Reasons for optimism: 'Grid Parity' for renewable energy sources

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Four (unrelated) working assumptions

1. ‘Grid Parity’ in the UK means approximately £50/MWh or 5p per kWh

2. No democratic society will tolerate renewable costs that are substantially above fossil

3. Low carbon electricity is important, so is transport fuel. And heat decarbonisation is central

4. There’s enough solar/wind to provide all the planet’s energy needs many times over. Tidal, wave + biomass are bonuses

Low carbon technologies usually have

- High capital cost
- Low operating costs
- Long life

PV versus gas power

	PV	Natural Gas CCGT	Ratio: PV/CCGT
Capital cost	£800/kW = £0.7/kWh/pa in UK	£500/kW = £0.06/kWh/pa	12
Operating cost	£0.005/kWH	£0.03/kWh	1/6
Life	30+ years	20 years	1.5+

What matters for renewables?

(Or nuclear, for that matter)

- Capital cost per unit of capacity
- Annual cost of capital (‘interest rate’, ‘discount rate’ or Weighted Average Cost of Capital)
- Asset lifetimes

What matters for renewables?

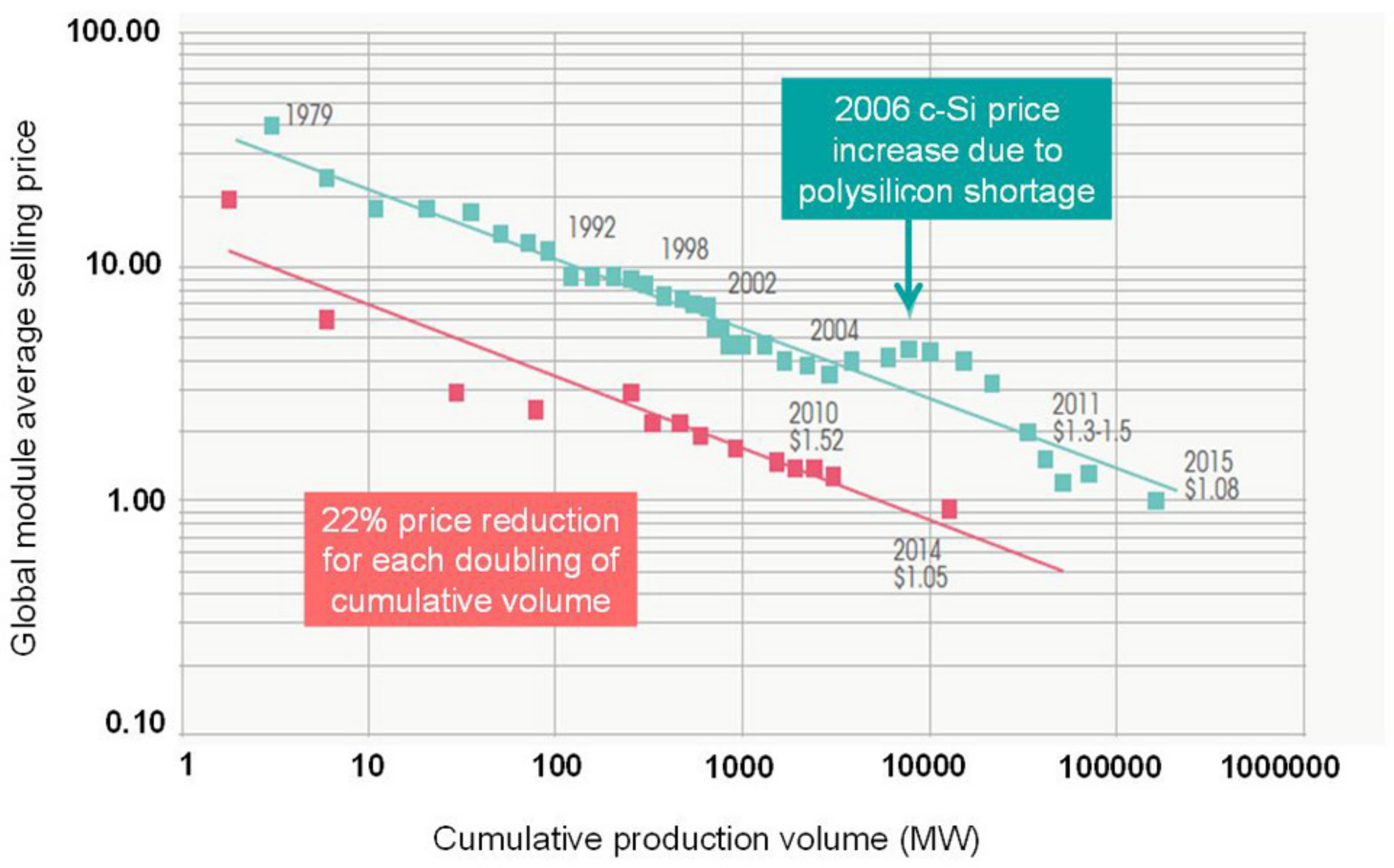
- Capital cost per unit of capacity
- ~~Annual cost of capital ('interest rate')~~
- ~~Asset lifetimes~~

Current capital cost

- UK solar fields - about £800 per kilowatt
- Slightly under half is panels, just over half balance of plant
- (Down from about £1,300 in early 2012, source DECC)

Learning curve predictions

- Over last half century, PV learning curve (a.k.a Wright curve, experience curve) about -20%
- That is, every doubling of **accumulated production volumes** has cut 20% from production costs
- What happens if the current growth in PV continues and the learning curve persists?



