The University of Nottingham

Scaling Up Renewables

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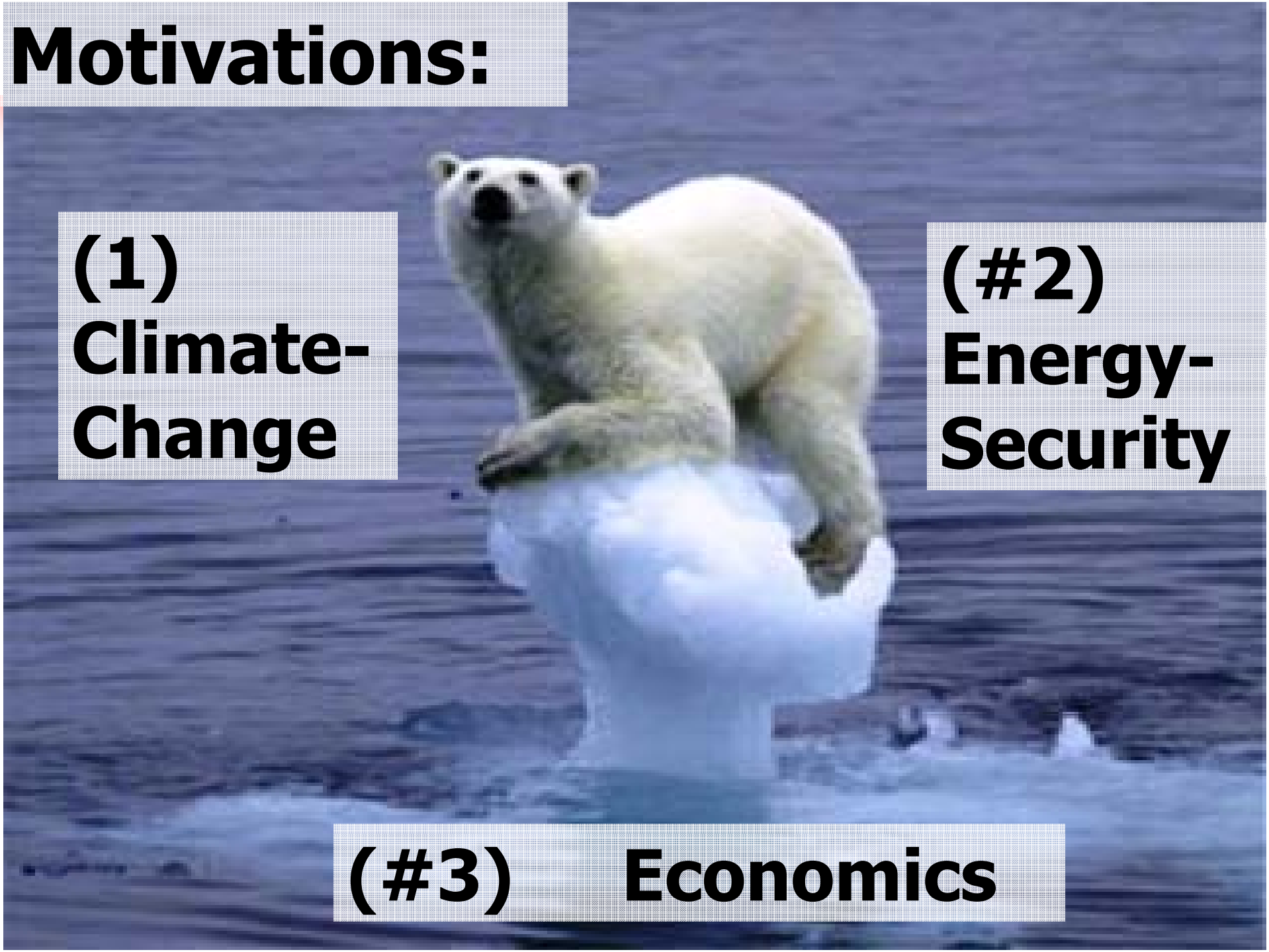
IoM3 UK Energy Symposium, Nottingham, Oct 14, 2010

Motivations:



(1) Climate-Change

(#2) Energy-Security

(#3) Economics

Contents:

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(1) Power, Energy, Quantities and Costs

(2) Mechanical Design and Wind Turbines

(3) Dispatching Energy

(4) A 100% renewable 2030.

Power and Energy #1

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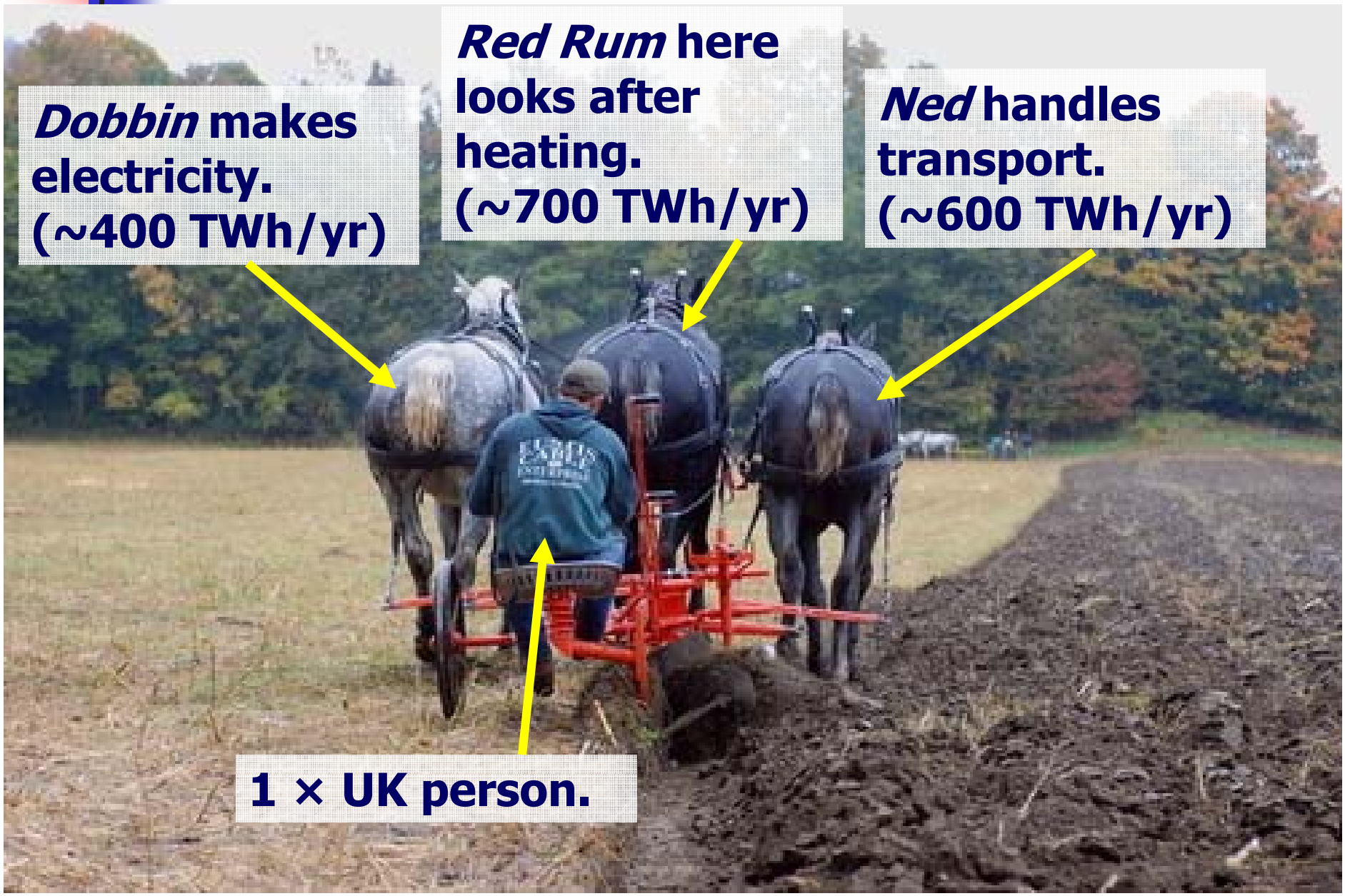
For every UK person,
1 × *Dobbin* here works
"24/7" making electricity

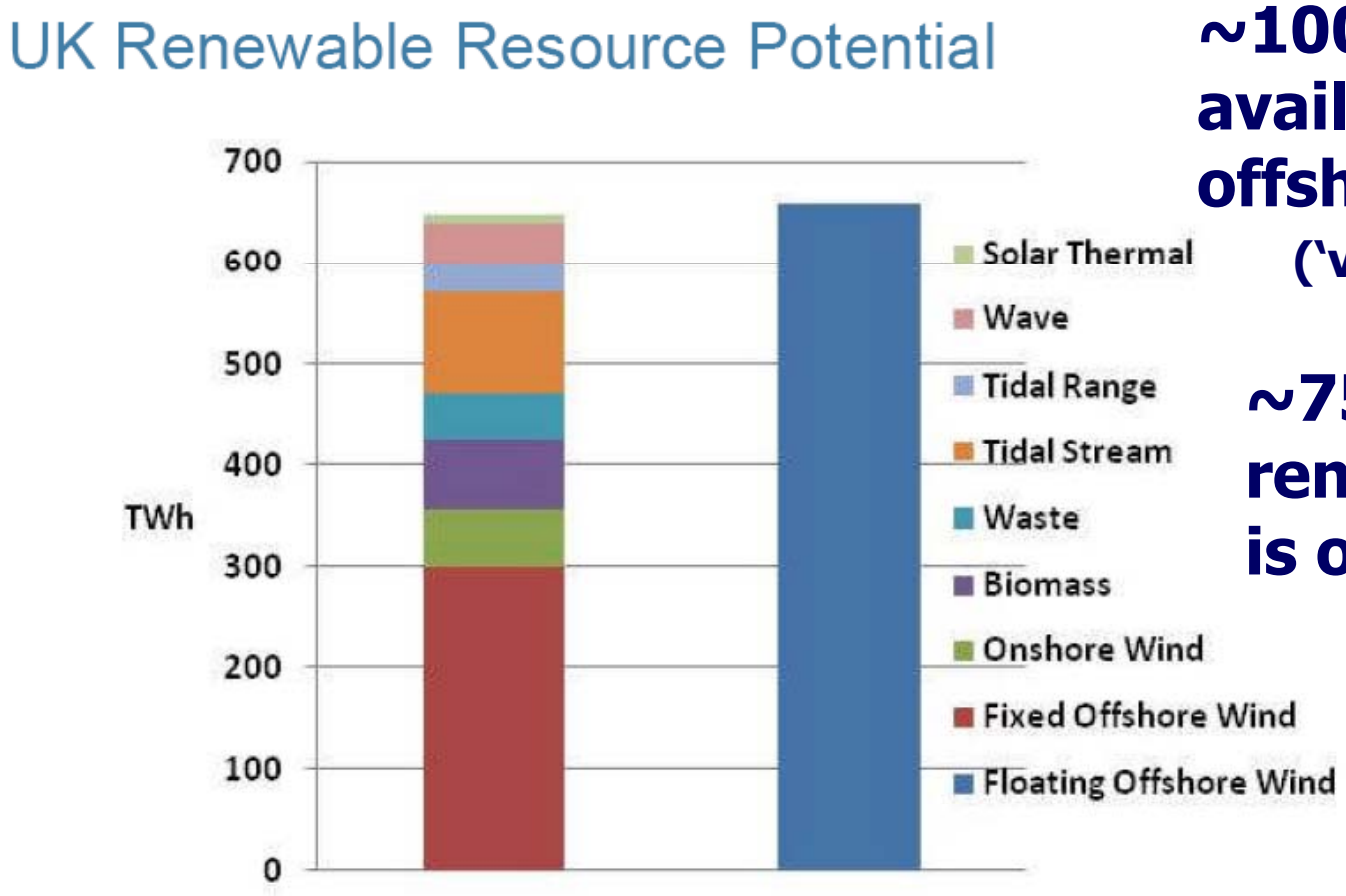
UK genr^{n}: 1.1 TWh / day
≈ 400TWh/ year

