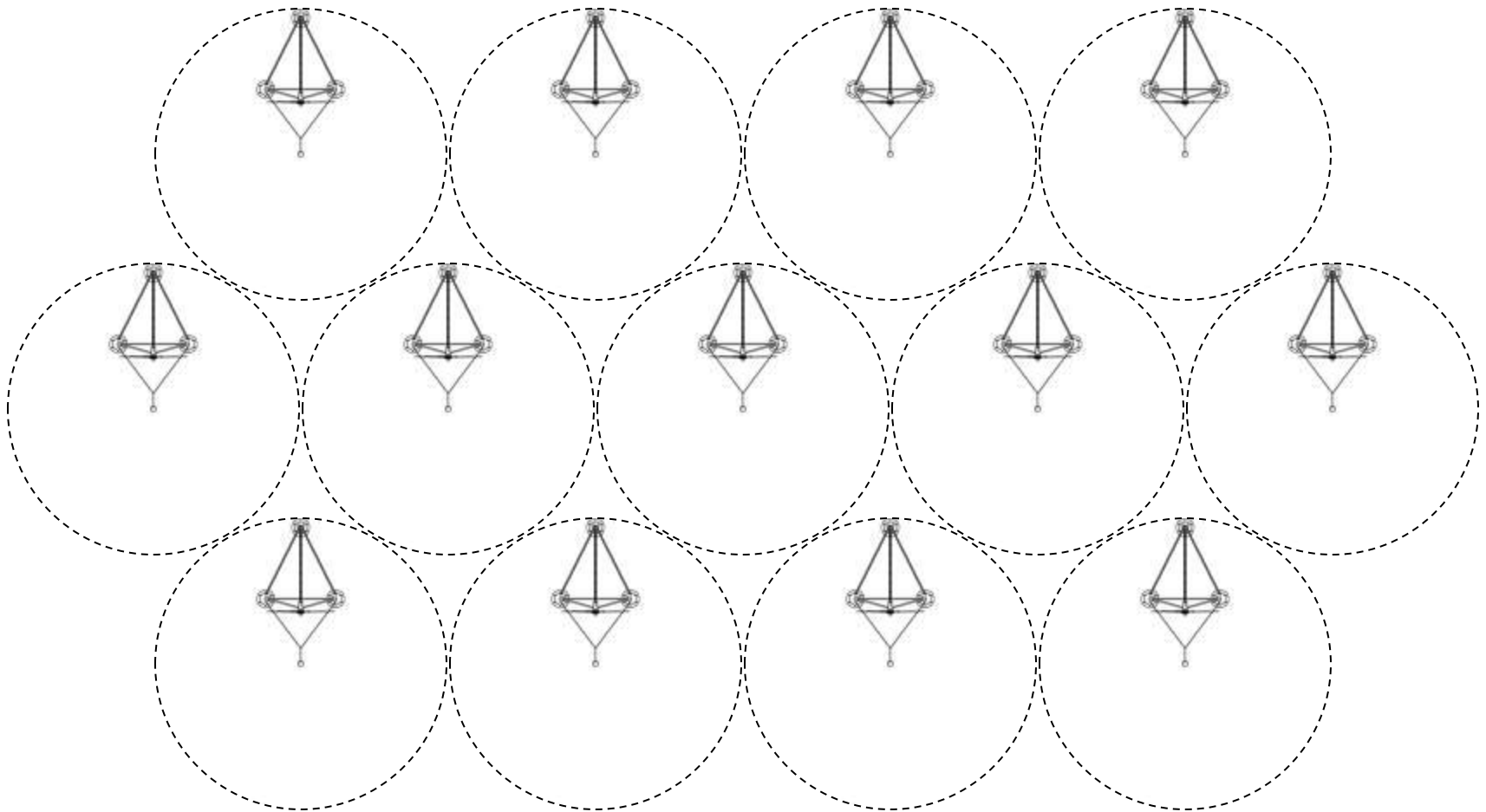
Yaw Mechanism #1 :- pure weathervaning

TETRAFLOAT: Floating Platform



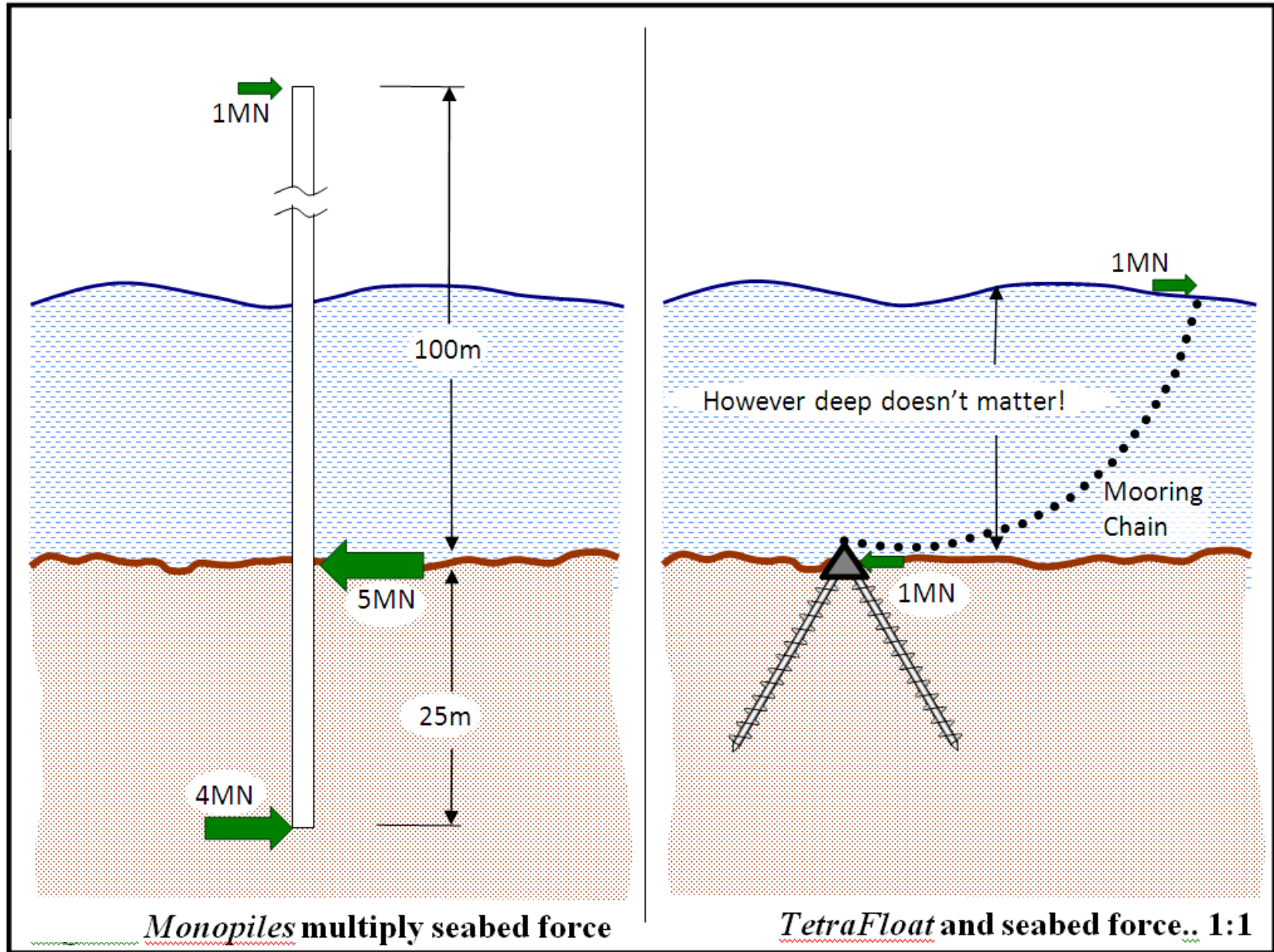
**Individual units
would make poor
use of space.**