100.00
10.00
1.00
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Global module average selling price
Cumulative production volume (MW)
1979
1992
1998
2002
2004
2006 c-Si price increase due to polysilicon shortage
2010 $1.52
2011 $1.3-1.5
2014 $1.05
2015 $1.08
22% price reduction for each doubling of cumulative volume

Capital cost of solar

Accumulated production experience end 2014 - about 200 gigawatts

Expected installed volume 2050 - about 4,600 gigawatts* (4+ doublings of experience)

If 20% learning curve, implies UK price falls from about £800/kW today to around £300/kW in 2050. Most of this will be achieved by 2020 or so because doublings are much more frequent.

* Source: International Energy Agency

But it could be quicker than that…

• Recent (2013) growth rate of total installed capacity	-	35% a year
• Therefore installed PV doubles every	-	Just over 2 years
• And therefore costs down every two years	-	About 20%
• At current rates, installed capacity increase by end 2020	-	About 8 fold (or 3 doublings)
• If learning curve holds, then PV costs will fall	-	Almost 50%

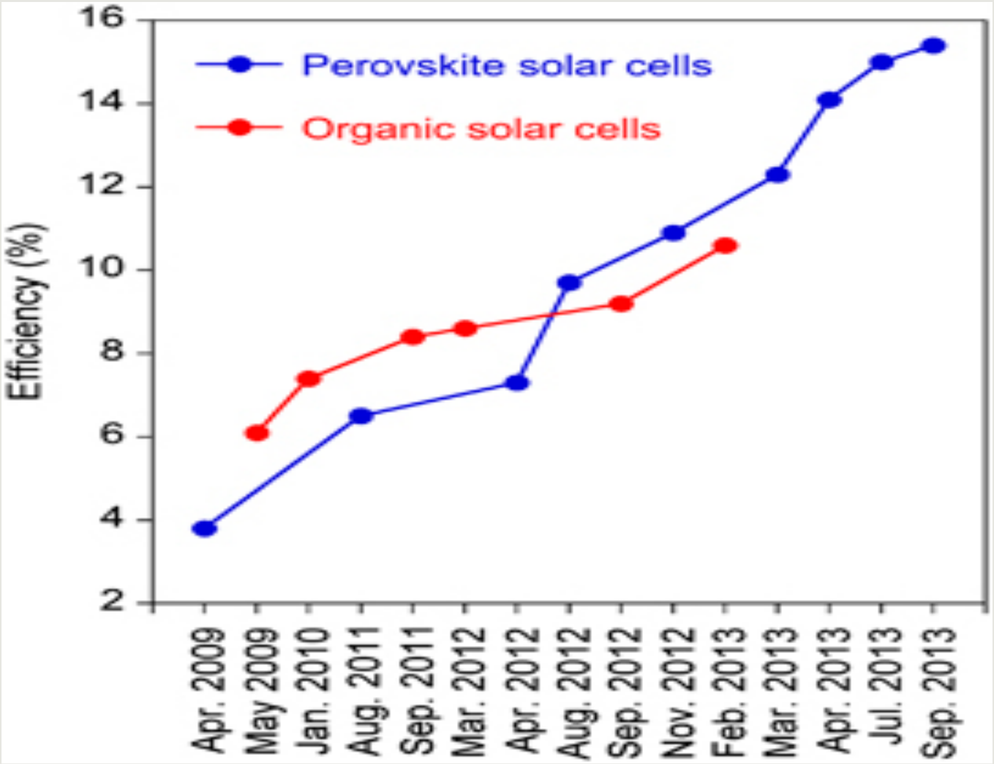
Capital costs of solar

- No reason why this shouldn’t happen, or even be improved upon
  - Improvements in solar manufacturing efficiency
  - Continued reduction in inverter and B of P costs
  - And increasing real prospect of perovskite semiconductors producing rapid step-down in costs per watt. Perovskite likely to be applied as a surface to conventional silicon raising overall efficiency of solar collection to 40% plus