Power and Energy #2

The University of Nottingham



Renewable Resource #1



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

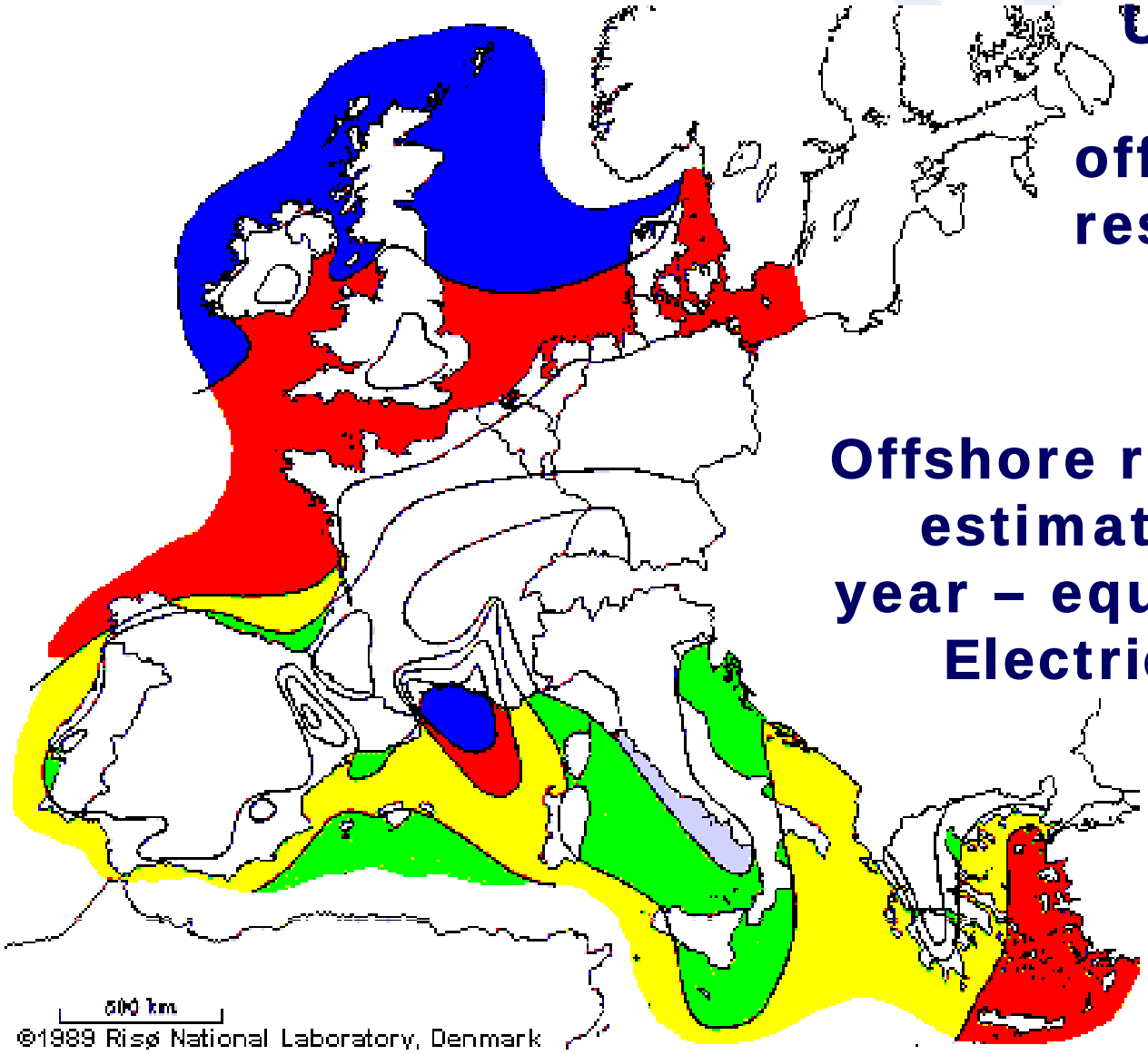
('very conservatively)

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

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

energy technologies institute

Renewable Resource #2



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

Electricity Costs

=

Private consumers pay about 7p/kWh = £70/MWh (equivalent to £1.25 per day for "Dobbin").

Generating companies get ~£30 - £35 / MWh

Renewable energy is "encouraged" by an <u>extra</u> ~£40/MWh (onshore wind) and ~£60/MWh (offshore wind). ⇒ Renewable energy expensive (?)

Wind Turbine Costs & Output

What is average power from a “5MW” W.T. ?

2 MW !! (= 2600 “Dobbins”)

What does a “5MW” W.T. cost ?

Offshore .. ~£15M

Value of power per year (at £35/MWh) ?

~£0.6M

UK Renewables Targets

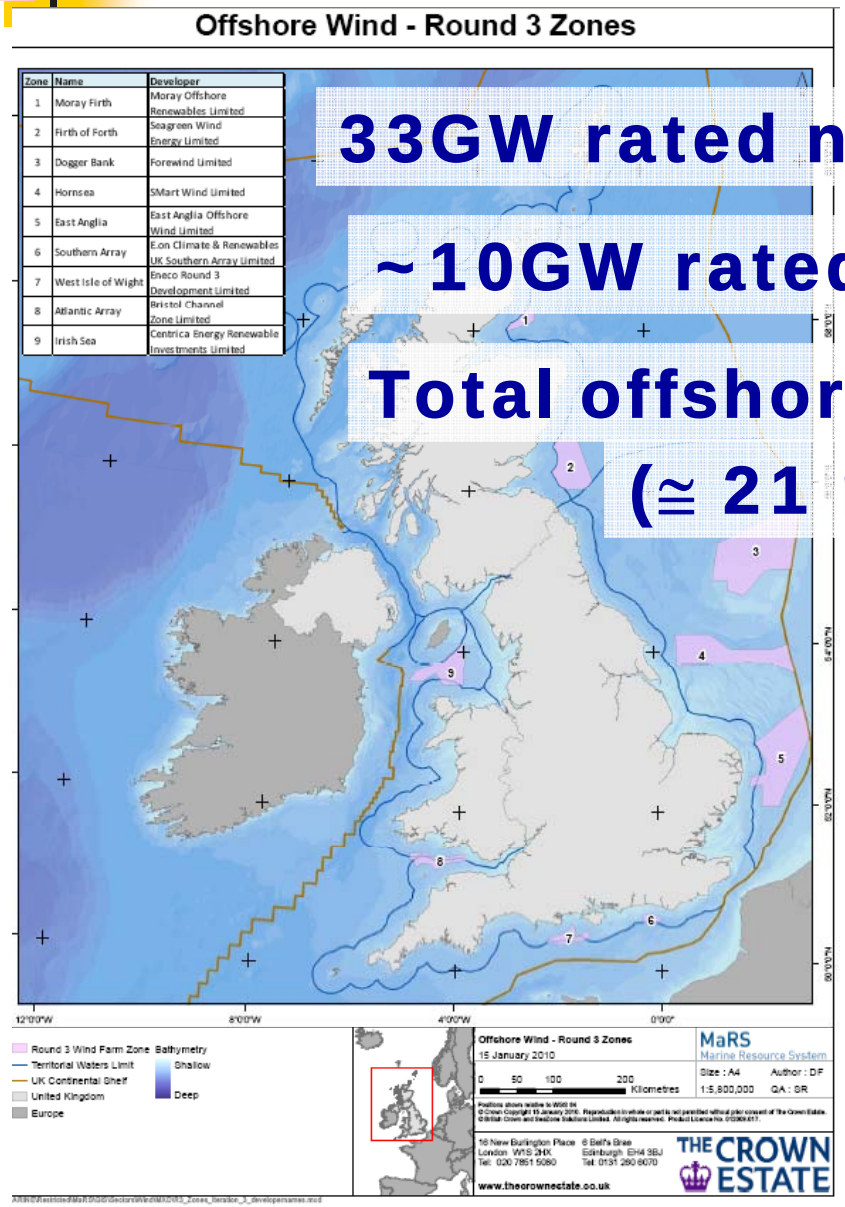
UK renewable energy strategy 09

15% of all energy

>30% of all elec.

Offshore wind will be the biggest contributor.

Offshore Wind by 2020

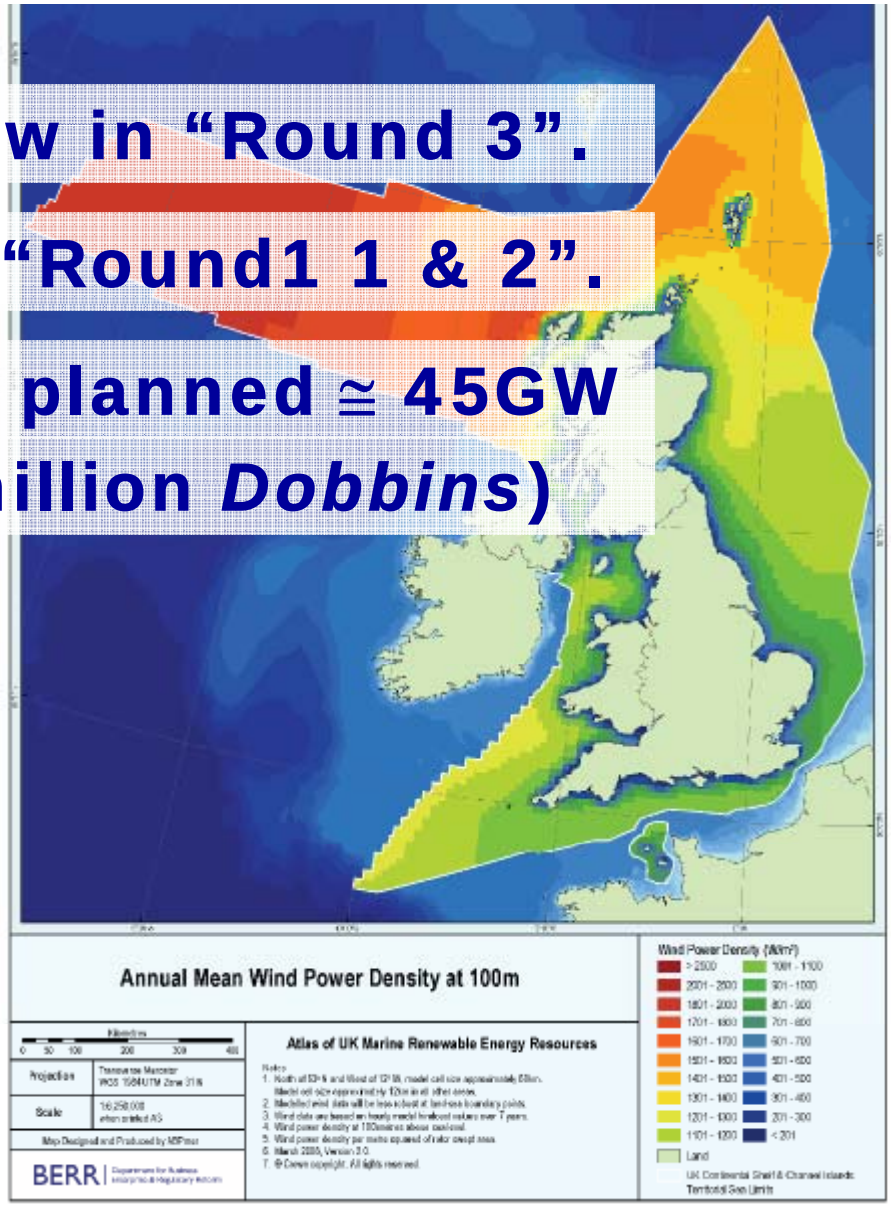


33GW rated new in "Round 3".

~10GW rated "Round1 1 & 2".

Total offshore planned ≅ 45GW

(≅ 21 million *Dobbins*)




Source: DECC

Why is Wind Power Expensive?

There are two coupled reasons:

(1) **The power density is low**
=> collect over a large area/distance.

(2) **The velocities are low.** (Power = F × v)
=> large forces needed for a given power.

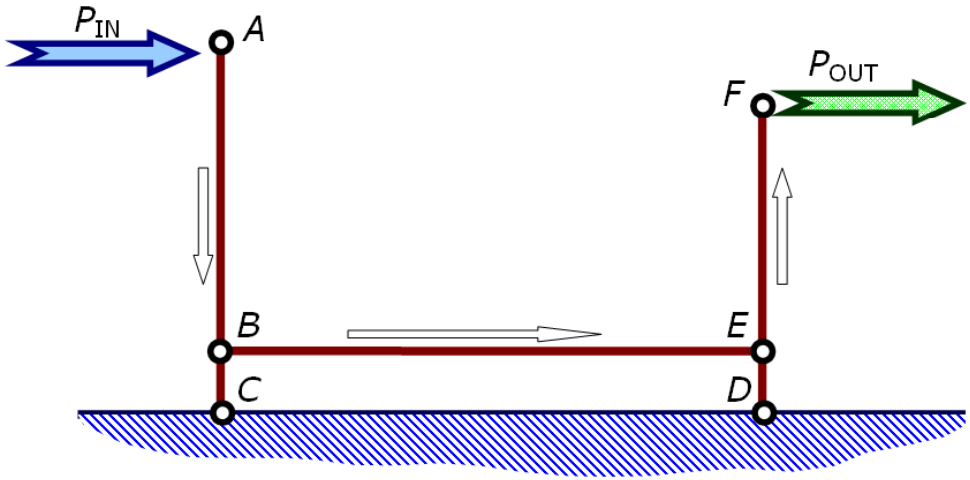
The product *Force* × *Distance* is *Structural Capacity*.
Units (Nm) ***(Also work and also torque!).***

[1] Garvey, S.D.. *Structural Capacity and the 20MW Wind Turbine*, Submitted to IMechE Jrnl. of Power & Energy, Jan 2010. Draft copy available at http://www.box.net/shared/oc5znst4im

3 Machine Design Tips:

… relevant to converting and / or transmitting mechanical power

- **Avoid very low linear velocities**
- **Avoid carrying large loads in bending**
- **Utilise high working *stress* in the conversion**