TETRAFLOAT: Floating Platform

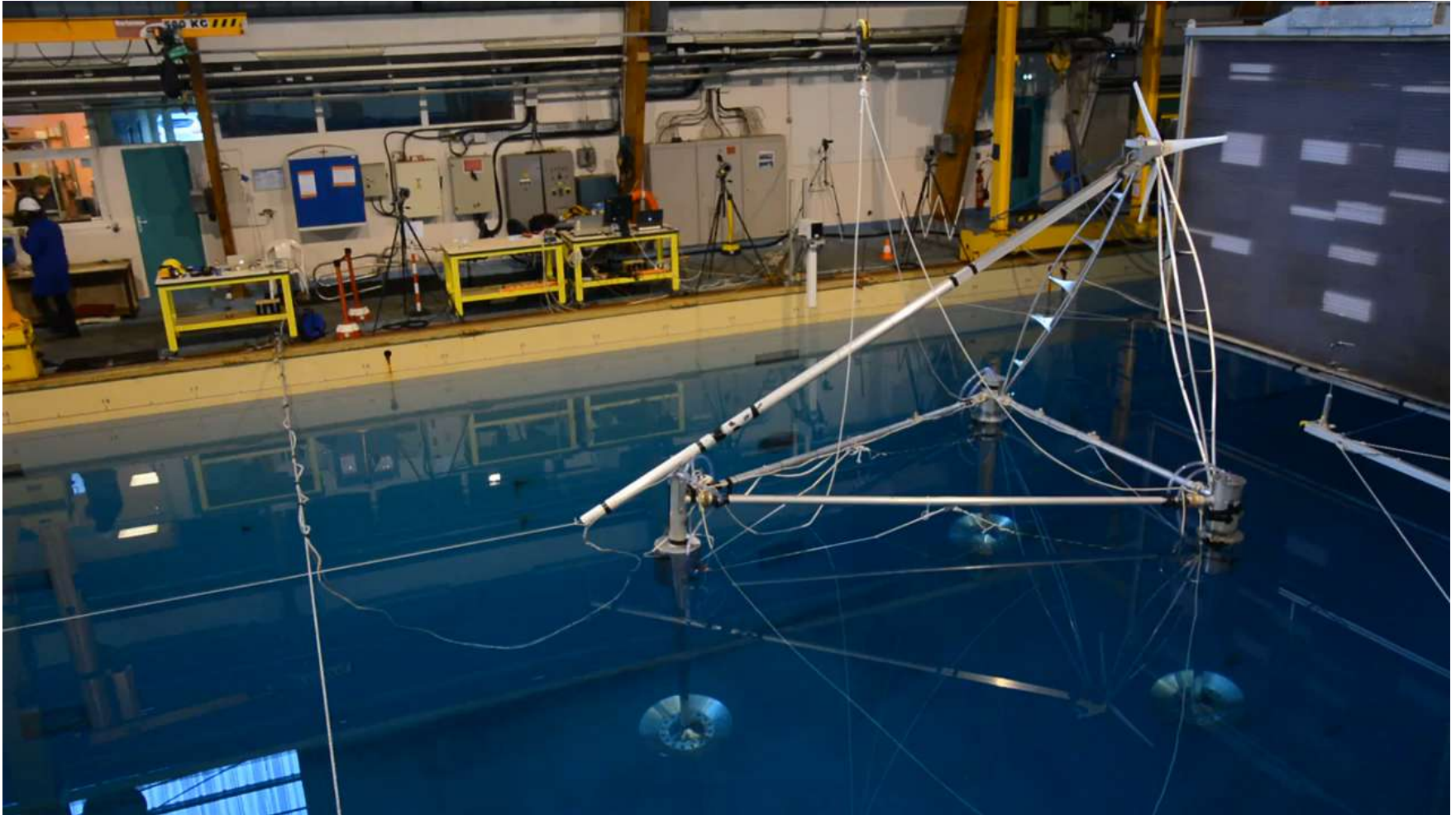


Farms of floating units sacrifice almost no additional space compared with fixed-foundation wind turbines.

TETRAFLOAT: Floating Platform



TETRAFLOAT: Floating Platform



View these files in YouTube!

<https://www.youtube.com/watch?v=kk9T0vfN0iA>

https://www.youtube.com/watch?v=F_phhZZ8RH8

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WINDTP – dispatchable wind

WINDTP is a power-transmission system for large HAWTs. It takes in mechanical power directly from the main rotor shaft and delivers out electricity from a synchronous generator.

WINDTP employs reversible *Thermal Pumping* to enable storage of ~ 100 hrs of rated power



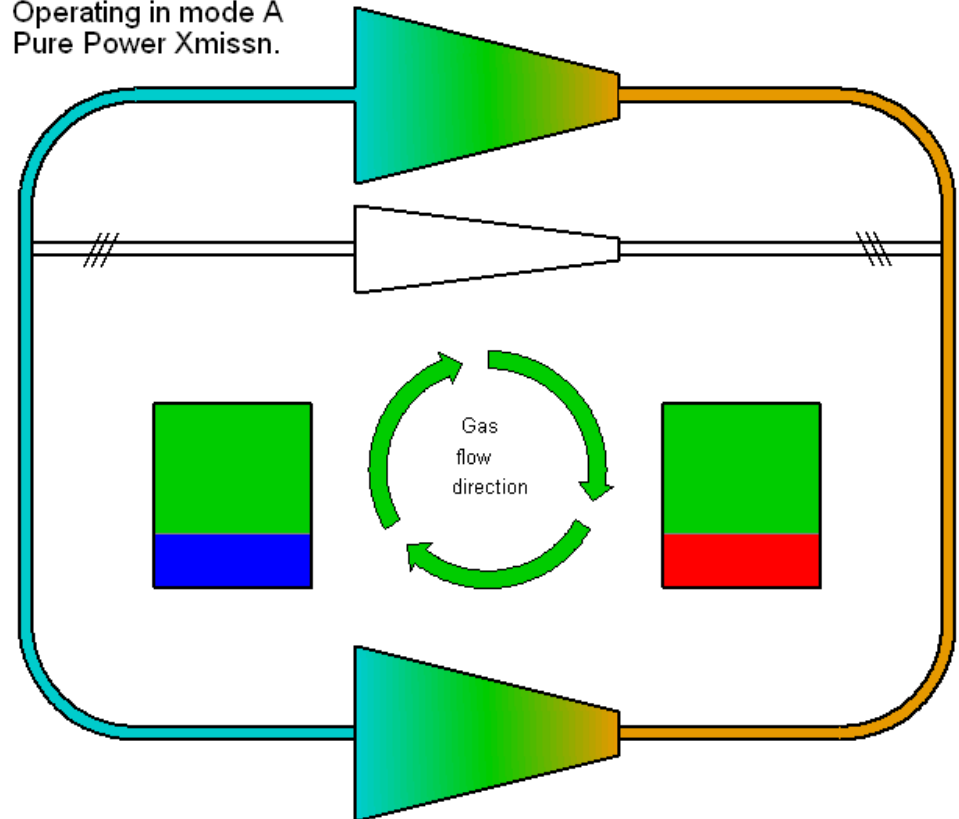
WINDTP – dispatchable wind

***WINDTP* = Wind-Driven Thermal Pumping**

WINDTP employs a high-pressure closed gas circuit to form a power transmission for wind turbines that can put energy into store and recover it later.

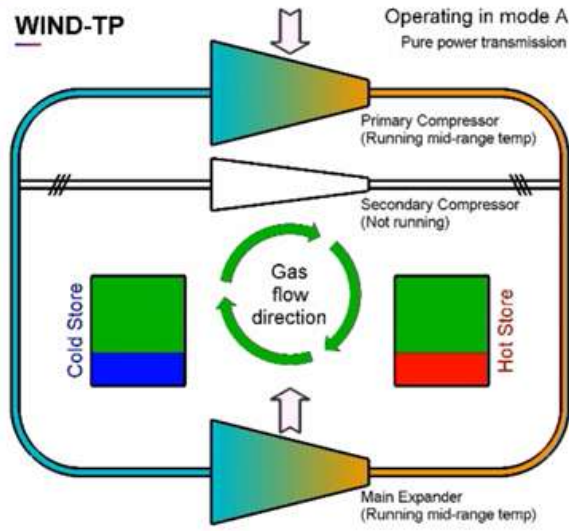
WIND-TP ..

Operating in mode A
Pure Power Xmissn.