Rapid progress in perovskite cells

*

19.3% UCLA team led by Yang Yang, Aug. 2014



From Burn and Meredith, *Nature*, January 2014

- ~~Capital cost per unit of capacity~~

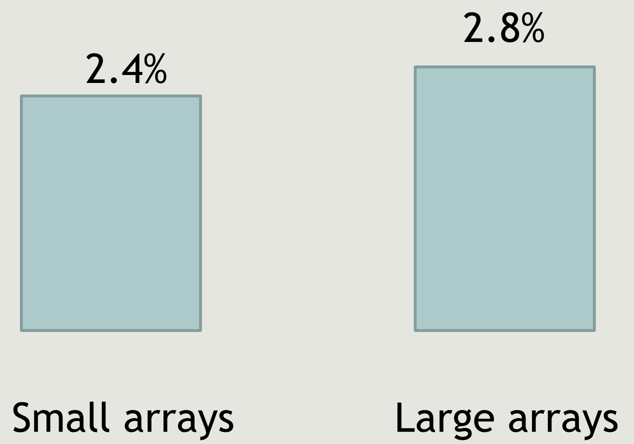
- Annual cost of capital (‘interest rate’, ‘discount rate’ or ‘WACC’)

- ~~Asset lifetimes~~

Cost of capital

- IEA estimates 8% annual for PV globally (2014)
- UK Committee on Climate Change says 5.3% (2014)
- I say that today this is far too high. Reasonable assumptions are much lower

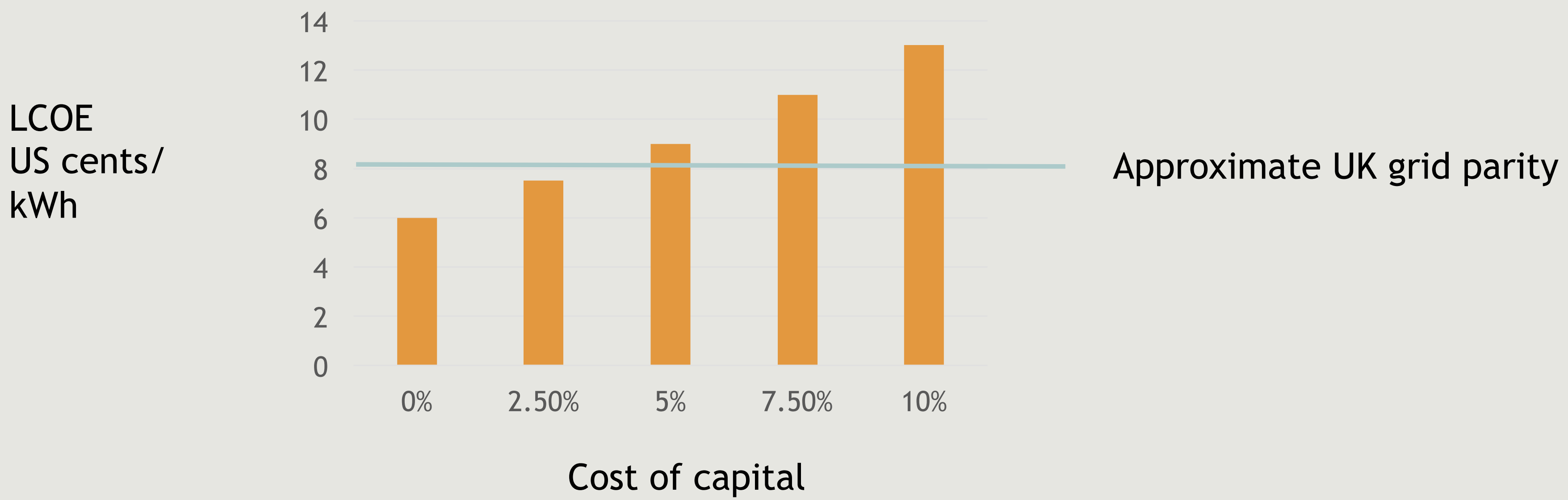
Fraunhofer 2103 assumptions on Weighted Average Cost of Capital (WACC) in Germany



www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf

Impact of annual cost of capital – IEA global averages

2014 Levelised Cost of Electricity (LCOE) US cents/kWh



Core assumptions: 1,360 kWh/kW/pa, 20 year project life, $1,500 per kW, annual O+M=1% capital

Source: IEA 2014, Technology Roadmap, Solar Photovoltaic Energy, Table 12

Moving assumed cost of capital from 7.5% to 2.5%

- On its own, cuts the levelised cost of electricity (LCOE) by over a third
- Pushes PV from being extremely competitive with global fossil electricity to being more expensive

What is the correct assumption for the cost of capital?