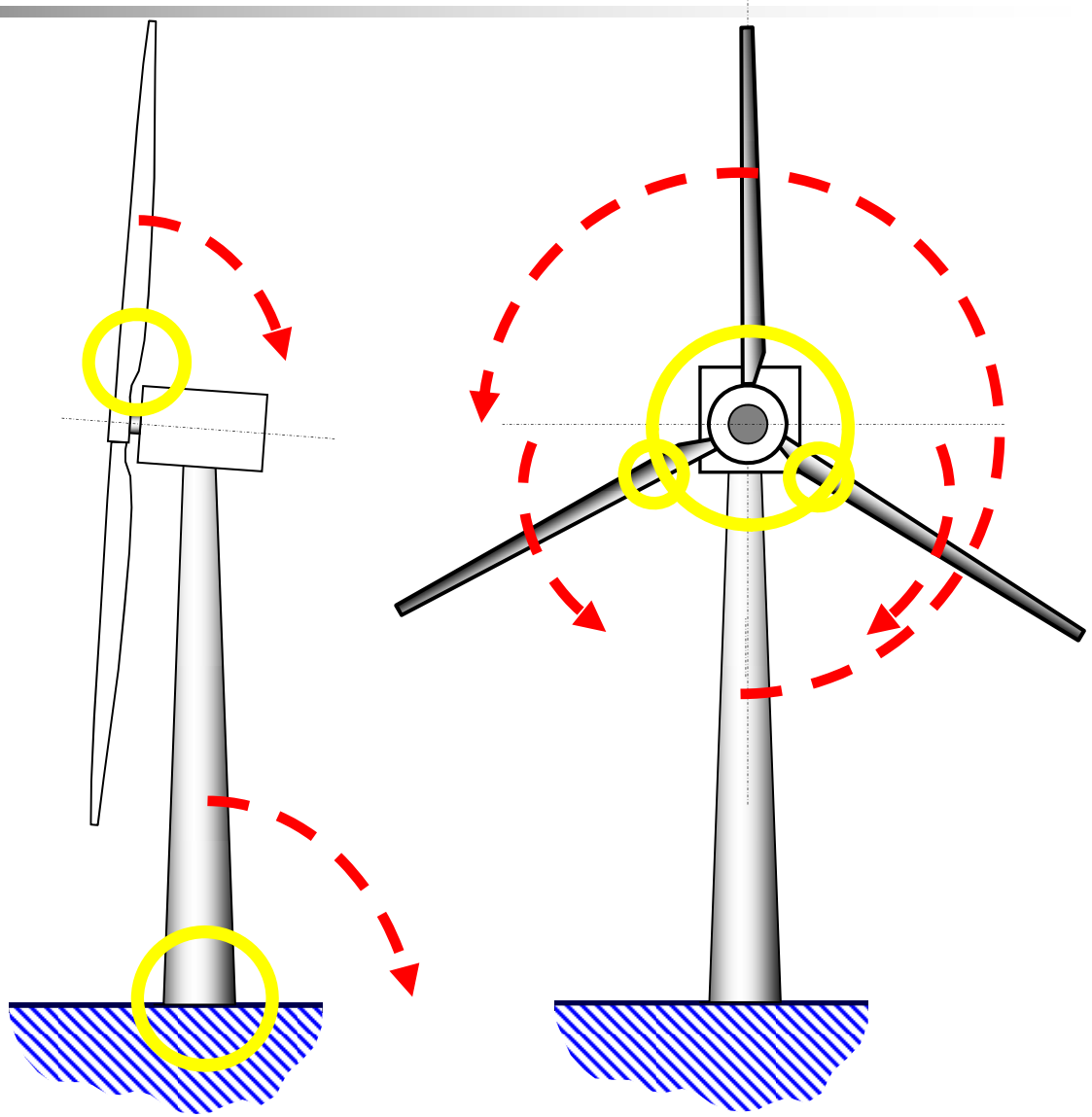
Bending moments in large WTs

* Tower downwind bending moments.

* Blade downwind bending moments.

* Gravity bending moments in blades.

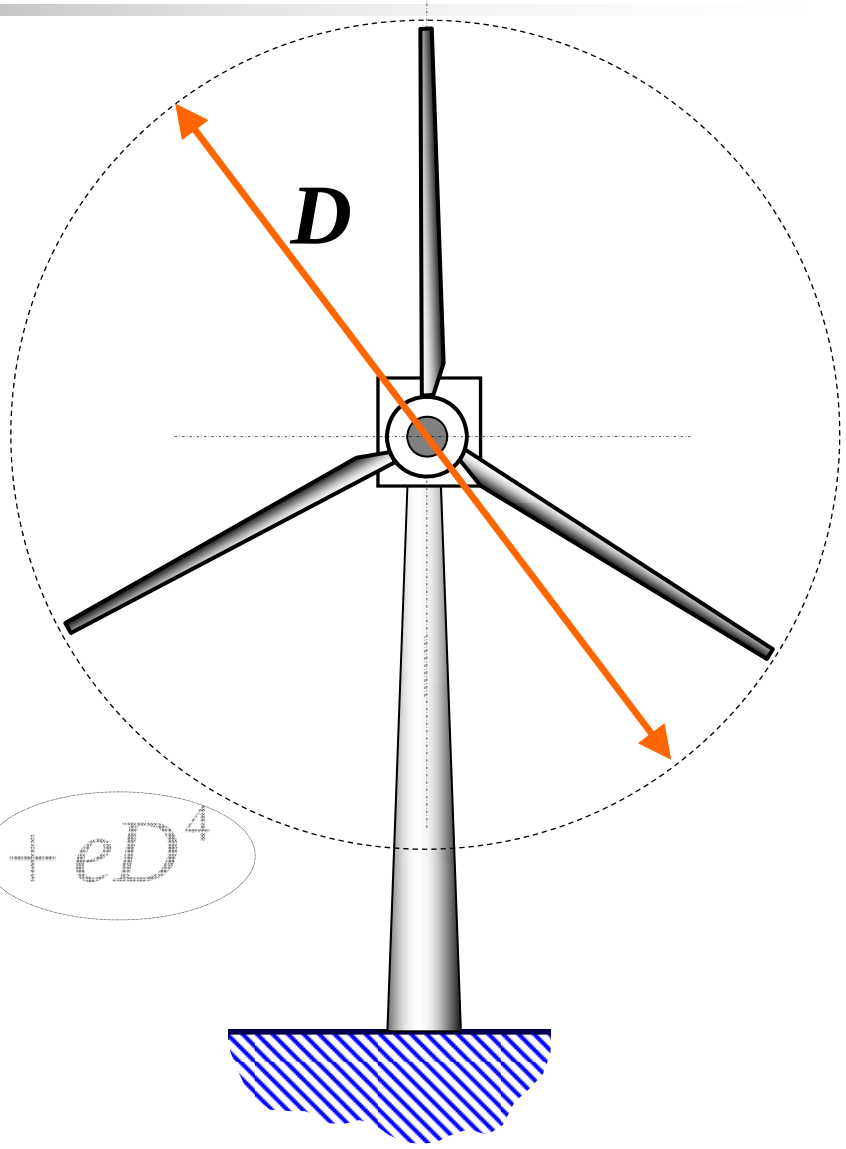
* Shaft Torque.



Are W.T.s Badly Designed?

On the whole, NO.

They are well-designed – **for the scale that they have reached so far!**



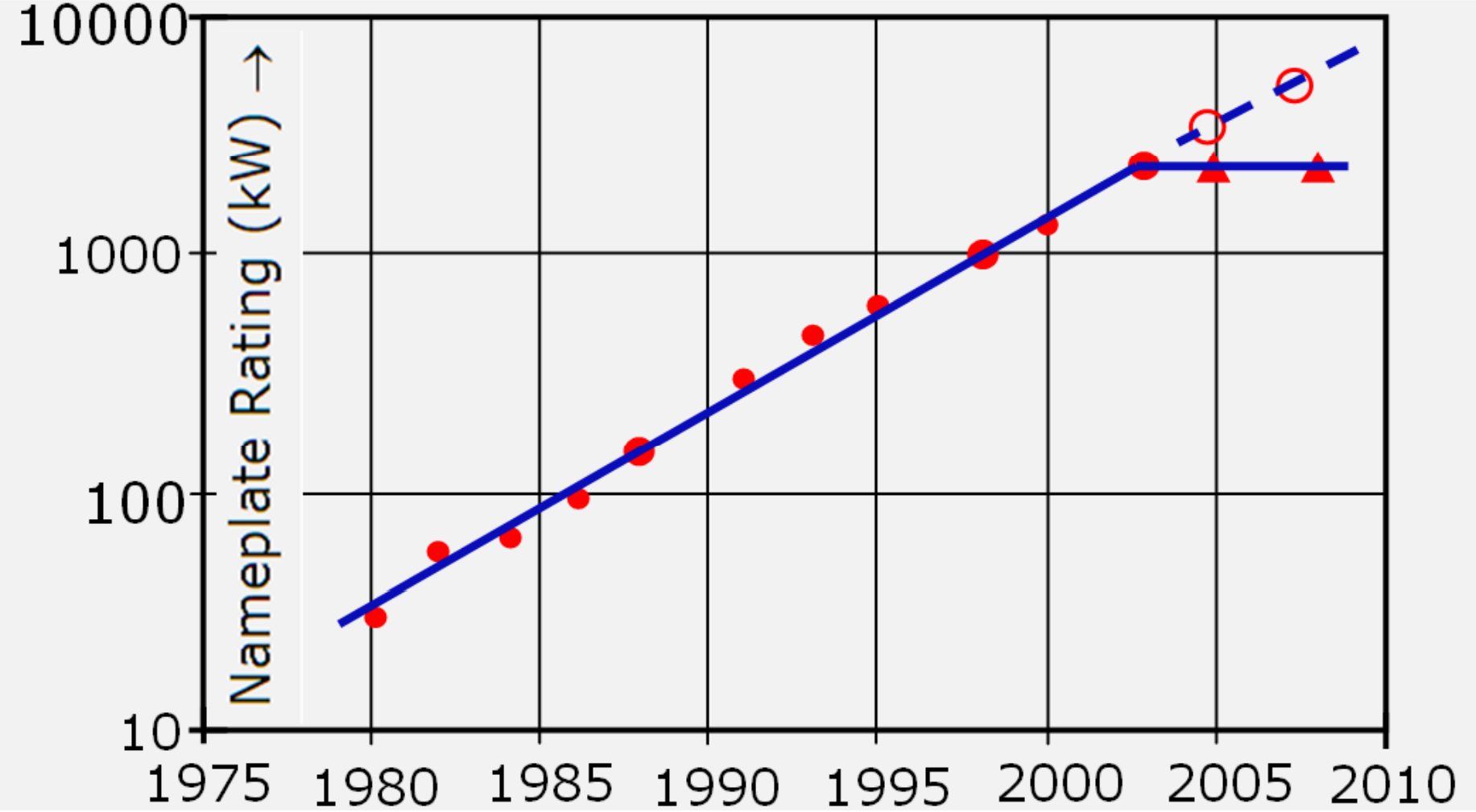
For a given design:

$$Cost = a + bD + cD^2 + dD^3 + eD^4$$

$$Power = kD^2$$

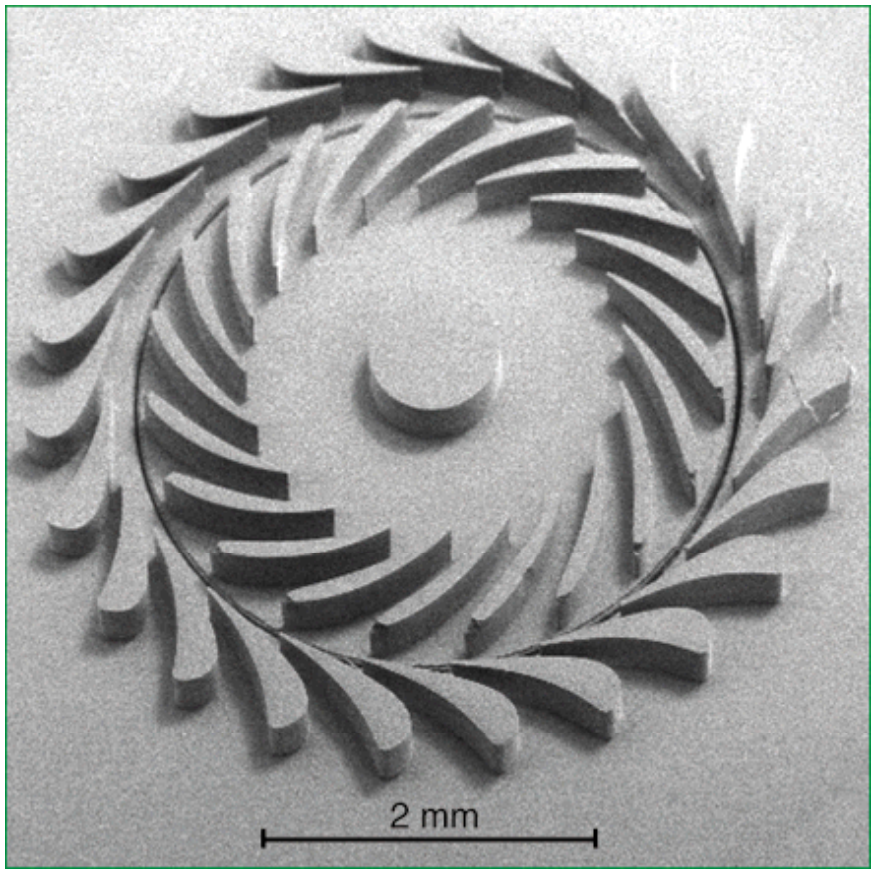
Scale affects design (#1)

Wind Turbine Size - ceased "exponential" growth



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

Scale affects design (#2)