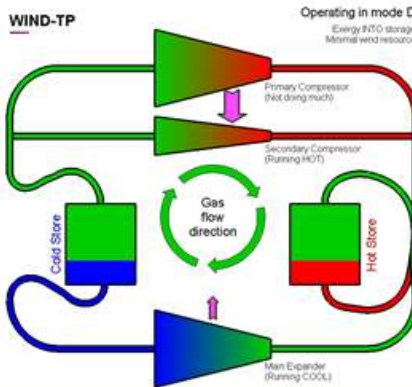
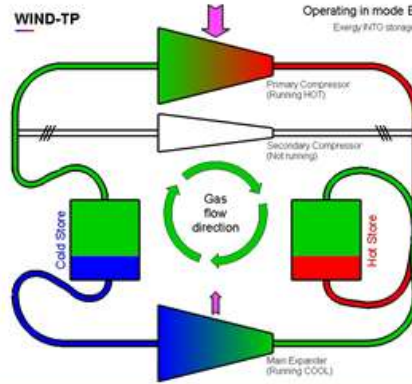
WINDTP – dispatchable wind

UNITED KINGDOM • CHINA • MALAYSIA

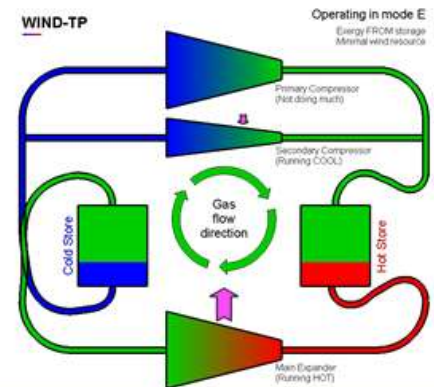
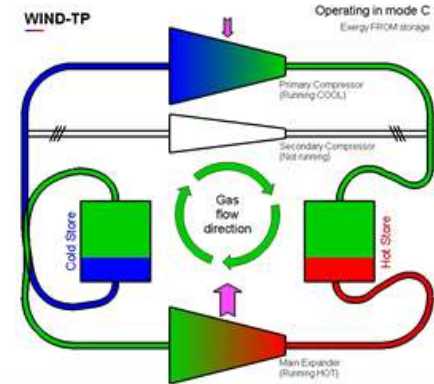


Pure Power Transmission

140K	221K	350K	554K	878K
-133°C	-51°C	77°C	281°C	605°C



Energy into storage



Energy from storage

Strong Wind

Weak/No Wind

WindTP has 5 main operating modes:

(a) Pure power transmission

(b) Some energy transferred into store

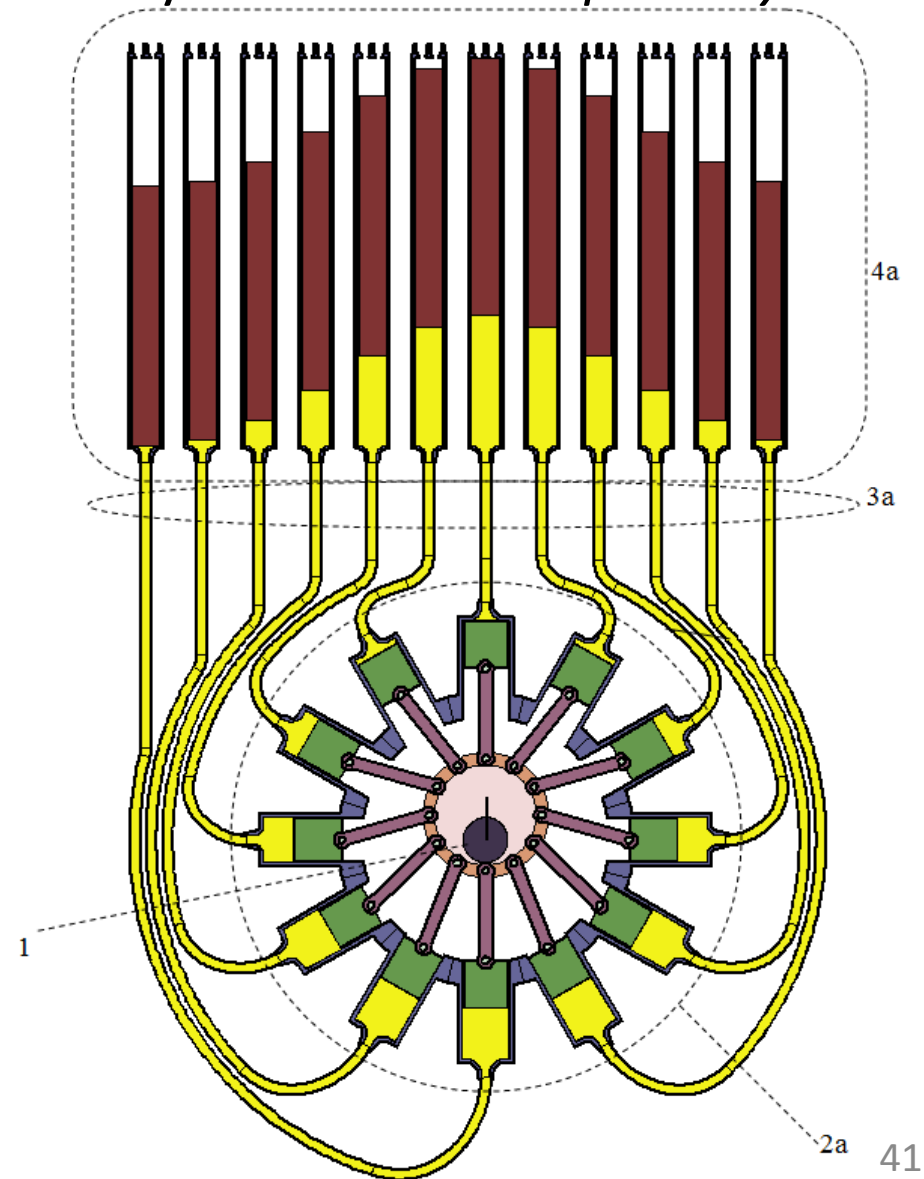
(c) Energy recovery from store (with wind)