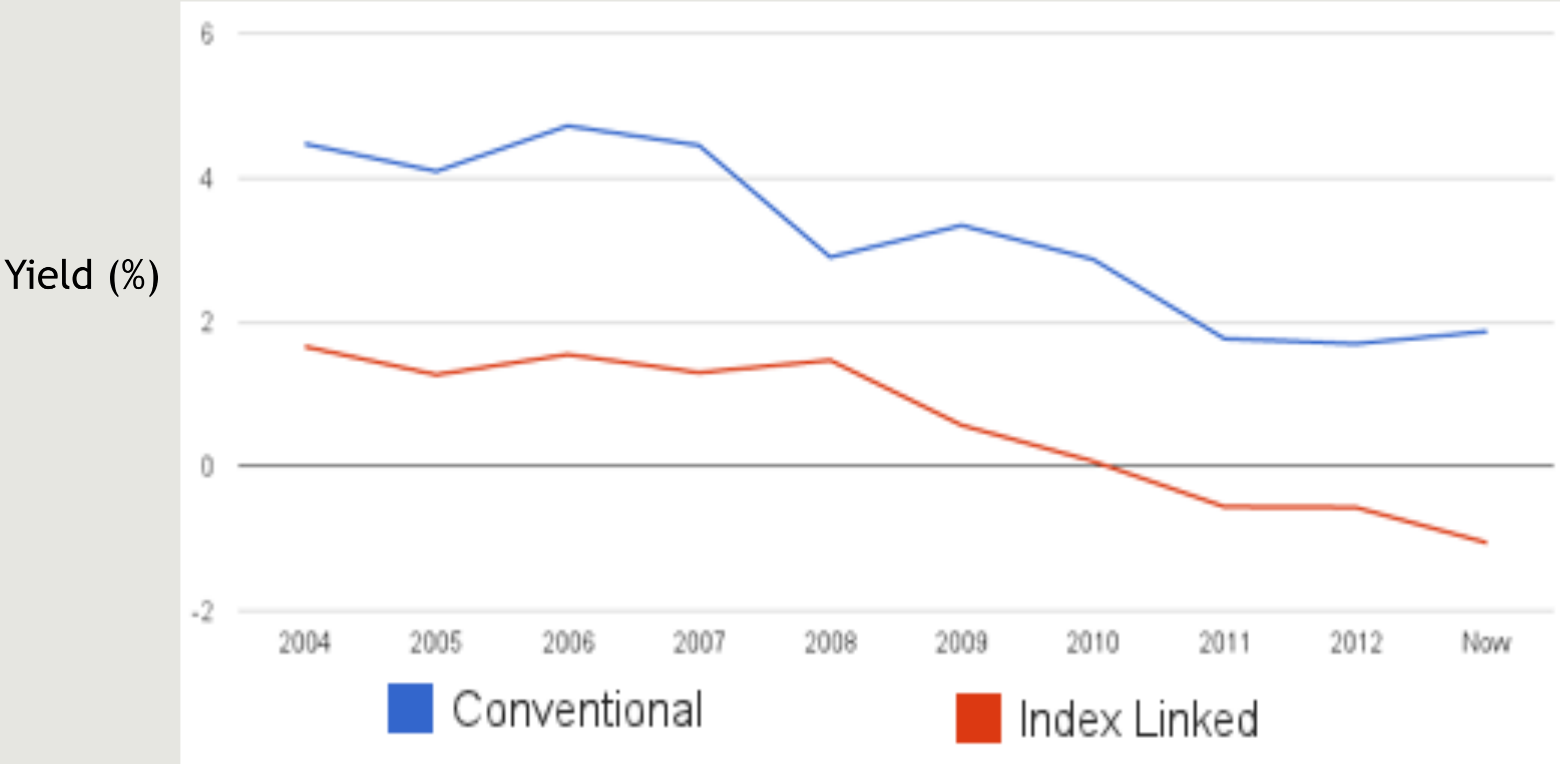
- Westmill 5MW Solar Farm near Swindon
- Equity owned by community
- Debt owned since early 2013 by Lancashire Council pension fund at 3.5% real return

Characteristics of UK PV that makes it very similar to index-linked gilts ?

- Guaranteed prices for output under FiT regime. Guarantee is almost state backed.
- Price inflates by retail price inflation (RPI) for 20 years
- Warranties for performance by large and stable manufacturers for ten years
- High consistency in yearly solar radiation received in west Oxfordshire
- Almost perfect match to pension fund liabilities

What reason not to view Westmill bonds as approximately equivalent to government index-linked bonds?

Yields on index-linked and conventional gilts



The competition

Current (late October 2014) UK index-linked state bonds ('gilts')

Bond	Running yield
Maturing 2035	Minus 0.48%
Maturing 2024	Minus 0.68%

Capital markets will (eventually) realise that state guaranteed prices for PV power mean that solar farms should have a very low cost of capital indeed

- ~~Capital cost per unit of capacity~~
- ~~Annual cost of capital ('interest rate')~~
- Asset lifetimes