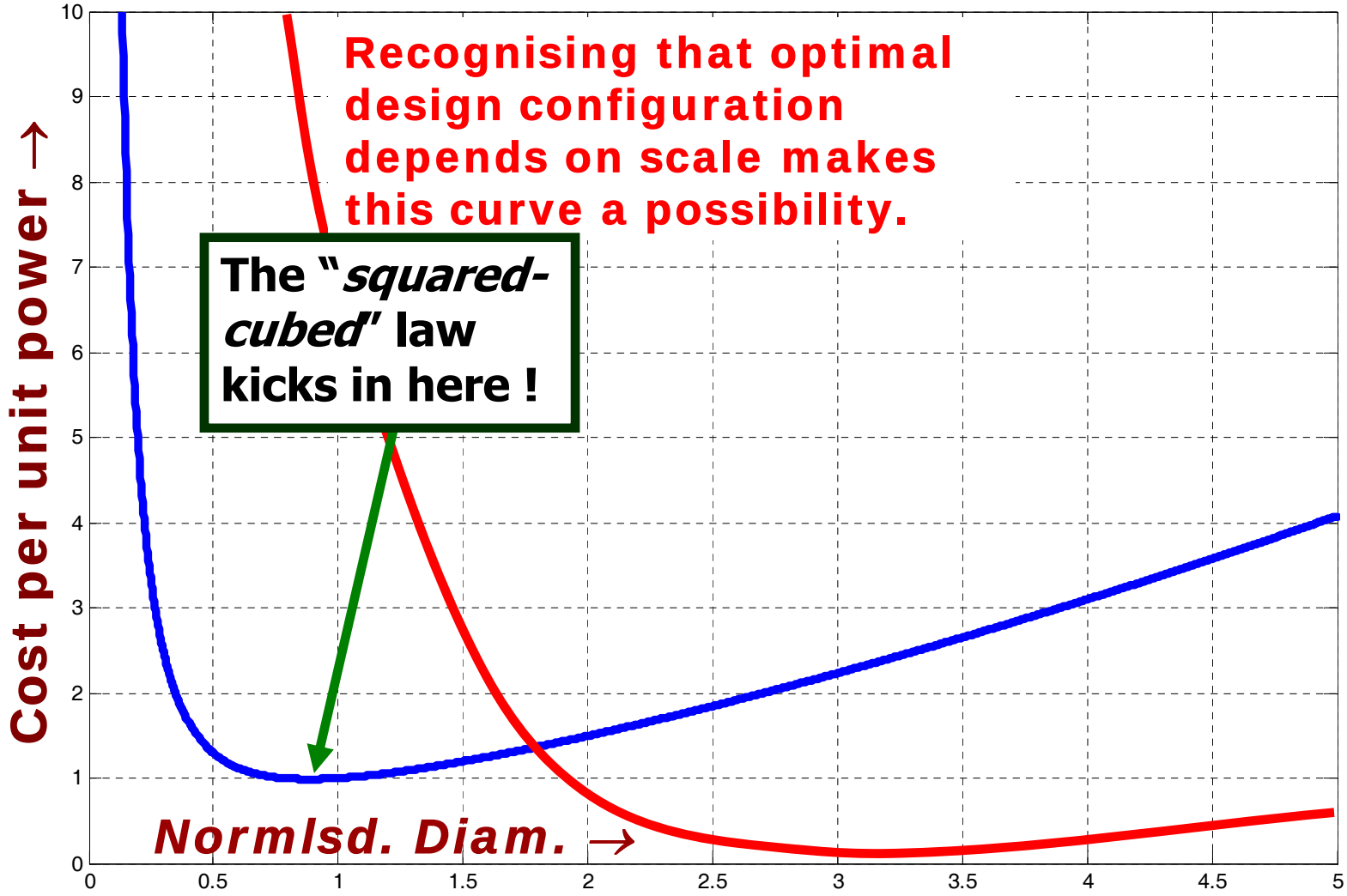
Prof. Alan Epstein's group at MIT developed this machine.

Do you recognise this ?

- a gas turbine engine optimised for mm scale.

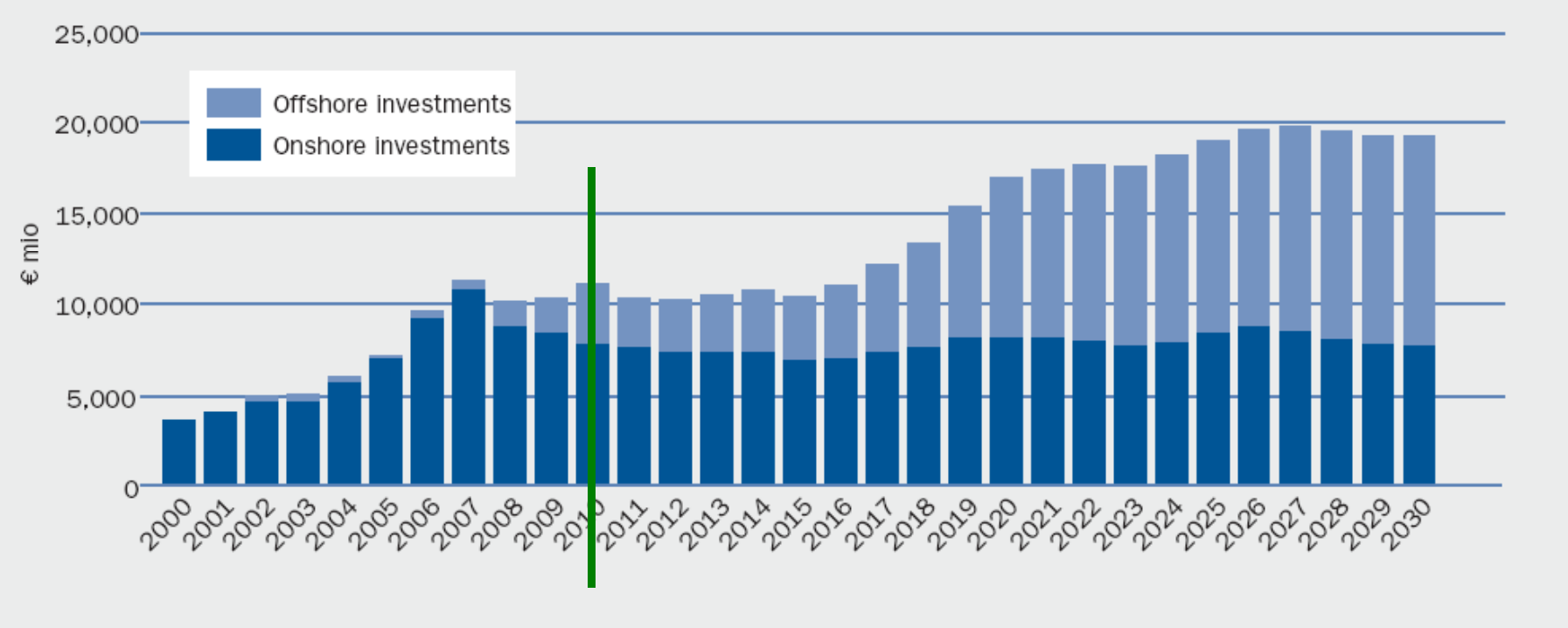
Existing wind turbine designs have persisted – largely-unchanged – over a power range from 1kW to 7.5MW – a factor of 7,500!

Scale affects design (#3)



'Good time for design change?

The Offshore Wind Market is Just Beginning!



Source EWEA, 2007

Expect €12Bn / year by ~2025.

http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Economics_of_Wind_Main_Report_FINAL-lr.pdf

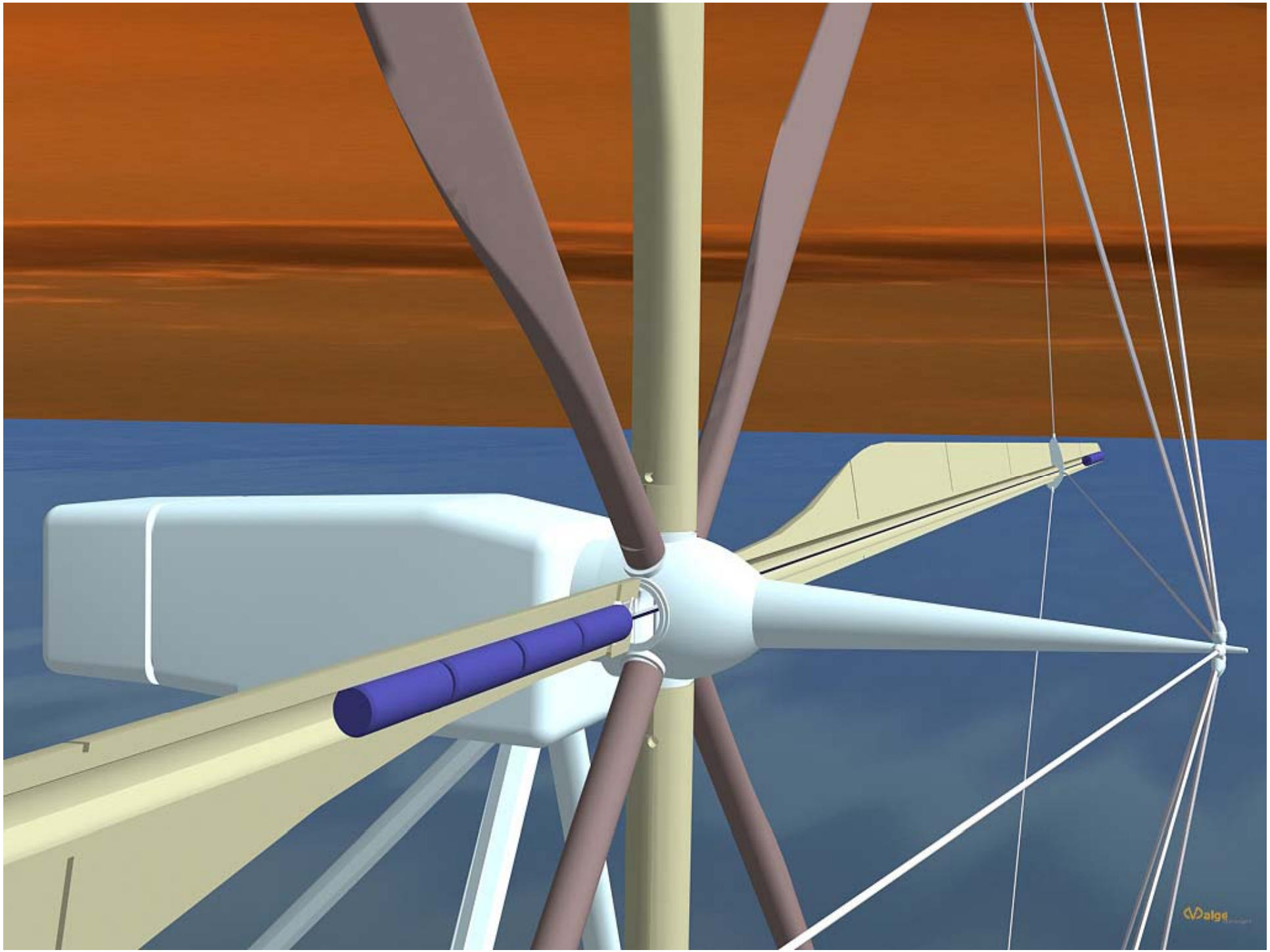
Introducing ICWTs.

Integral Compression Wind Turbines

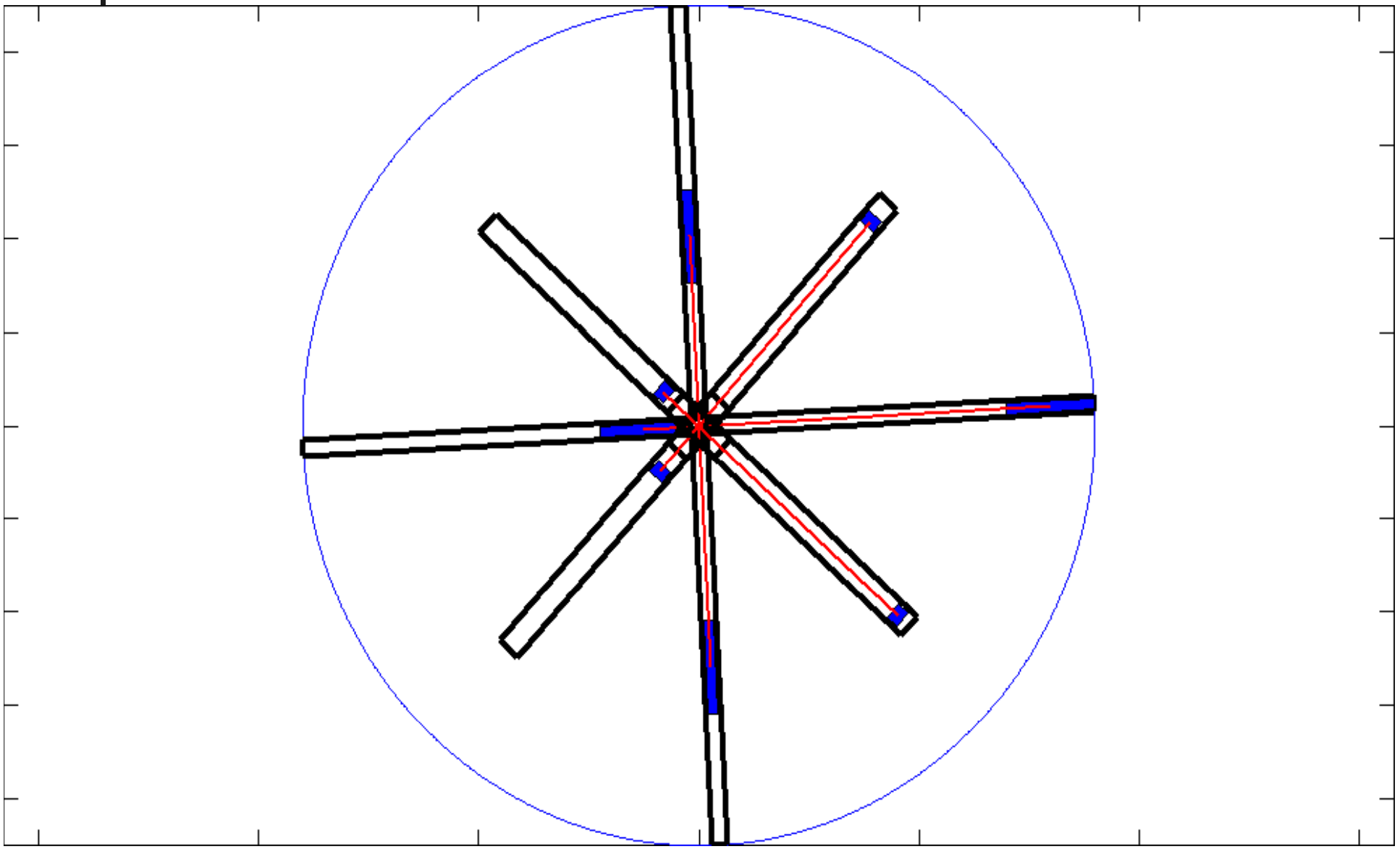
Ultra-large scale wind turbines that compress air directly.