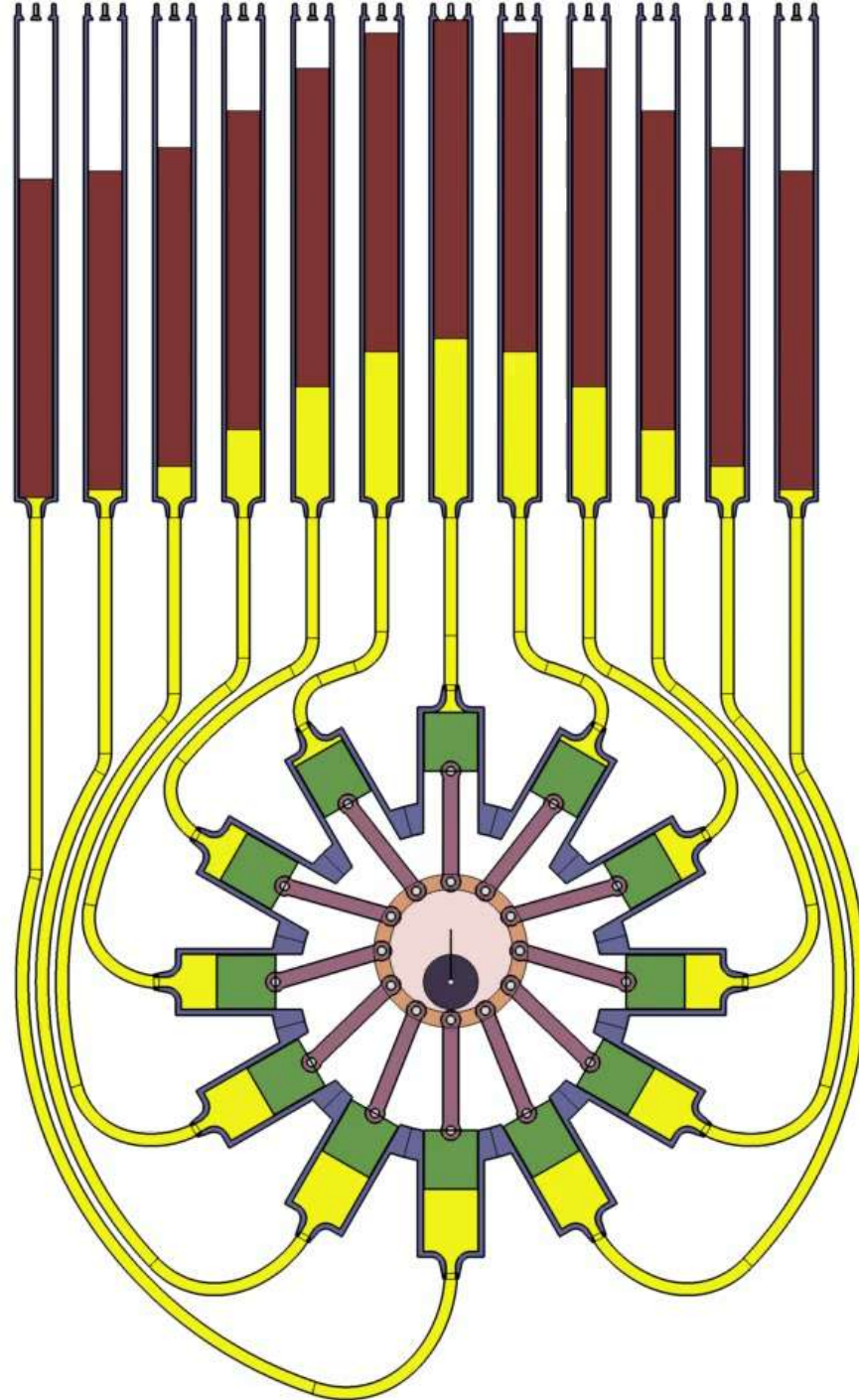
(d) More energy transferred into store

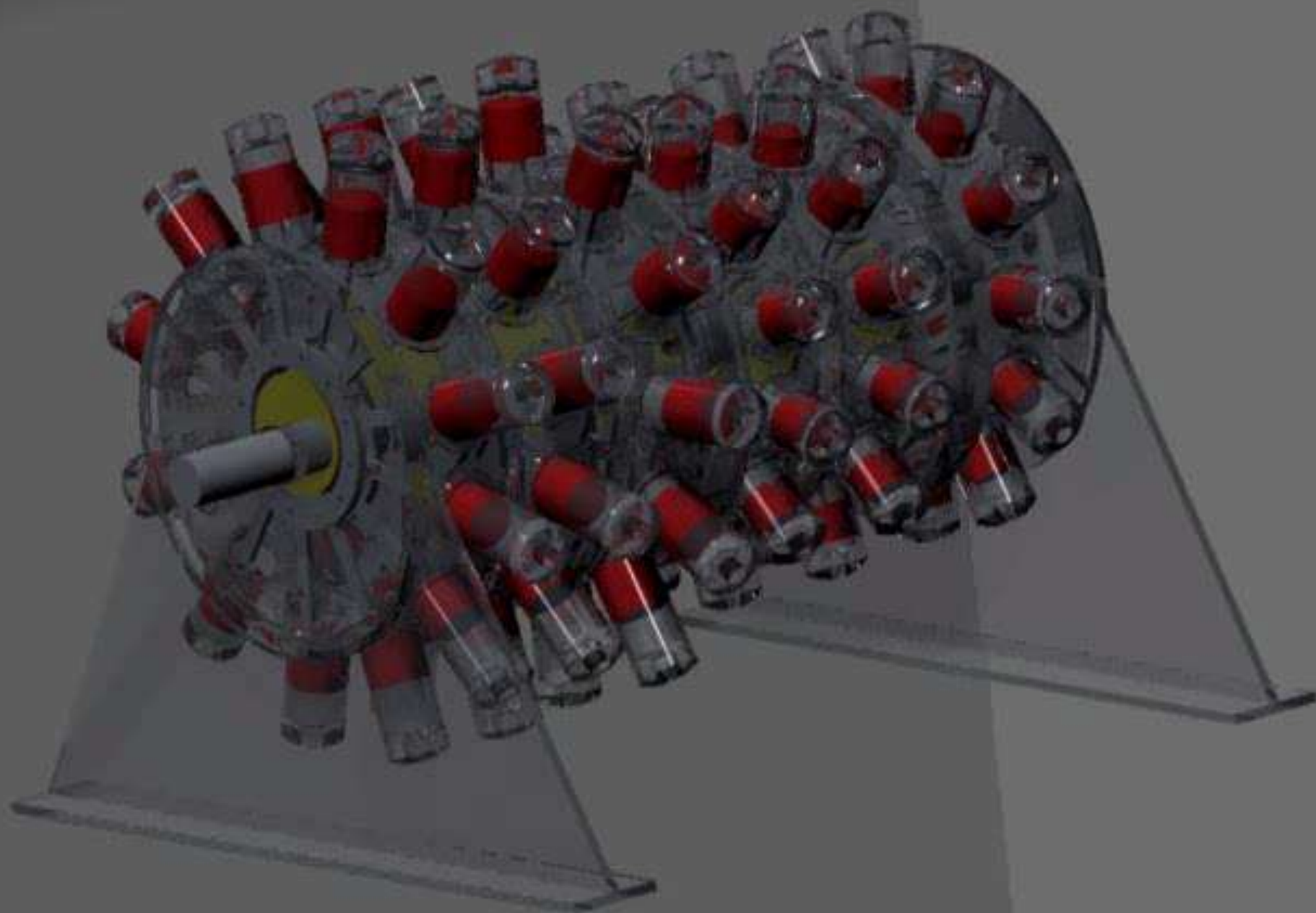
(e) Energy recovery from store (w/out wind)

Mode A

Pure power transmission







WINDTP – dispatchable wind

Undergraduate student
Nathaniel Newman completed
the detail design of the internal
parts of the WindTP displacer.
He looked specifically at:

- Piston Profile
- Piston ring design

NN also addressed:

- Assembly of the displacer
- Testing of the displacer



WINDTP – dispatchable wind

Assembly of the Displacer



WINDTP – dispatchable wind



WINDTP – dispatchable wind

Testing of the Displacer

- Gather data to assess the friction of parts and features
- Four tests:
 - Torque test of each stage prior to cylinder honing without piston rings
 - Torque test of each stage post honing without piston rings
 - Torque test of each stage after honing with piston rings assembled
 - Pressure test of each stage after honing with piston rings assembled
- Future testing:
 - Torque test with pistons immersed in oil at ambient pressure
 - Torque test with pistons immersed in oil at high pressure