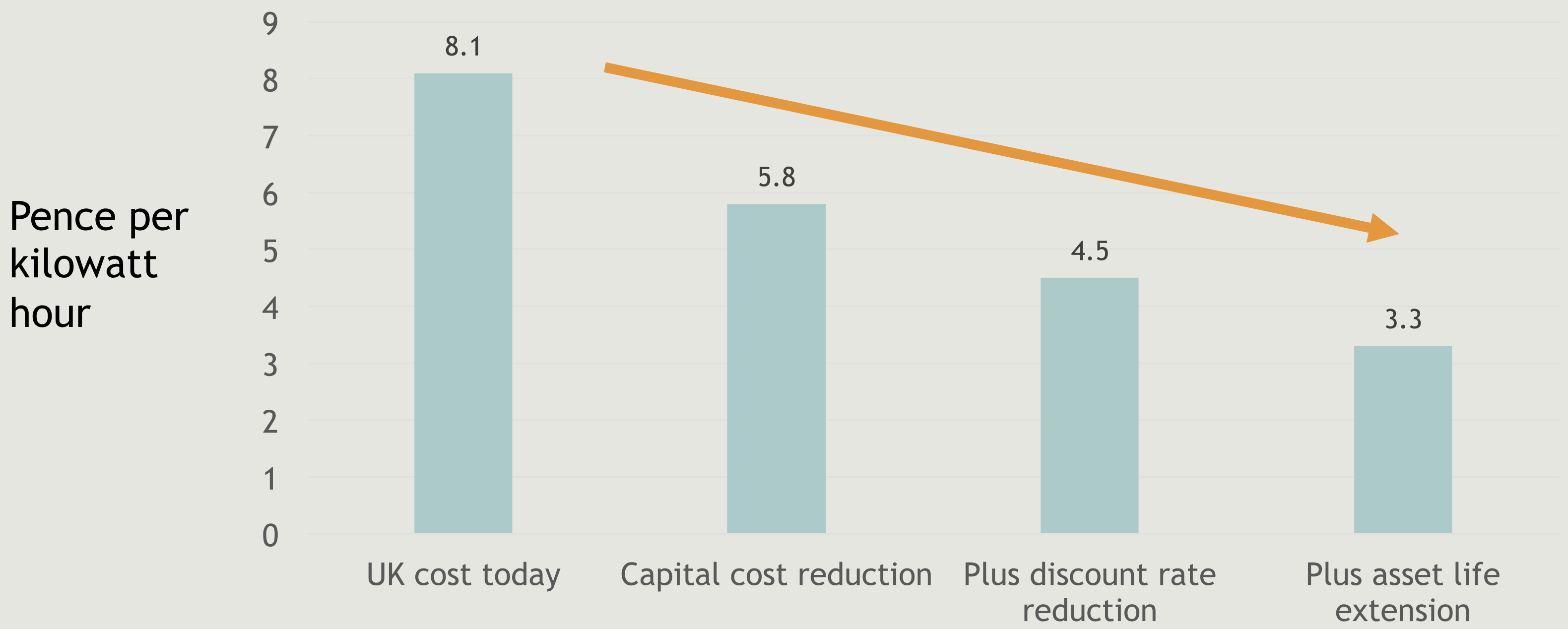
Life of a PV system

- Usual assumption – 20 years or so
- Realistic – at least 30 years
- Reduces the implied capital cost per unit of output by 50% or so

Combining the three forces

Capital cost of PV	Down from £800/kW to, say, £550 by 2020
Cost of capital	Down from perhaps 6% to 2.5% real
Asset life assumption	20 years to 35 years

Getting solar PV down to 3.3 pence per kilowatt hour by 2020

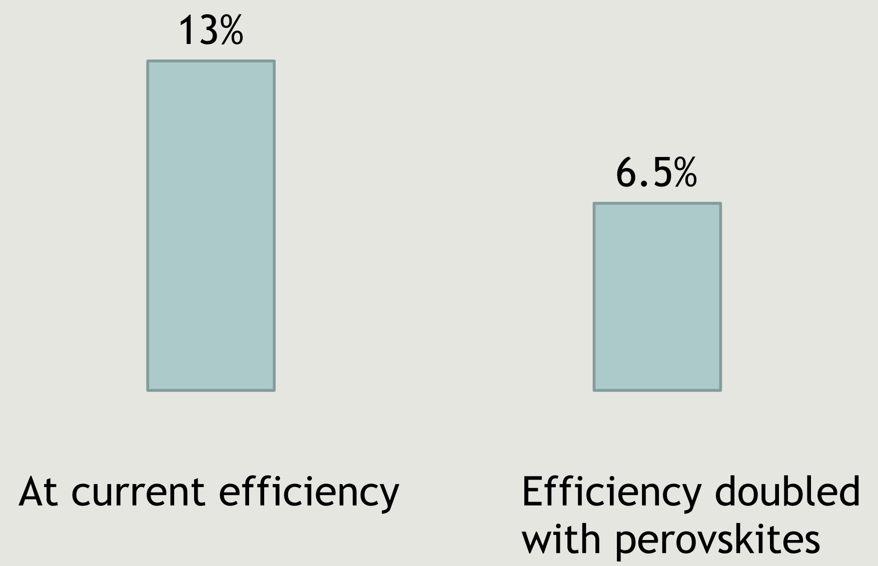


Numbers calculated on the US government's Levelised Cost calculator at http://www.nrel.gov/analysis/tech_lcoe.html, using key UK assumption of 1,100 kWh per kW per year