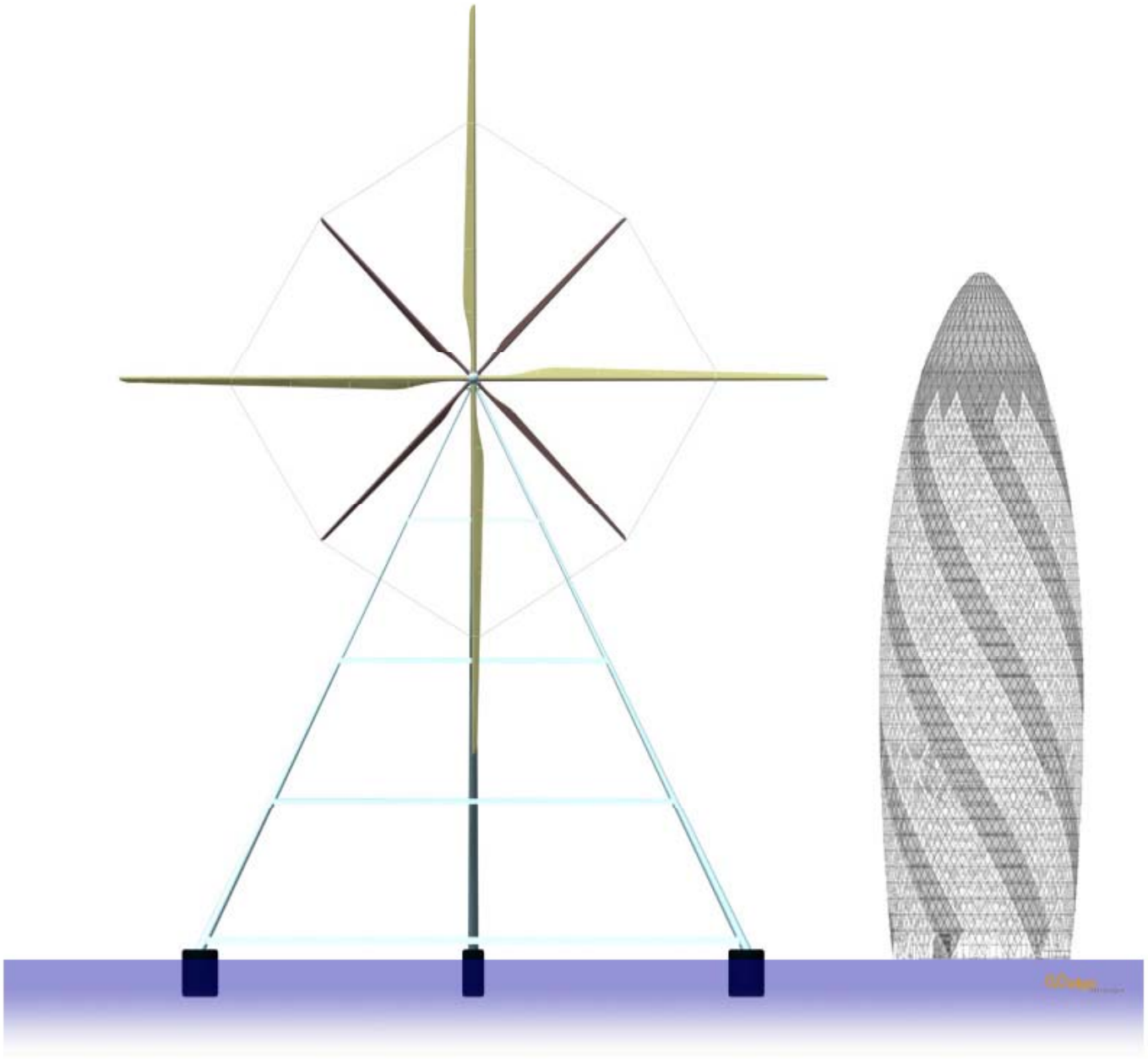
Viable only at huge scales (>250m diameter)

‘Can demonstrate that these take up <25% of the materials per MW of generation taken by conventional WT designs.



Getting the power out …



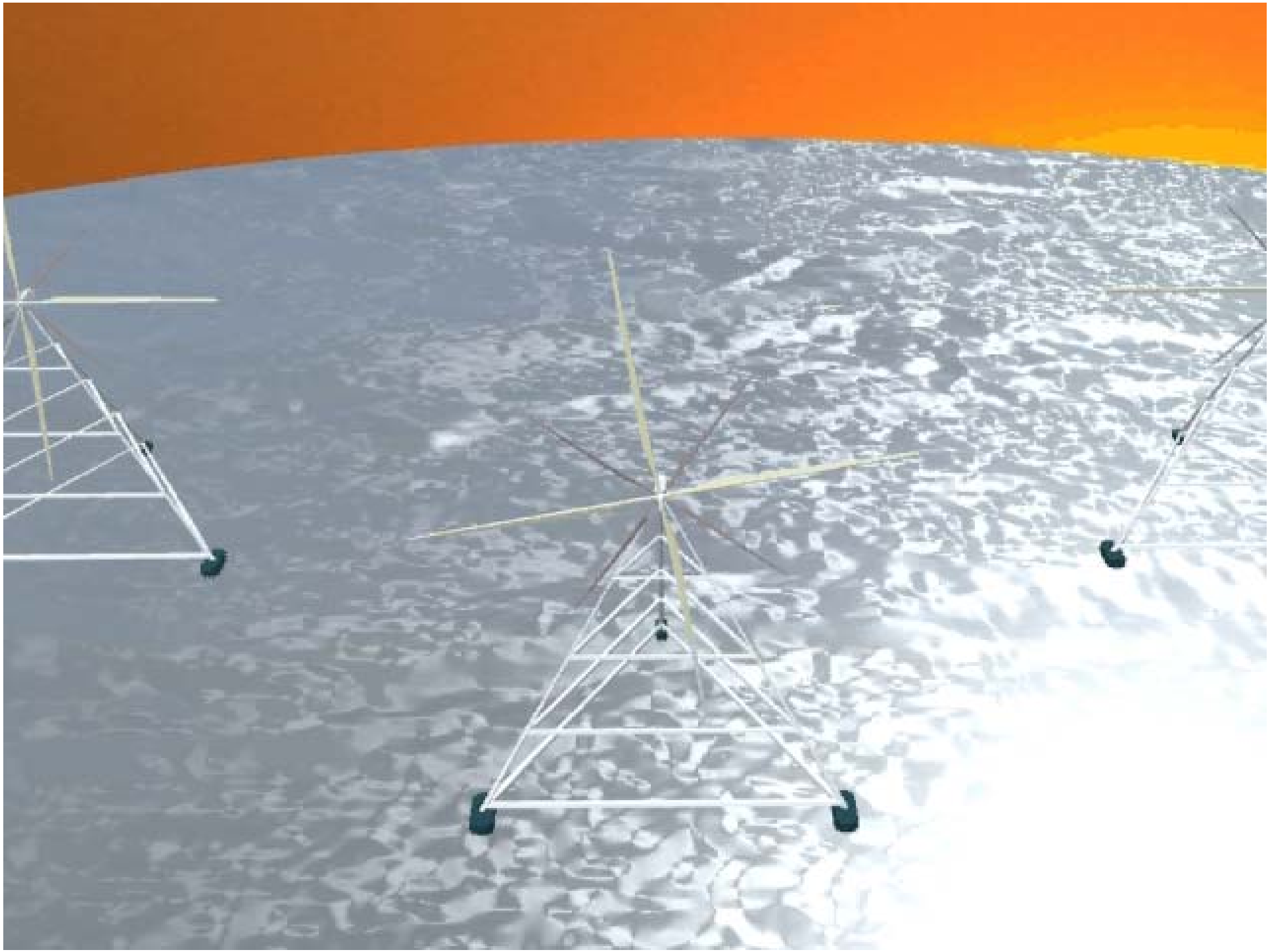


ICWTs Summary.

Cheap per unit of output electrical power.

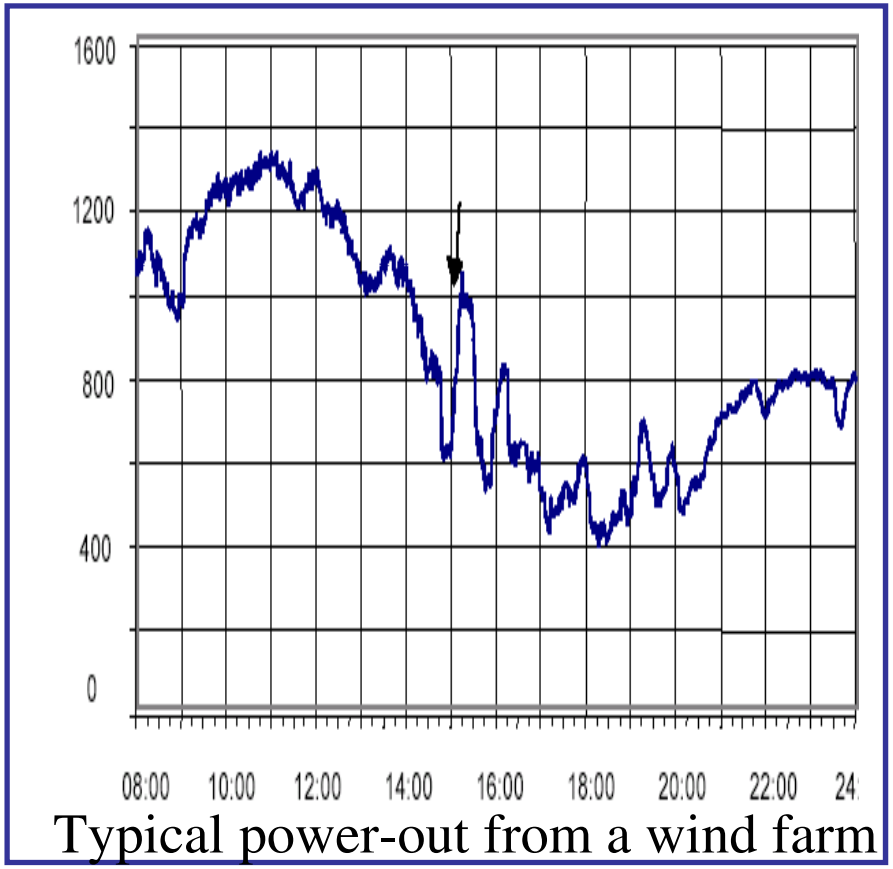
~~£600K/MW rated for ICWTs.

~~£3000K/MW rated for conventional offshore wind turbines.

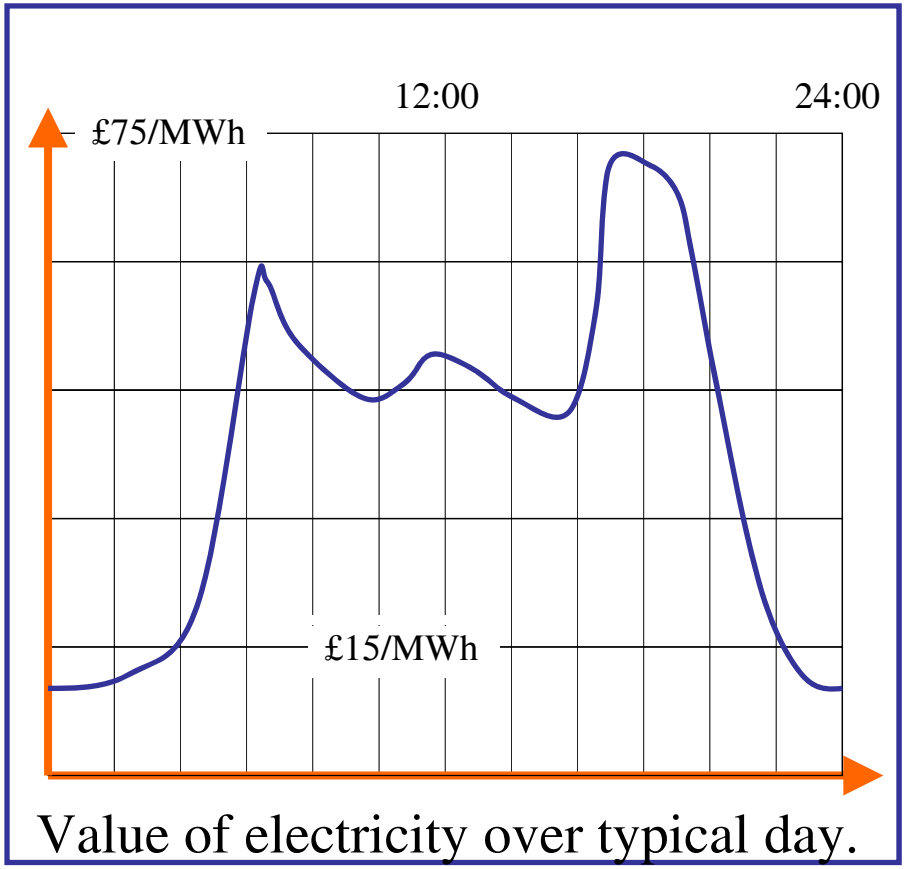


Dispatchable Energy (#1)

Energy storage reconciles supply with demand.



Typical power-out from a wind farm



Value of electricity over typical day.

Dispatchable Energy (#2)

Electricity consumption per day: **~1.1 TWh**
(60 million "Dobbin-days")

Dinorwig pumped-storage system is the UK's largest store ~ **0.01TWh**.
(50,000 "Dobbin-days")

To deal with a 3-day "calm" by 2020, we need at least **1 TWh** of storage.
2030, 100% renewables - **10 TWh** storage.