WINDTP – dispatchable wind





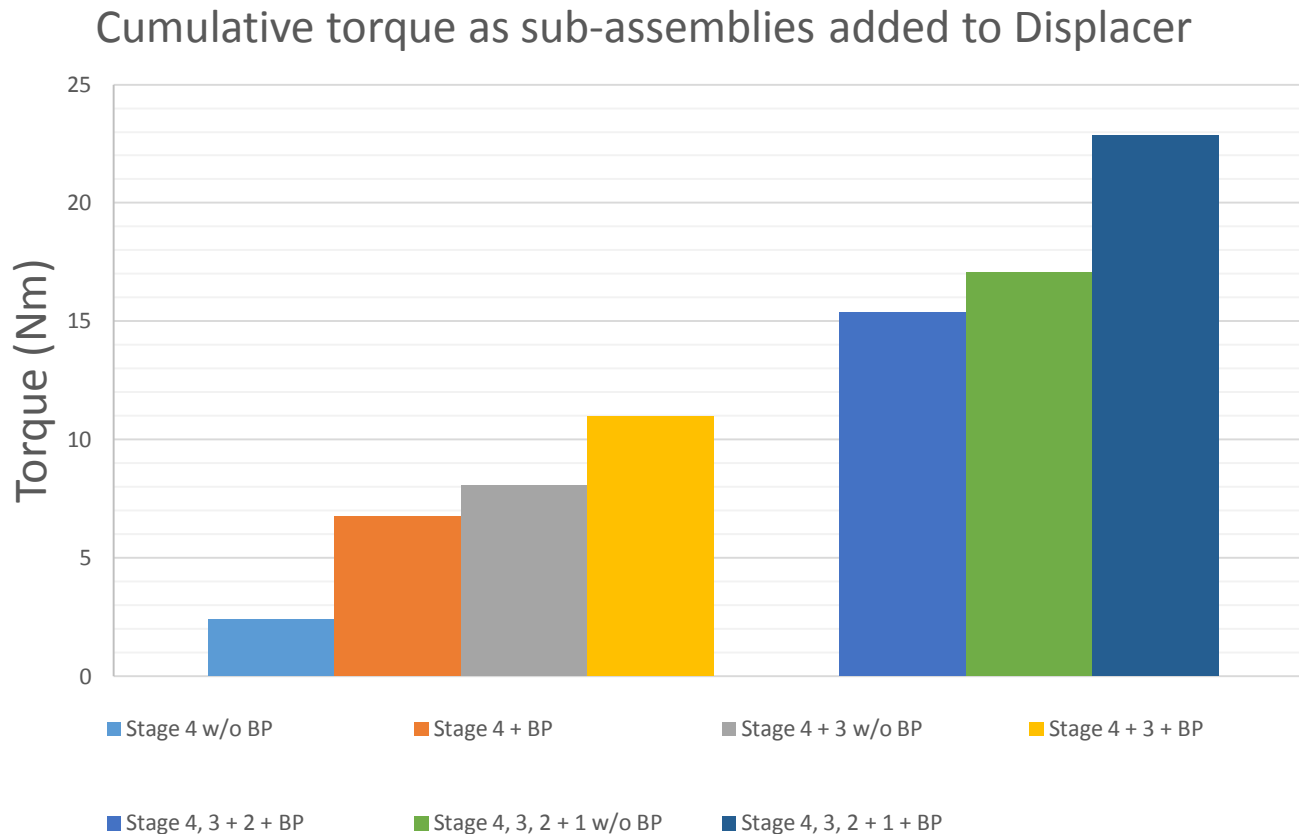
WINDTP – dispatchable wind



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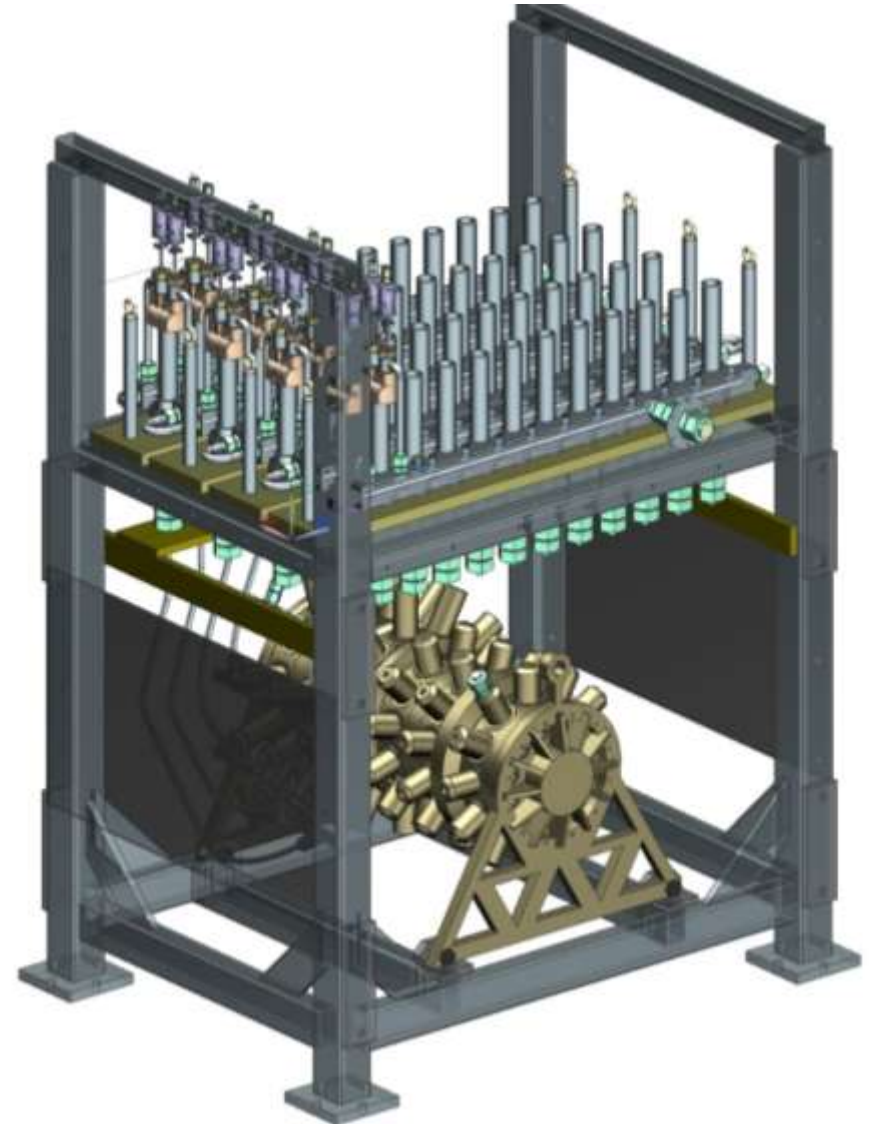
WINDTP – dispatchable wind

Preliminary experience with *displacer* seems very promising
60kW machine ~10m blade tip radius ~1rpm.
Rated torque ~9.5kNm.

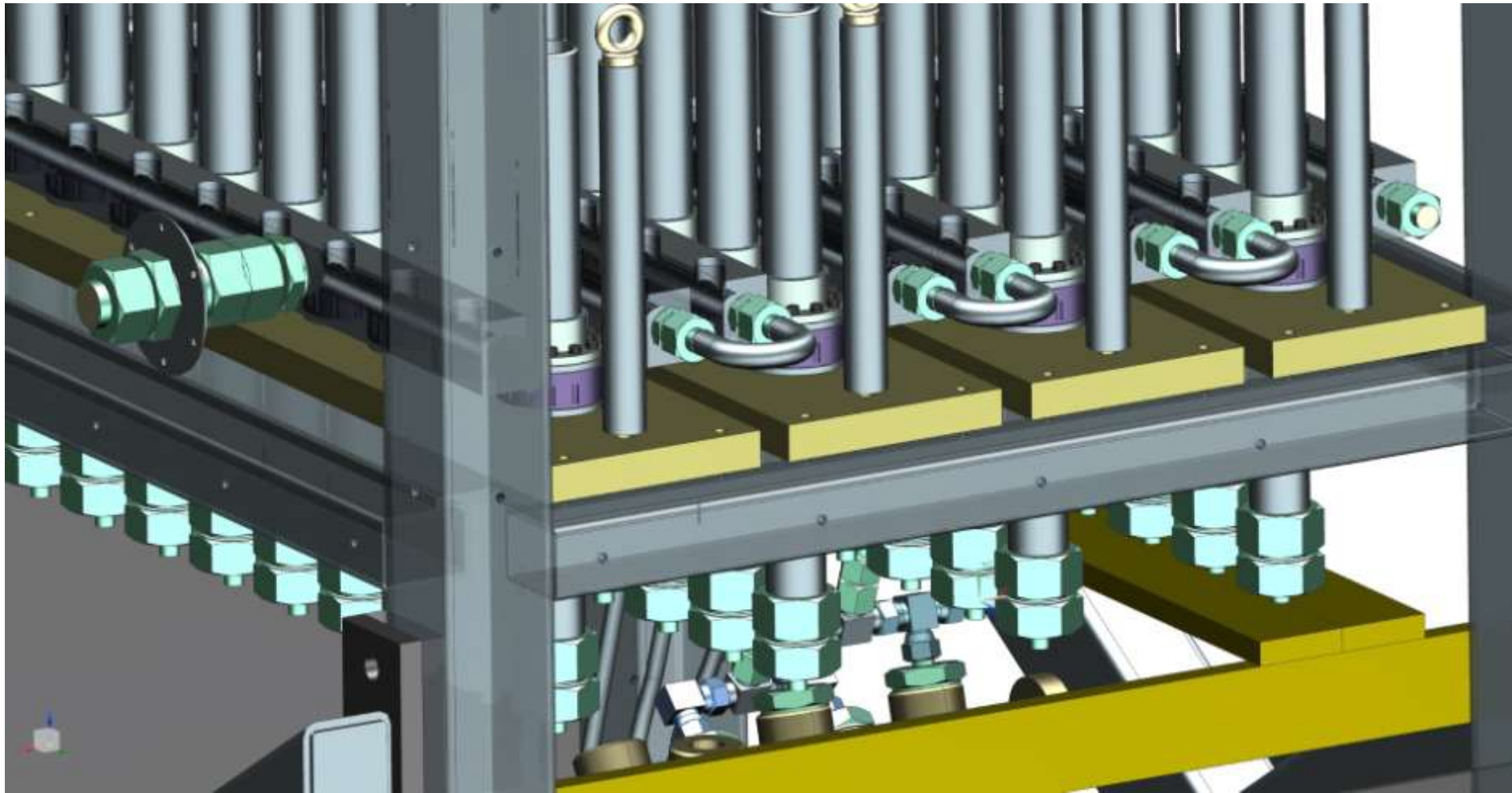


WINDTP – dispatchable wind

The *Converter* design is complete.