Objections to this optimism

- Land area of UK too small
- Need for storage
- ~~Cost~~

Percentage of UK land area needed if PV alone were to provide 100% of UK ENERGY demand



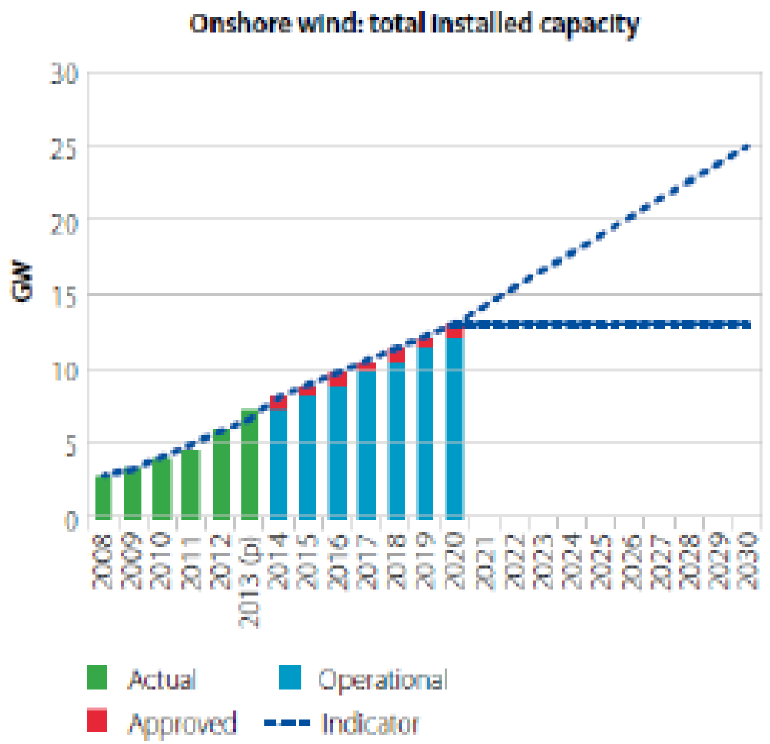
Reducing space requirements still further

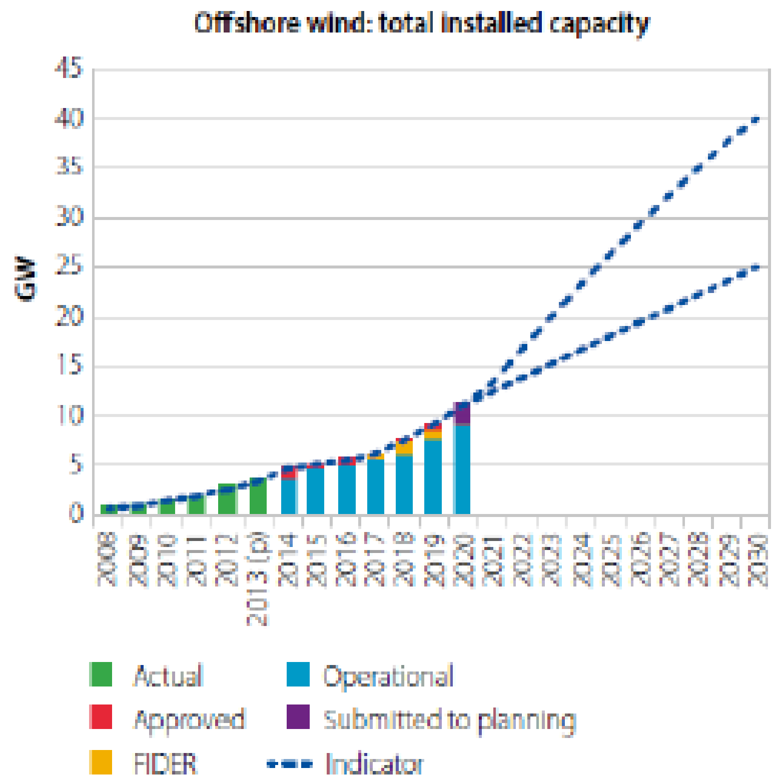
Onshore wind

Tidal lagoons

Biomass to liquids

Projections for installed wind capacity - 50 GW by 2030





Source: DECC (March 2014) *Energy Trends*; Pöyry (2013) Technology Supply Curves for Low-Carbon Power Generation; CCC estimates.
Notes: 2013 data are provisional. Other indicators begin from 2007, however for renewables a consistent data set is only available from 2008. Volatility in offshore wind additional capacity indicator to 2020 reflects expected dates that specific projects in pipeline commence operation.