Dispatchable Energy (#3)

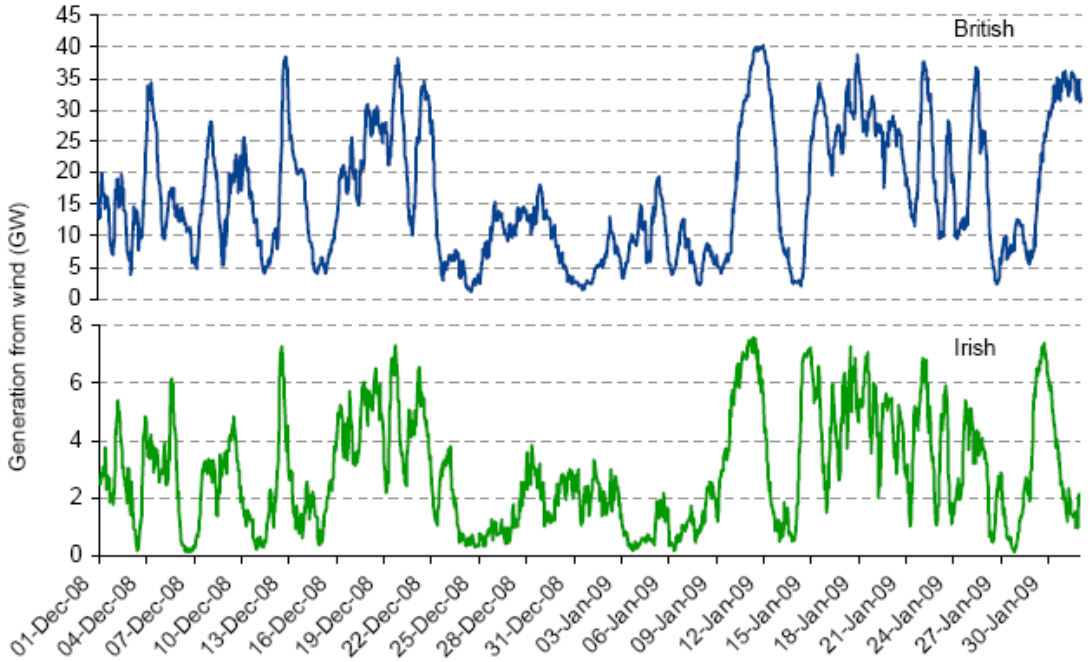
High penetration of intermittent renewables causes issues.

Prices spike to

26× "average"
by 2020 and to

160× "average"
by 2030.

Figure 2 – Example wind generation profiles for 2030 with wind of 2008/09



… between 2000-2007 there was <u>one period of almost three days at [<5% of maximum power]</u>.

(Jan 2010 was also salutary).

Pöyry. IMPACT of INTERMITTENCY: How wind variability could change the shape of the British and Irish Electricity Markets. July 2009.

Knowing that storage needed..

we should at least consider doing this …

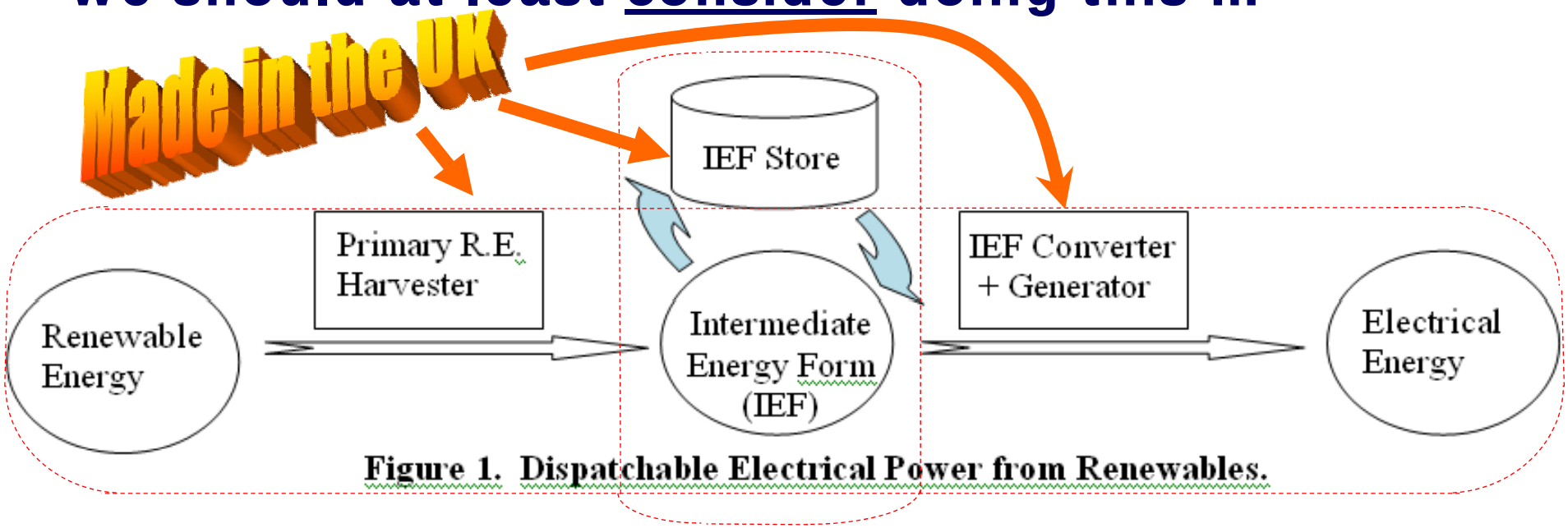


Figure 1. Dispatchable Electrical Power from Renewables.

Such a system would be a "no-brainer" if …

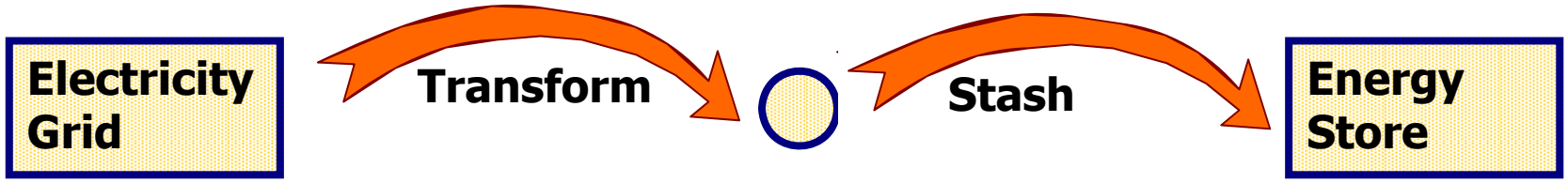
(a) The "Main path" produces very cheap output elec.

(b) The marginal costs of energy storage are very low

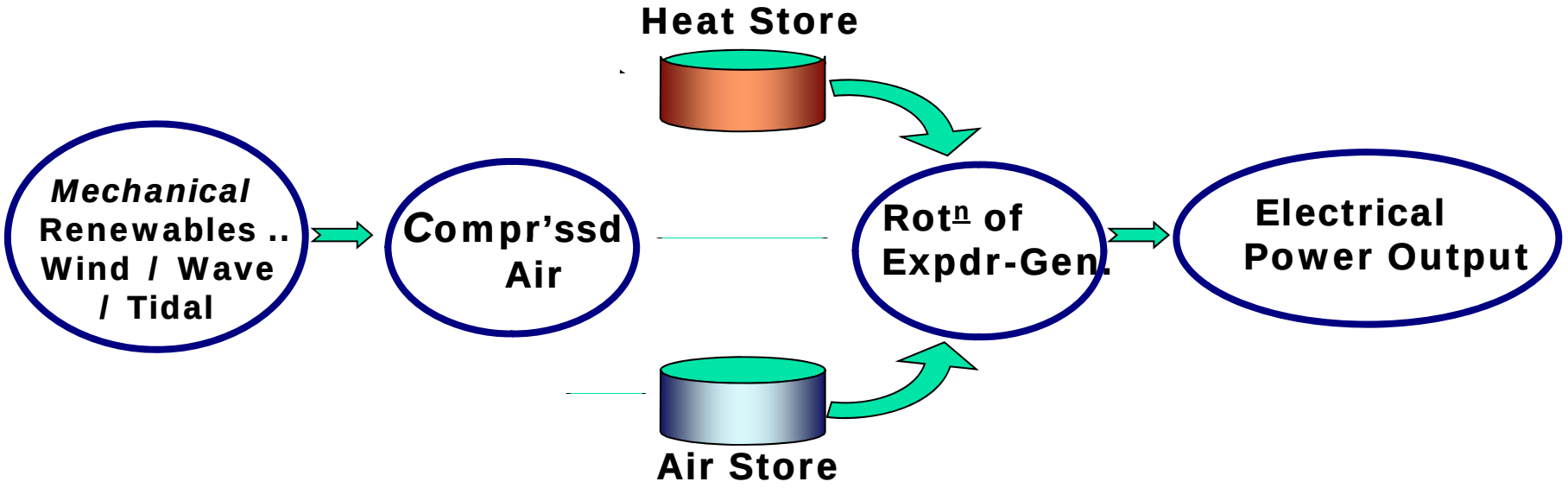
(c) Marginal losses of energy put into storage are v. low

Contrast with dumb storage ..

Traditional energy-storage approaches involve:



Transformations need occur only once !



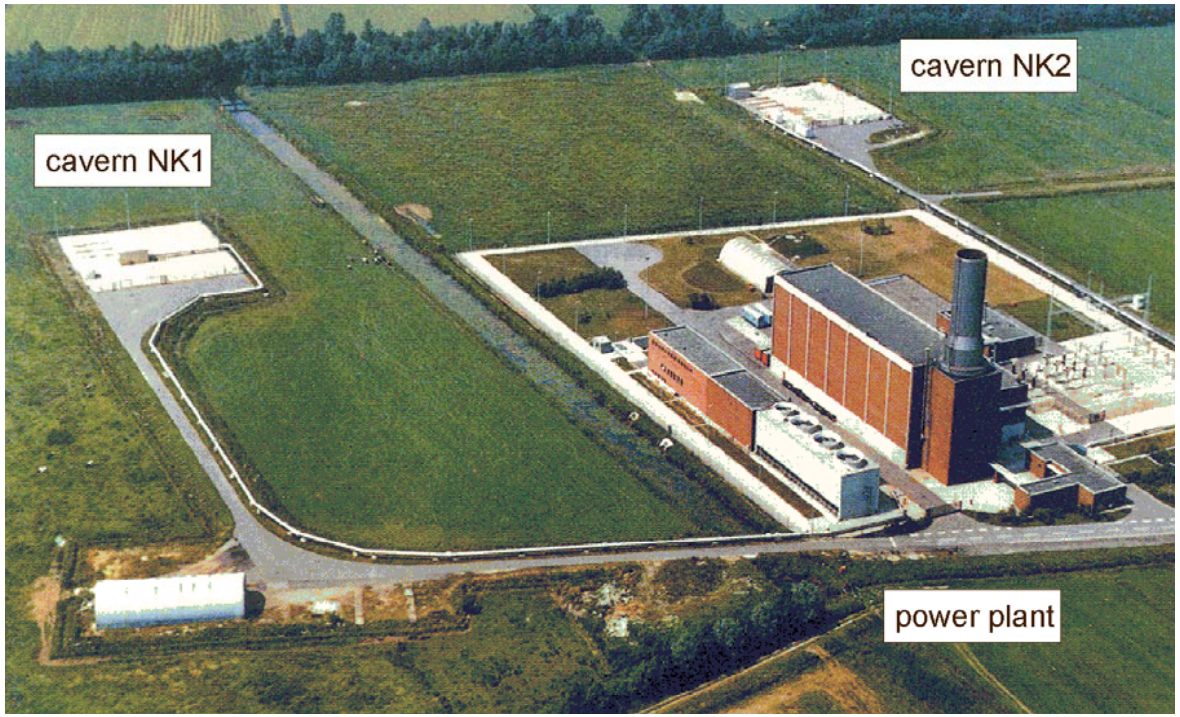
Energy storage is expensive..

Typical energy storage costs are[1]:

Electro-chem. Storage:> $400K/MWh

Pumped Storage: $80K/MWh

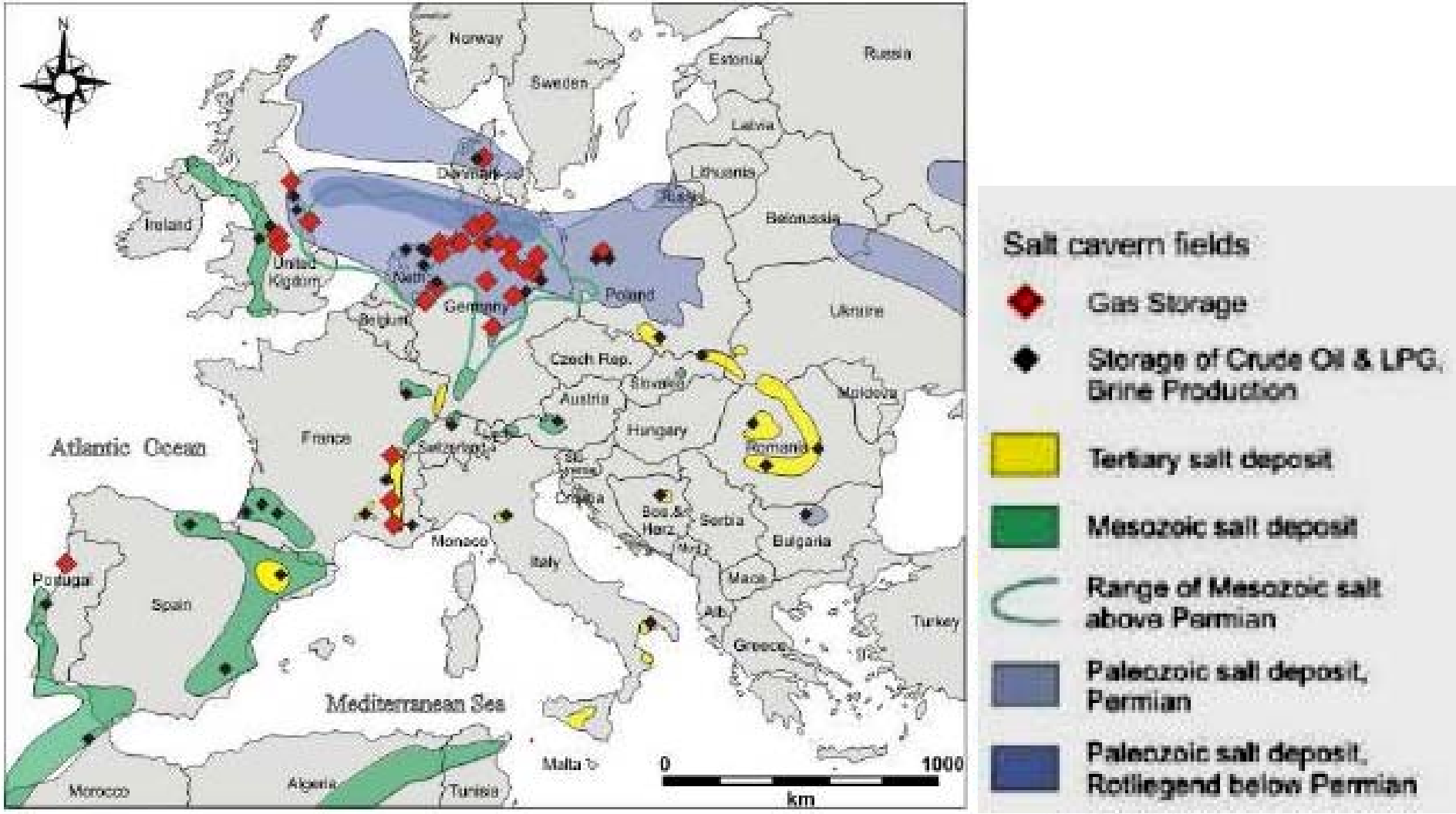
Compressed Air : **$1K/MWh**[ϒ] (salt caverns)



[1] **Price A.** ***The Current Status of Electrical Energy Storage Systems***

ESA London Meeting, Jan 2009.