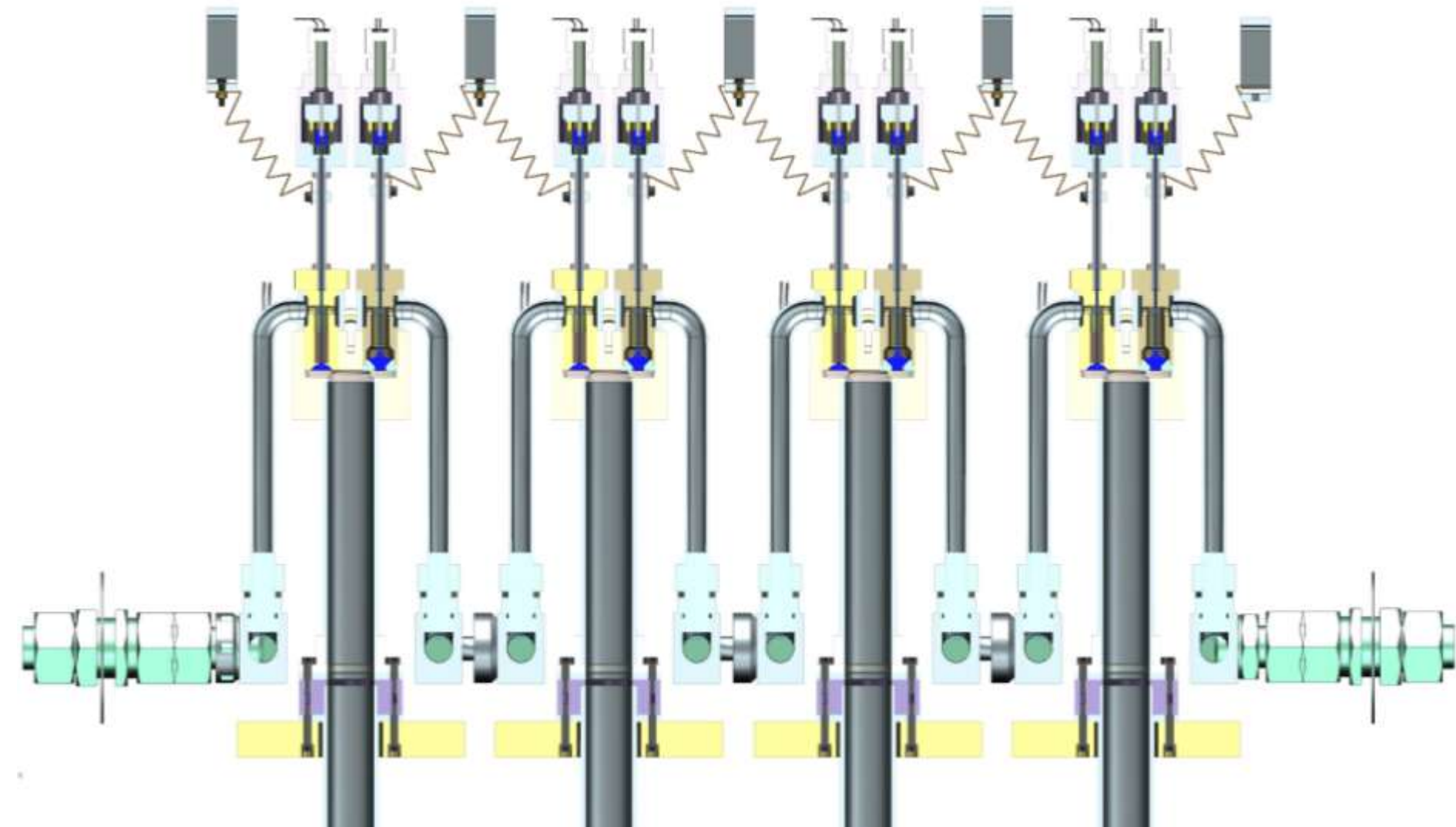


WINDTP – dispatchable wind

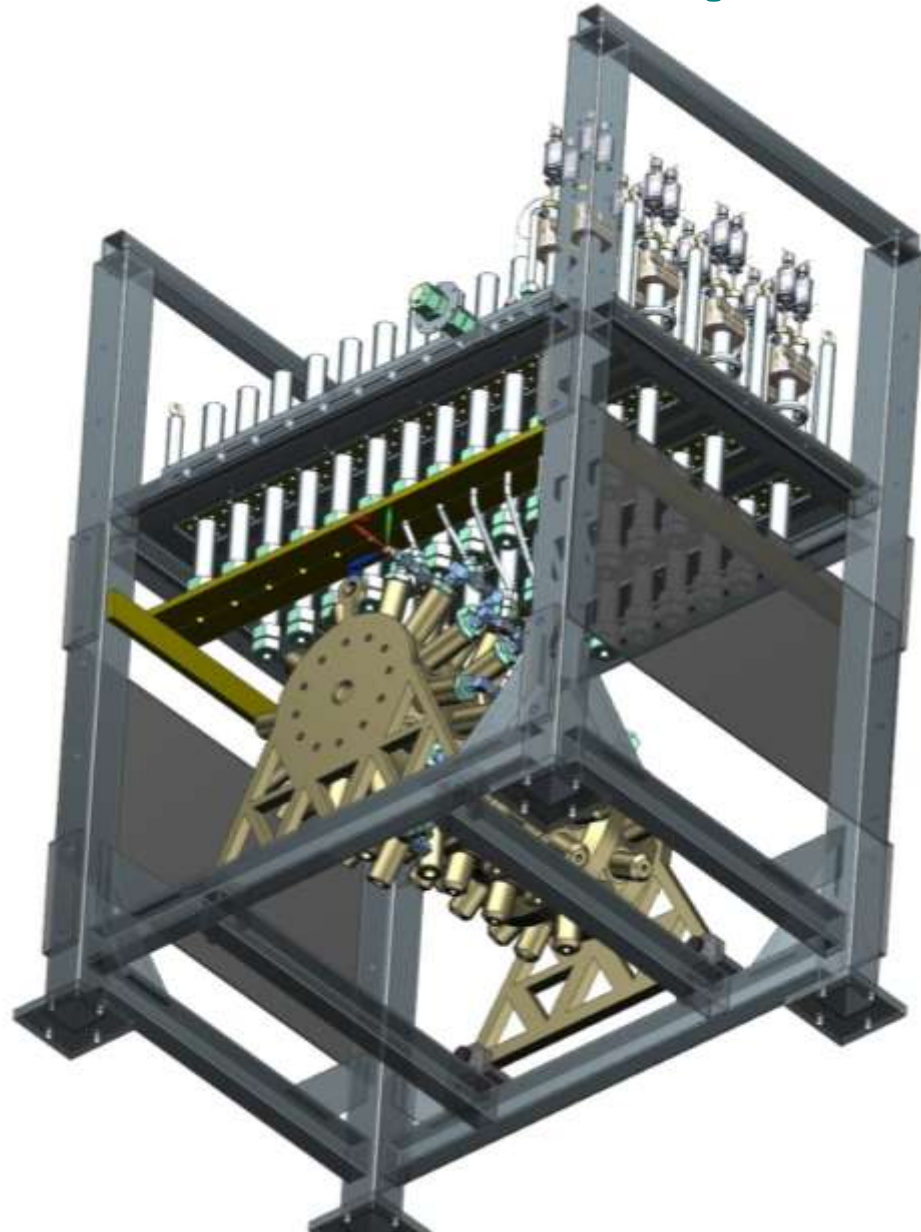




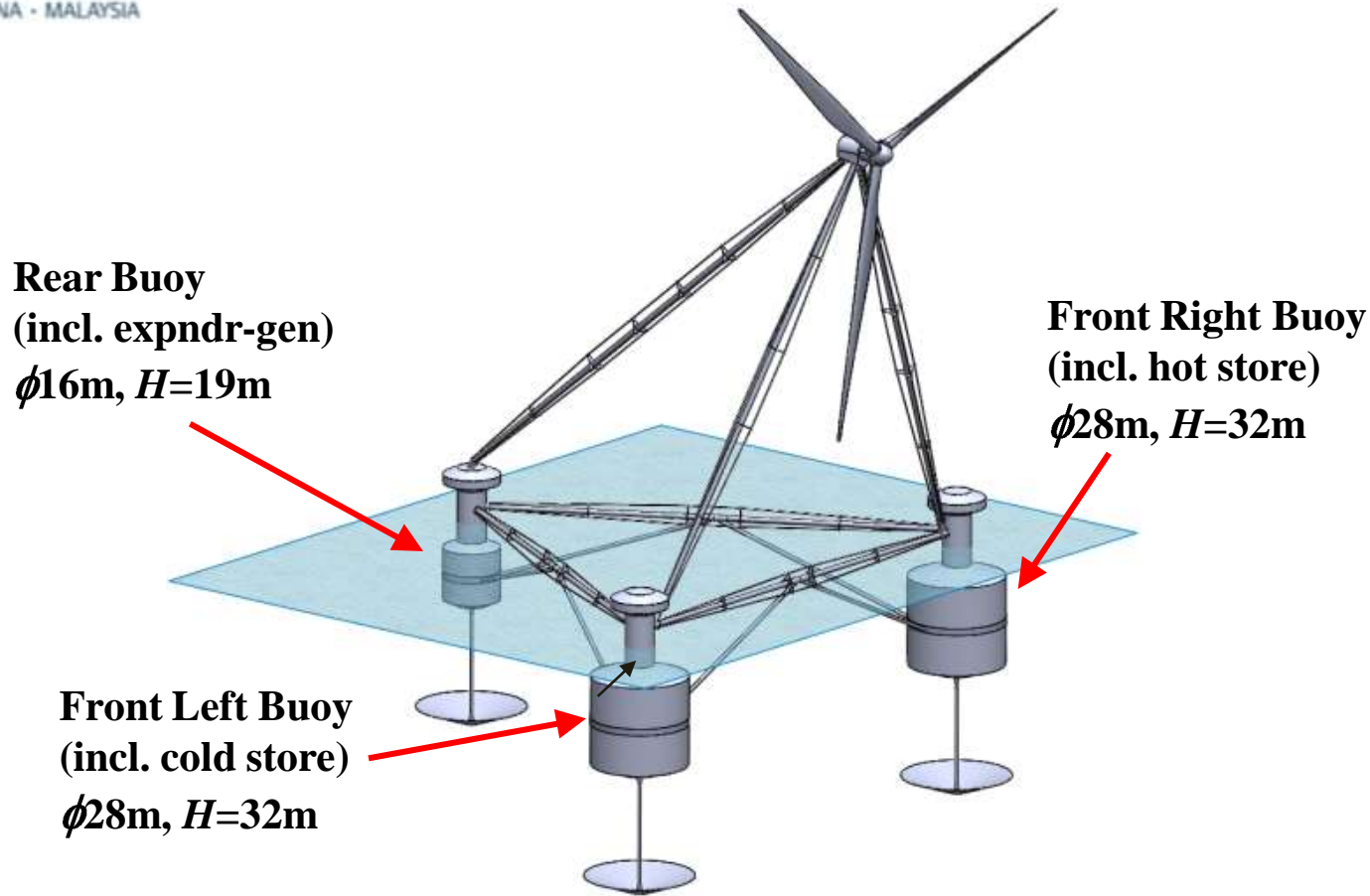
WINDTP – dispatchable wind



WINDTP – dispatchable wind



WINDTP – dispatchable wind



Offshore implementation of WindTP: 10MW system. 1GWh storage.
Cost $\sim 15\%$ greater than 10MW of conventional turbines

See www.Wind-TP.com and www.TetraFloat.co.uk

WINDTP – dispatchable wind

WINDTP transforms wind power generation into a *dispatchable* resource – with most of the qualities of a fossil-fuelled power station.

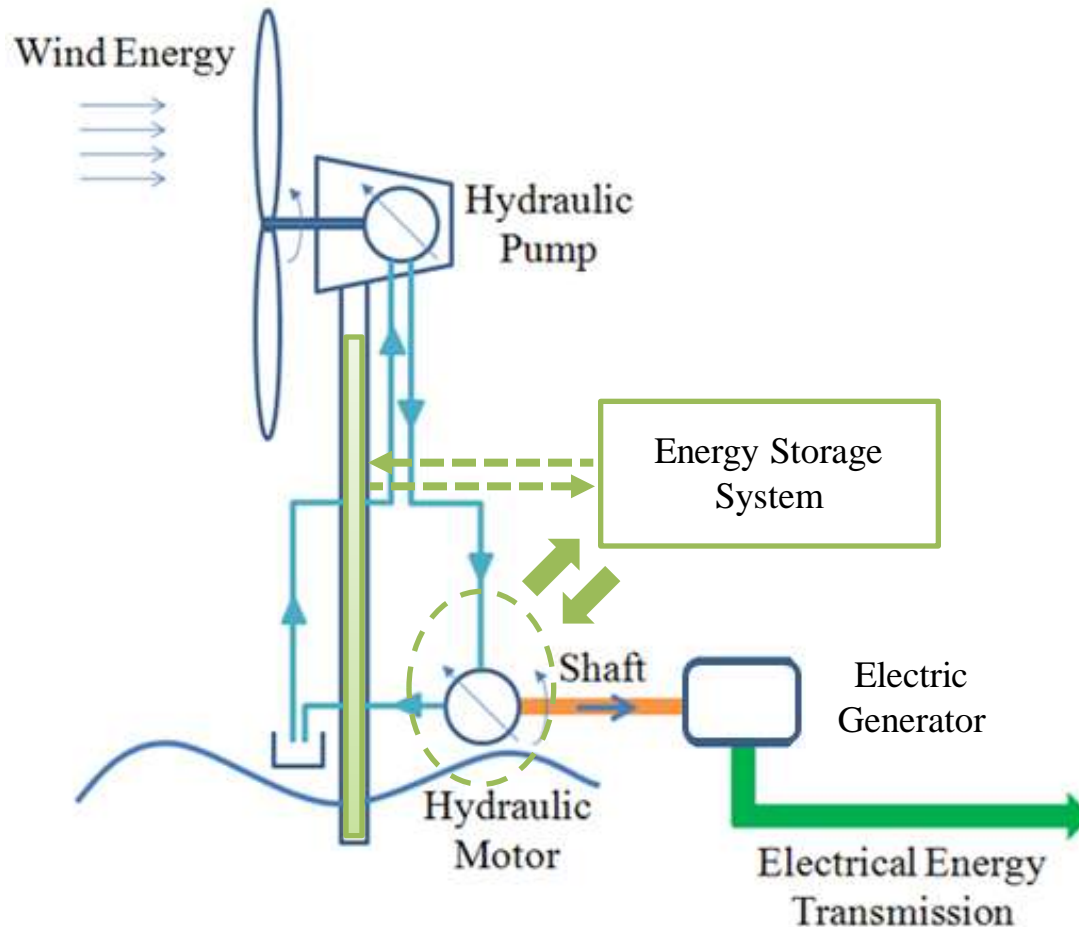
WINDTP delivers a higher performance and much lower cost solution than a combination of conventional wind farm + standalone E.S. – provided that a high proportion of output energy goes thru' storage.

WINDTP can be fitted into many existing designs of wind turbines where new wind-farms are being developed.

WINDTP is not a threat to any party in wind power. Ultimately, more installations of *WindTP* will mean more conventional turbines.

WINDTP relies on *system* thinking. The industry and policy makers need a jolt to change their views by 2020.

Other dispatchable wind



Eric Loth (Univ of Virginia) & Perry Li (Univ. of Minnesota)

Other dispatchable wind



The *BatWind* concept for dispatchable offshore wind.

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Concluding Remarks

Offshore wind is a staggeringly massive resource for the UK. We perhaps forget how large - ~5x times present electricity consumption. Offshore wind is NOT necessarily expensive!!