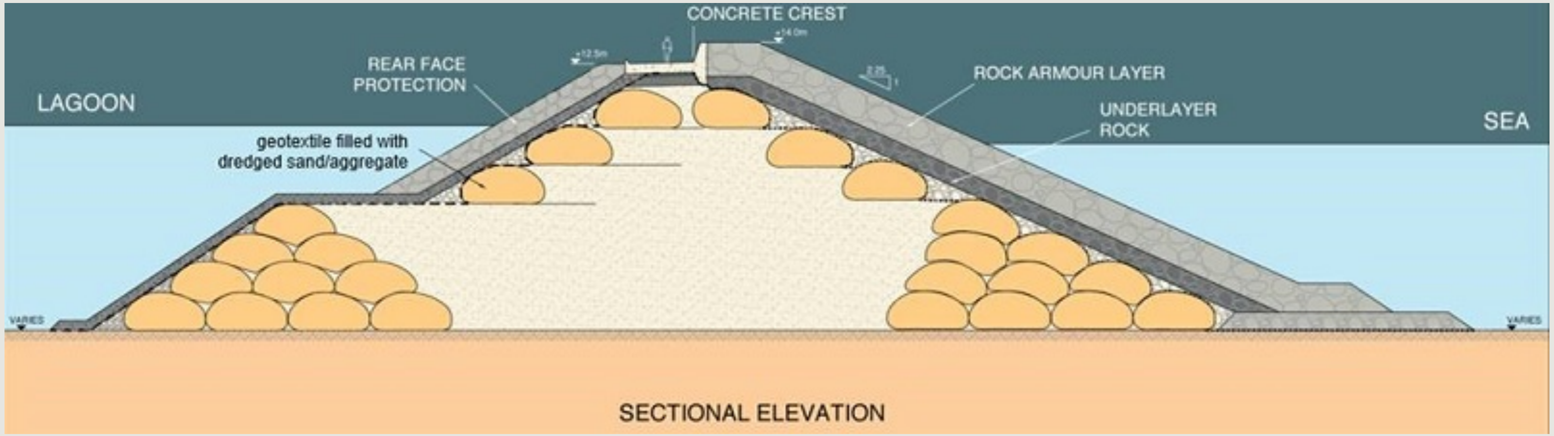
- This central DECC scenario sees about 10% of total UK ENERGY needs met by wind by 2030

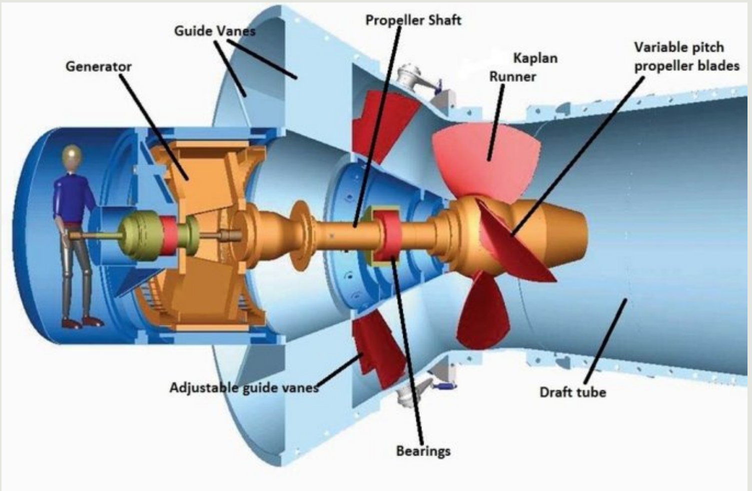
- This is before advances in very low cost, lower efficiency wind turbines

The equivalent of perovskites for onshore wind?

- Target - $1,000 a 1 kw panel
- LCOE – less than £50/kWh = grid parity
- Manufactured anywhere with CNC machines
- Installed by a bloke (no specific gender implied) with a tractor