North Sea has salt deposits!



Introducing *Energy Bags*™

Energy Bags™

Fabric containments for holding compressed air at great depths (>500m) in the sea – a (relatively) cheap way to store energy.

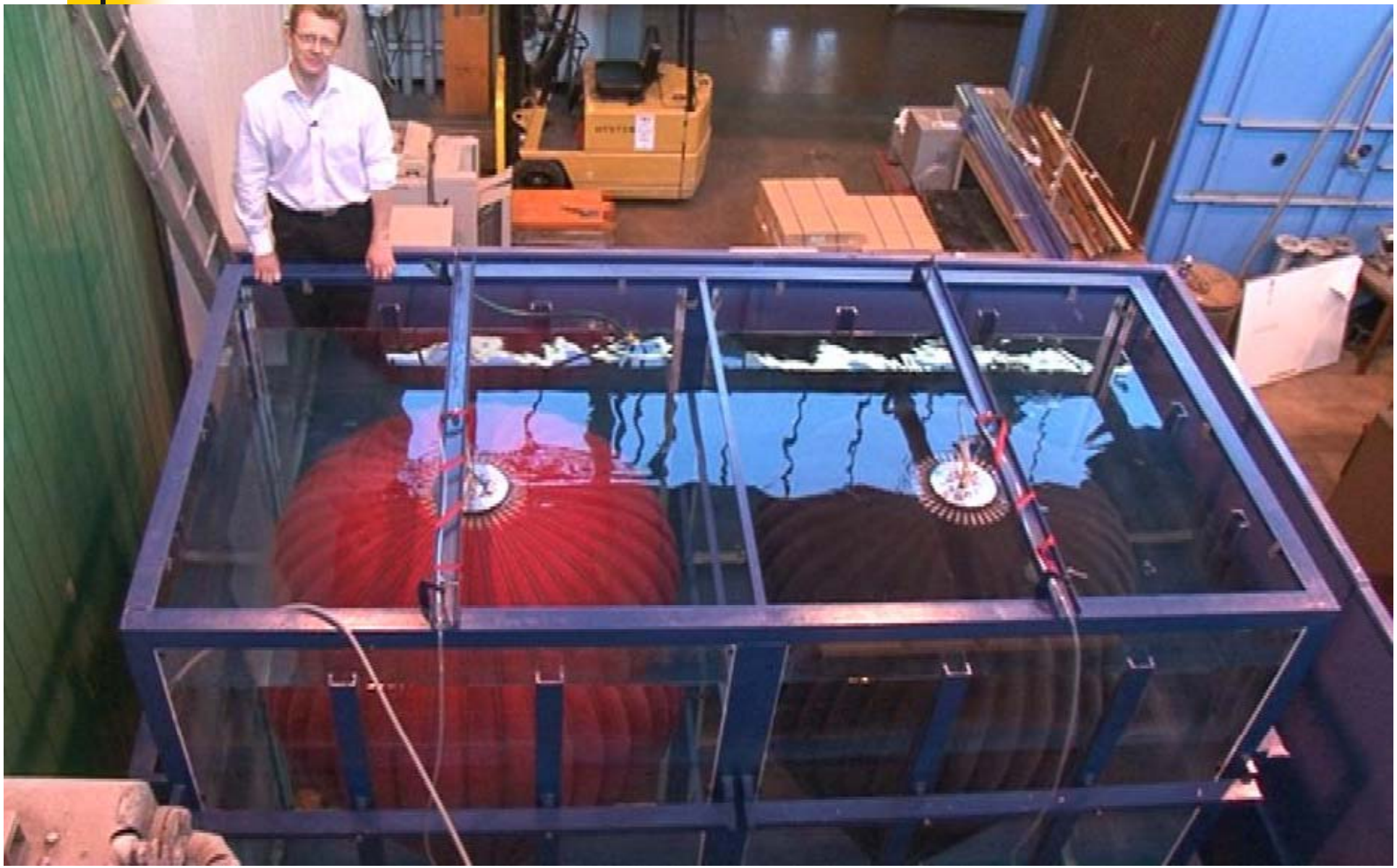
Salt-domes	~~	£600M/TWh
Energy Bags™	**~~**	**£6,000M/TWh**
Pumped Hydro	~~	£50,000M/TWh

Energy Bag (Prototypes)

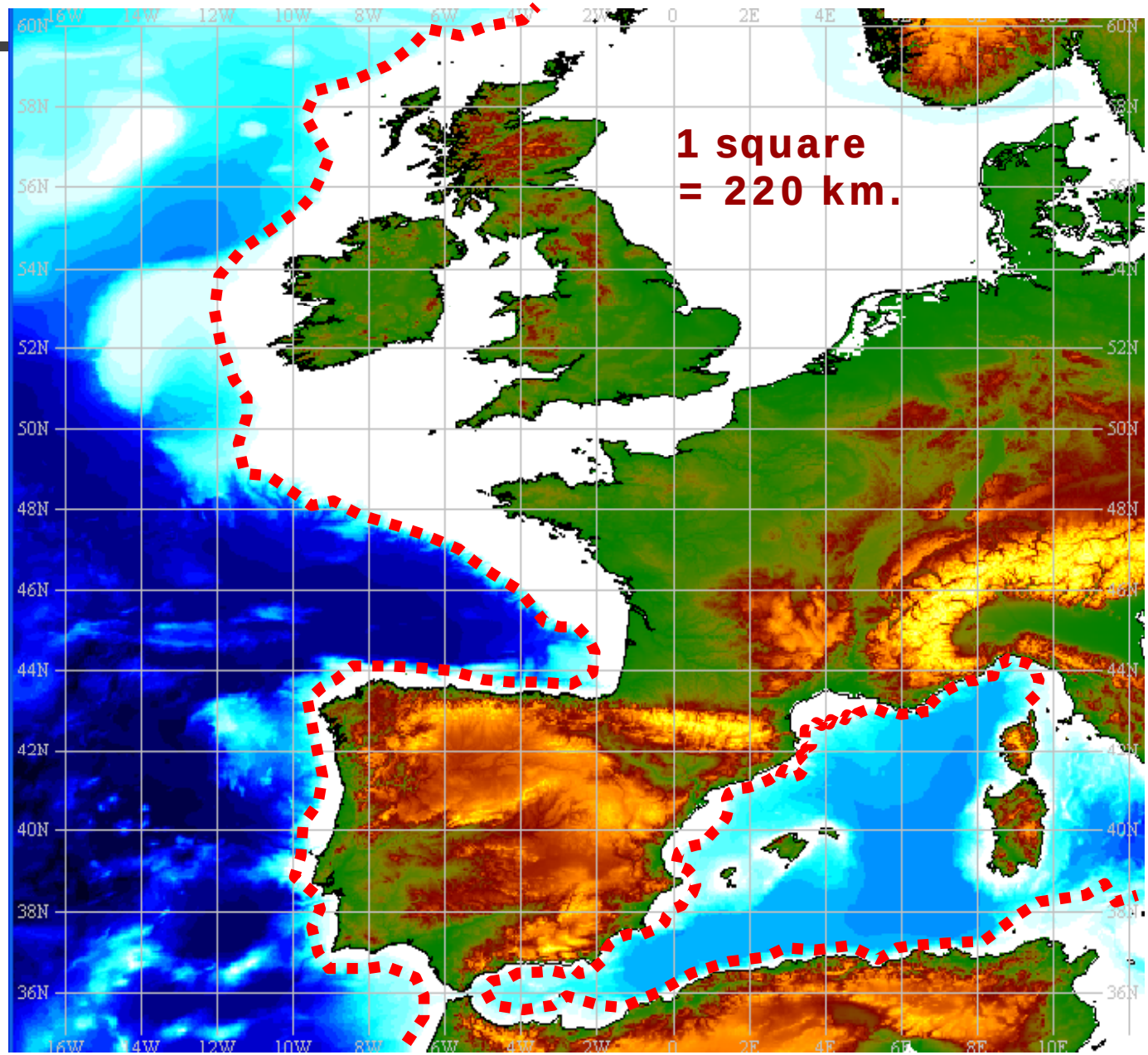
1/10th scale bags

Energy Bags™ in test (#1)

Energy Bags™ in test (#2)



Where is 500m deep water ?



Summarising *Energy Bags*™

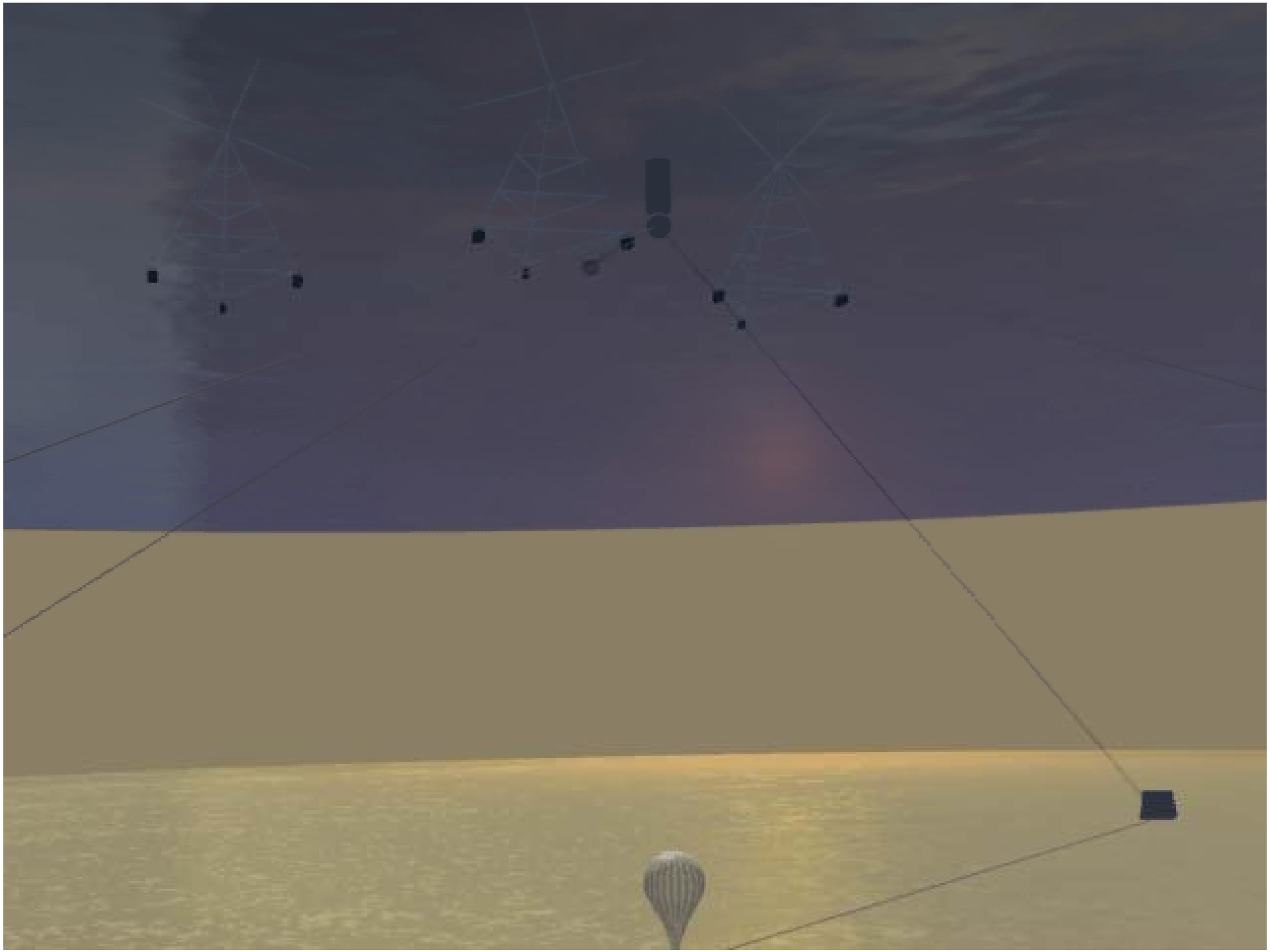
Fabric containments for holding compressed air at great depths (>500m) in the sea – a (relatively) cheap way to store energy.

At 600m, the energy storage density is 25MJ/m^3 - 50MJ/m^3 ¥.