Floater will come of age. BVG says (in 2014) 8-16GW in the UK by 2030. The first generation is already appearing (WindFloat, HyWind, Ideol, EOLFI, Sway etc.) but these may be supplanted. Cost may drive the market for floaters (rather than “depth problem”).

Dispatchability is key to large-scale penetration of wind power. This is achievable through clever energy storage – integrated with wind.

The UK should be aspiring to produce more of its own offshore wind hardware. ‘Probably much more than £100bn up to 2030.

Thank you for listening – and sincere thanks to EPSRC & E.ON for funding this work thus far.



Seamus.Garvey@nottingham.ac.uk

Wolfsdesign

The Presenter (+ATKINS)



OS ES 2014



OS ES 2015



OS ES 2016
Offshore Energy & Storage Symposium



OS ES 2017

Some background.



Hinkley Point C.

£92.5/MWh, index-linked to 2012 (CPI).

Equivalent to £113/MWh fixed price (2012) for 15 years.

Zero flexibility.

John F. Kennedy

**Address to the Dáil
(the Irish parliament)
in June 1963**

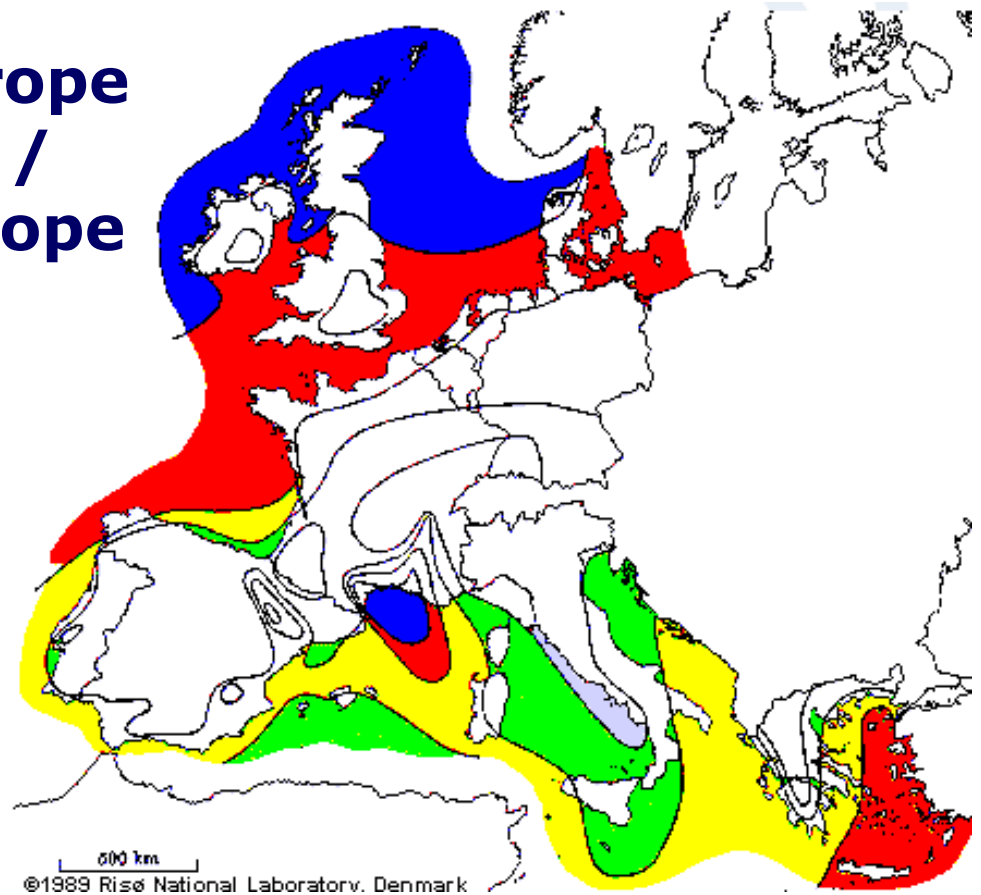


***The problems of
the world cannot possibly be solved by skeptics
or cynics, whose horizons are limited by the
obvious realities. We need men who can dream
of things that never were, and ask why not.***

Wind Power is Plentiful

**Offshore resource in Europe
estimated at 3,000 TWh /
year – equal to total Europe
Electricity Consumption.**

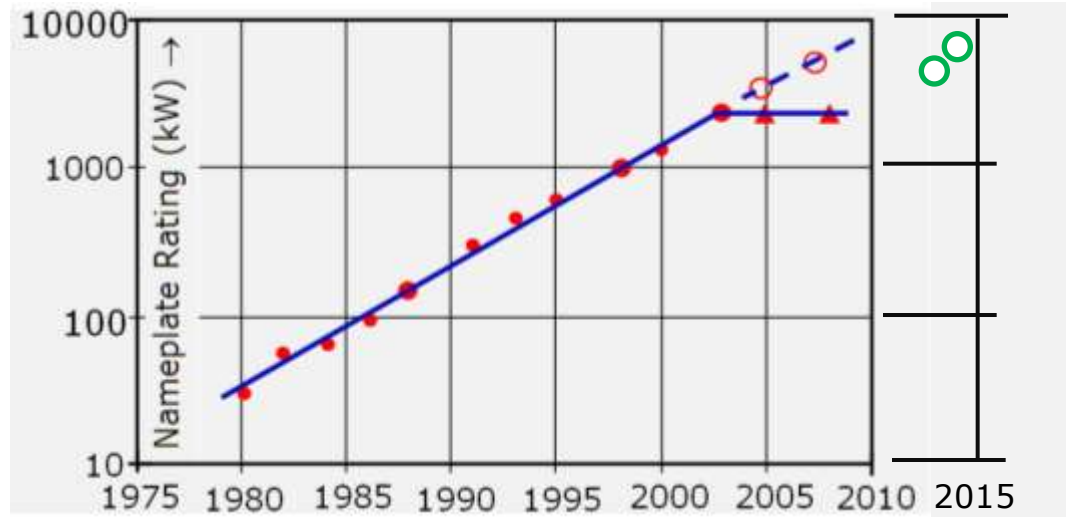
[http://www.nowireland.ie/pdf/
PDowlingPresentation.pdf](http://www.nowireland.ie/pdf/PDowlingPresentation.pdf)



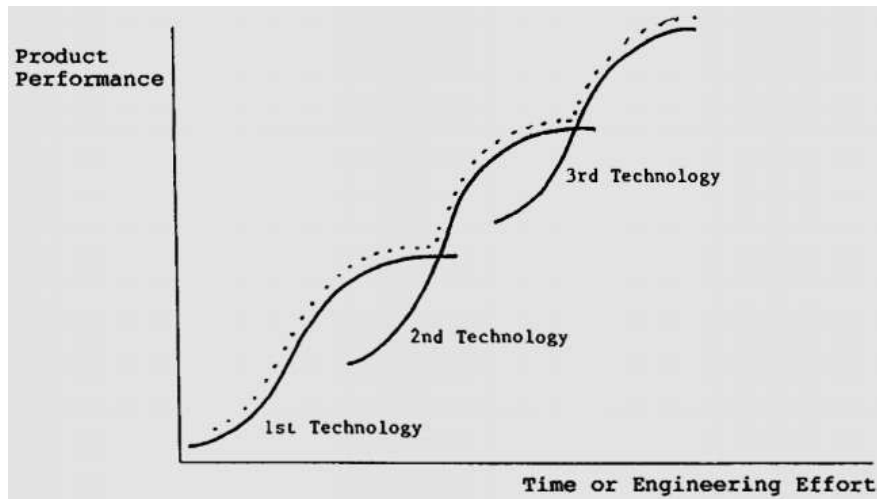
**UK Practicable Offshore Wind
resource > 2,000 TWh/year.**

http://publicinterest.org.uk/offshore/downloads/offshore_valuation_exec.pdf

Wind Power Development



(Original source: Henrik Stiesdal Presentation at AWEA, Nov. 2008)



From: CM Christensen,
Production & Operations Management, 1(4), 1992.



Switching to a new design might yield much lower costs per unit power – at higher D .

Questions to ask (again!)

What IS a wind turbine ?

Should offshore HAWTs look
like onshore HAWTs ?

Should HAWT rotors be
designed for max. efficiency?

Should HAWTs be supported
on towers ?

Should HAWT rotors be
braced with cables ?