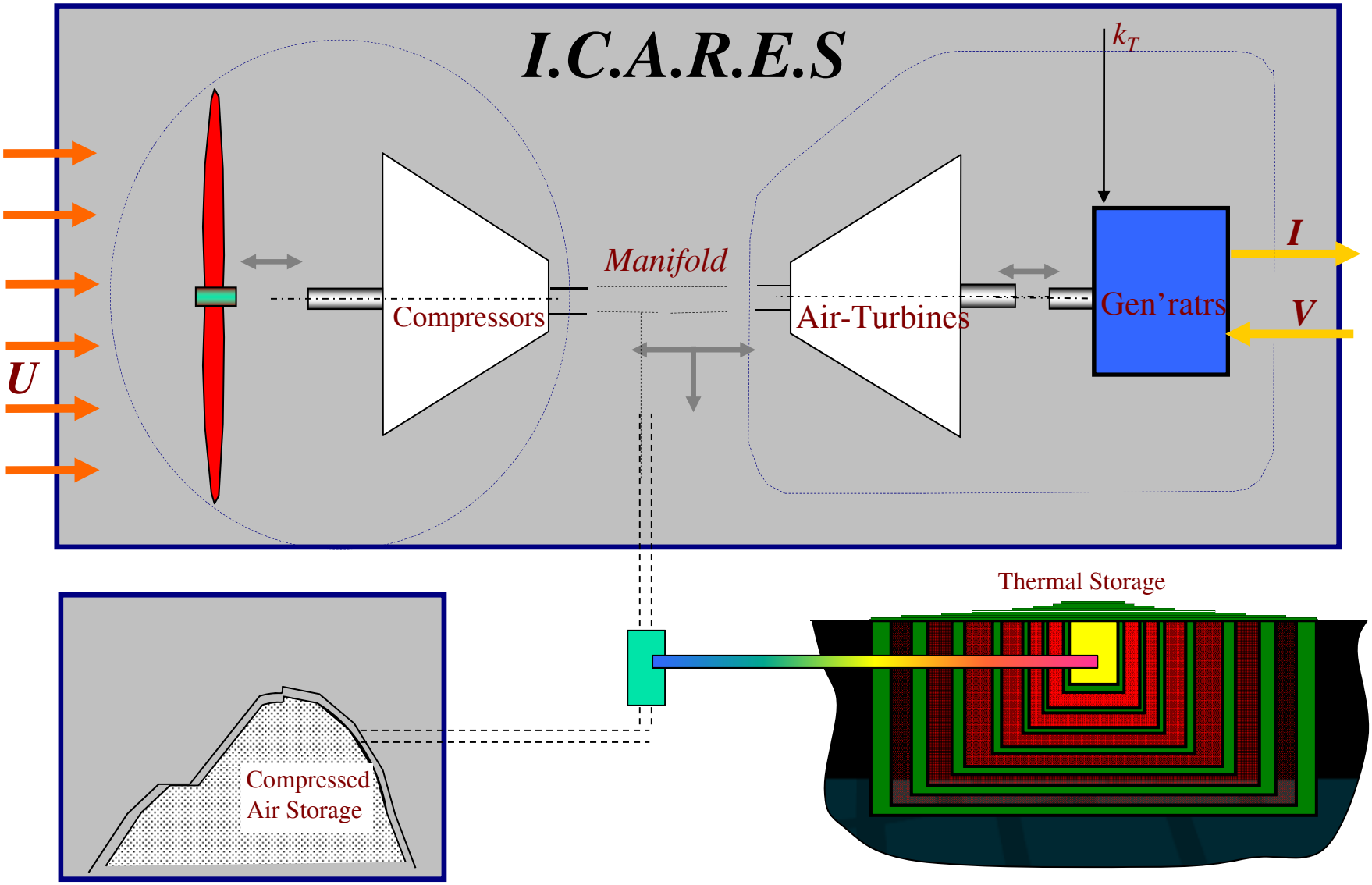
Materials cost ~ £50/m^3 (depth irrelevant)

⇒ **one-tenth of cost of pumped-hydro.**

¥ Depending on how/whether the compressed air is reheated during expansion.



UK Energy, 2030 - a vision (#1)



UK Energy, 2030 - a vision (#2)

Integral Compression Wind Turbines.

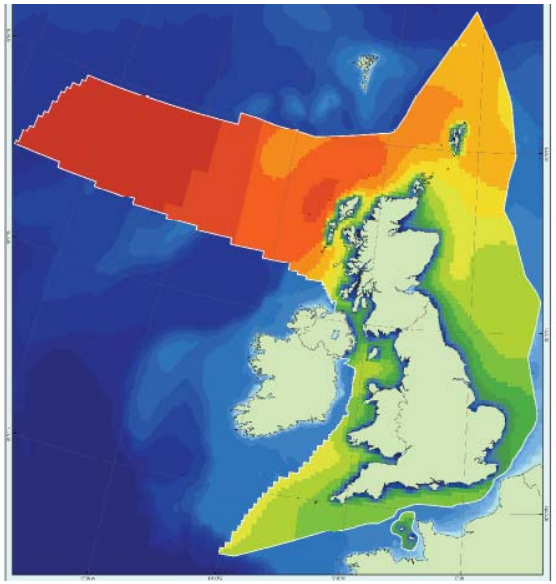
500m diameter – powers 120MW–250MW.

Each Rotor ~2000 tons (1000 tons moveable)

Each floating framework ~5,000 tons

Total fleet … 2000 off (**£150Bn**).
producing 1400 TWh per year

12 million tonnes of steel.
2 million tonnes G.R.P.



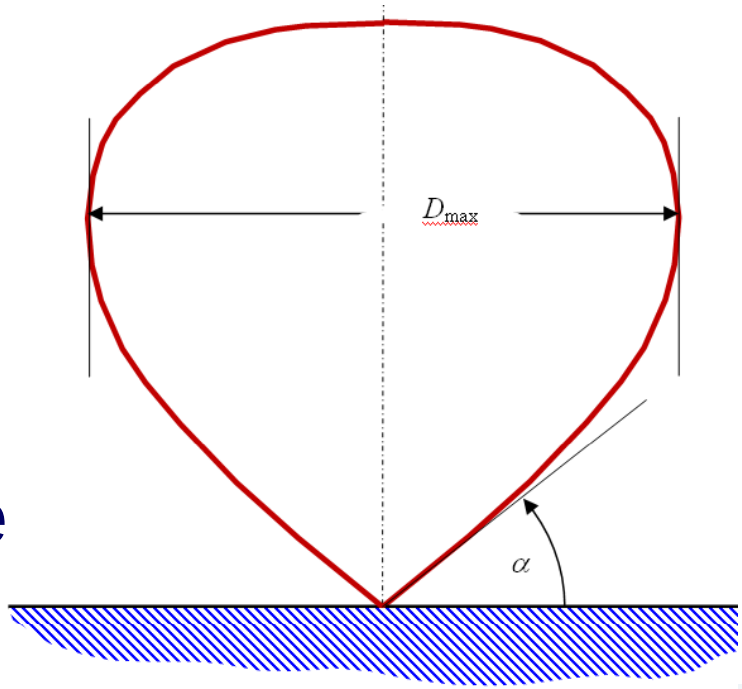
UK Energy, 2030 - a vision (#3)

Energy Bags.

Individual Bags ~20m diam.

Each Bag ~ 4000m³.

Each Bag ~ 1,250m² surface

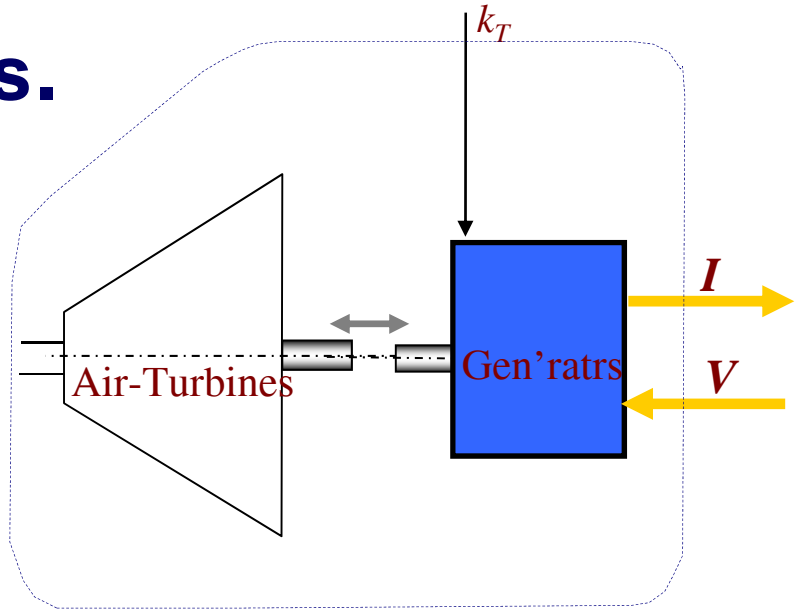


Total flock … 10 TWh
(9 days of UK electricity 2010)

260,000 such bags (**£50Bn**).
~ 350 km² of surface.

UK Energy, 2030 - a vision (#4)

Expander-Generator Sets.



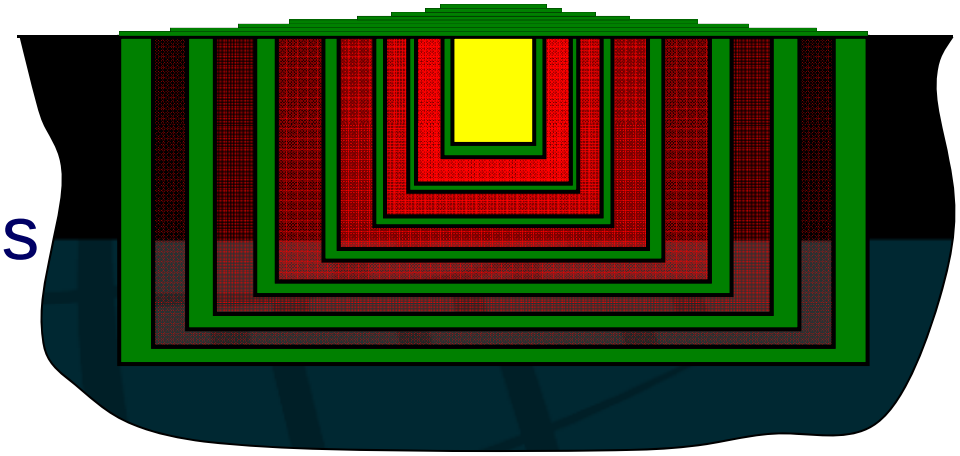
ICWT hardware arranged in ~70 "farms" of ~5GW each.

Expander-generator sets of 500 MW rating – 10 per "5GW farm".

At (£200M/GW … total tag of (**£70Bn**).

UK Energy, 2030 - a vision (#5)

Thermal Stores



Floating thermal stores

One per farm.

The total thermal storage required is similar to the compressed air in energy terms.

Total flock of thermal stores … 10 TWh

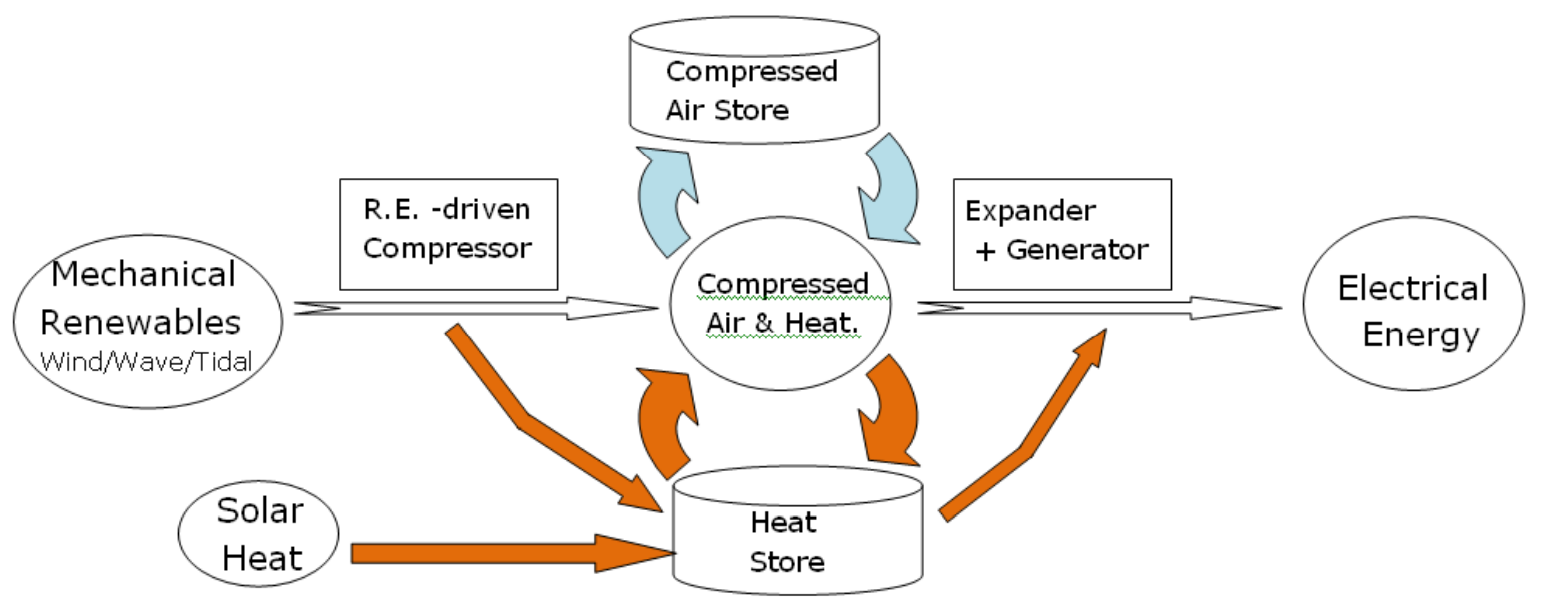
Based on 50°C temperature swing and 1000J/ kg°C, … **720 million tonnes** (largely seawater!). ~~**£50Bn**.

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.

Thanks for listening.



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