Tidal lagoons, simple reliable technology

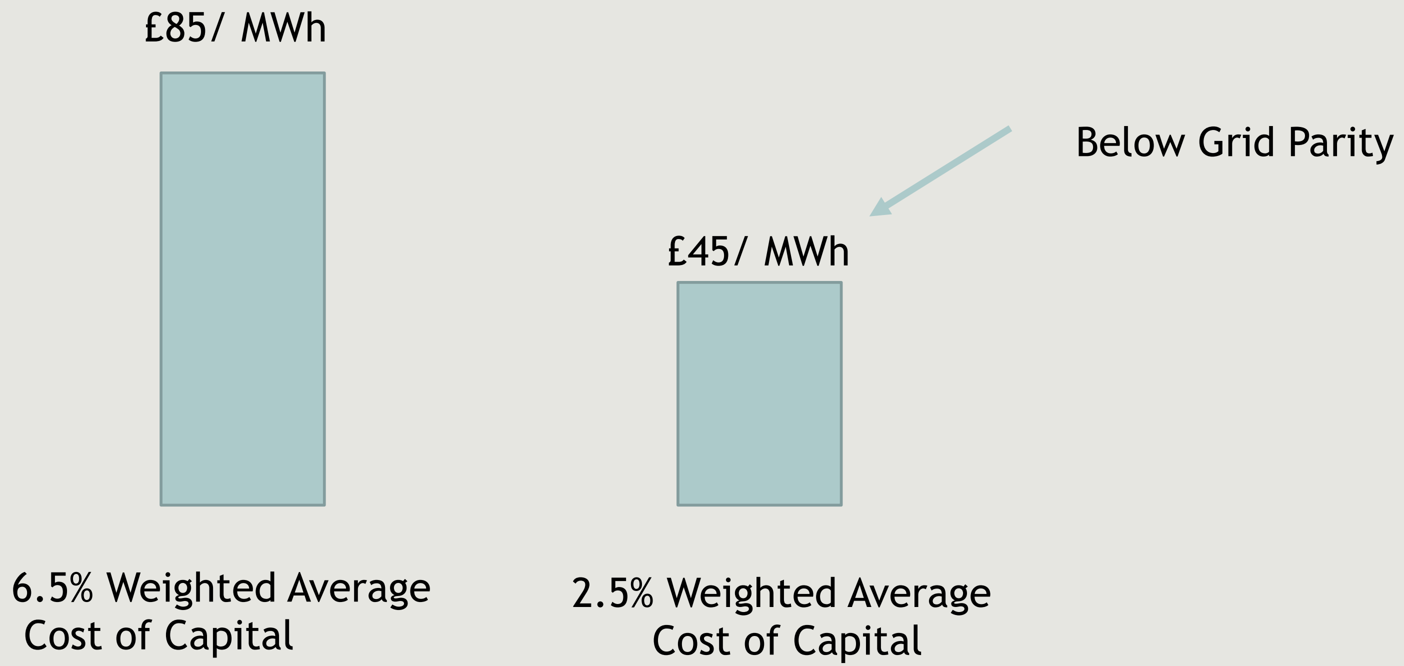




UK tidal lagoons – the world's best locations

- Large tidal range UK
- Tide times vary around the coast
- Absolute certainty about power generation
- Once installed, the lagoons will work for many decades, perhaps centuries
- 'Portfolio of sites could be operational by 2023' (Swansea Tidal)
- 10% of UK energy needs probably requires 20 lagoons – tiny land use requirements

Cost of capital impact on the economics of the third lagoon to be developed by the Swansea developers

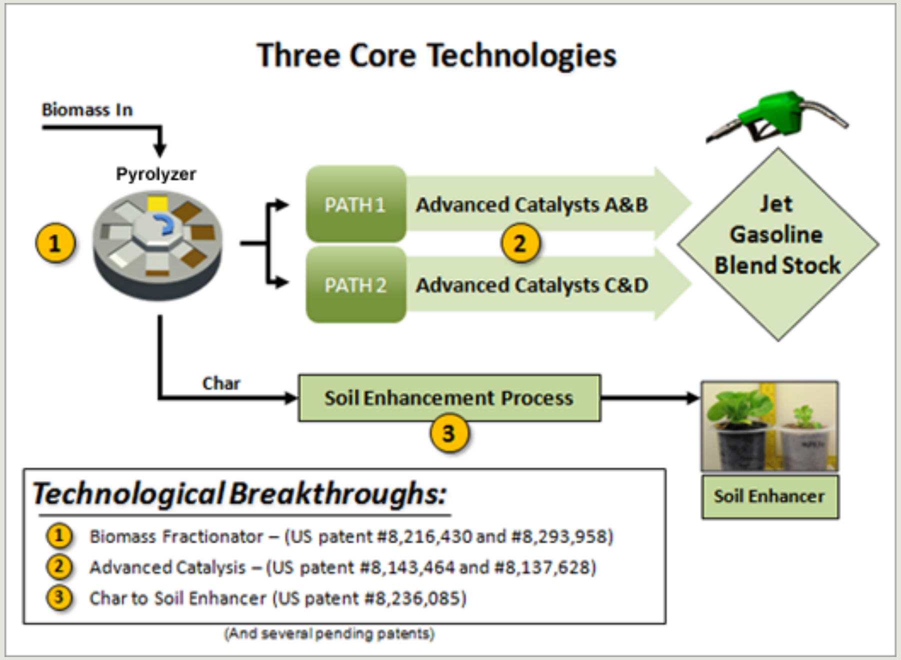


http://www.nrel.gov/analysis/tech_lcoe.html

Biomass to liquids

- Problem with biomass as an energy source is risk of competition for food land
- Hundreds of US companies – and virtually none in Europe – are working on this
- Net Primary Production (NPP) not unlimited – about 100 gigatonnes a year compared to about 12 gigatonnes of Carbon in fossil fuel use. This is going to be difficult
- Key is exploit genuinely renewable NPP and to use low NPP land

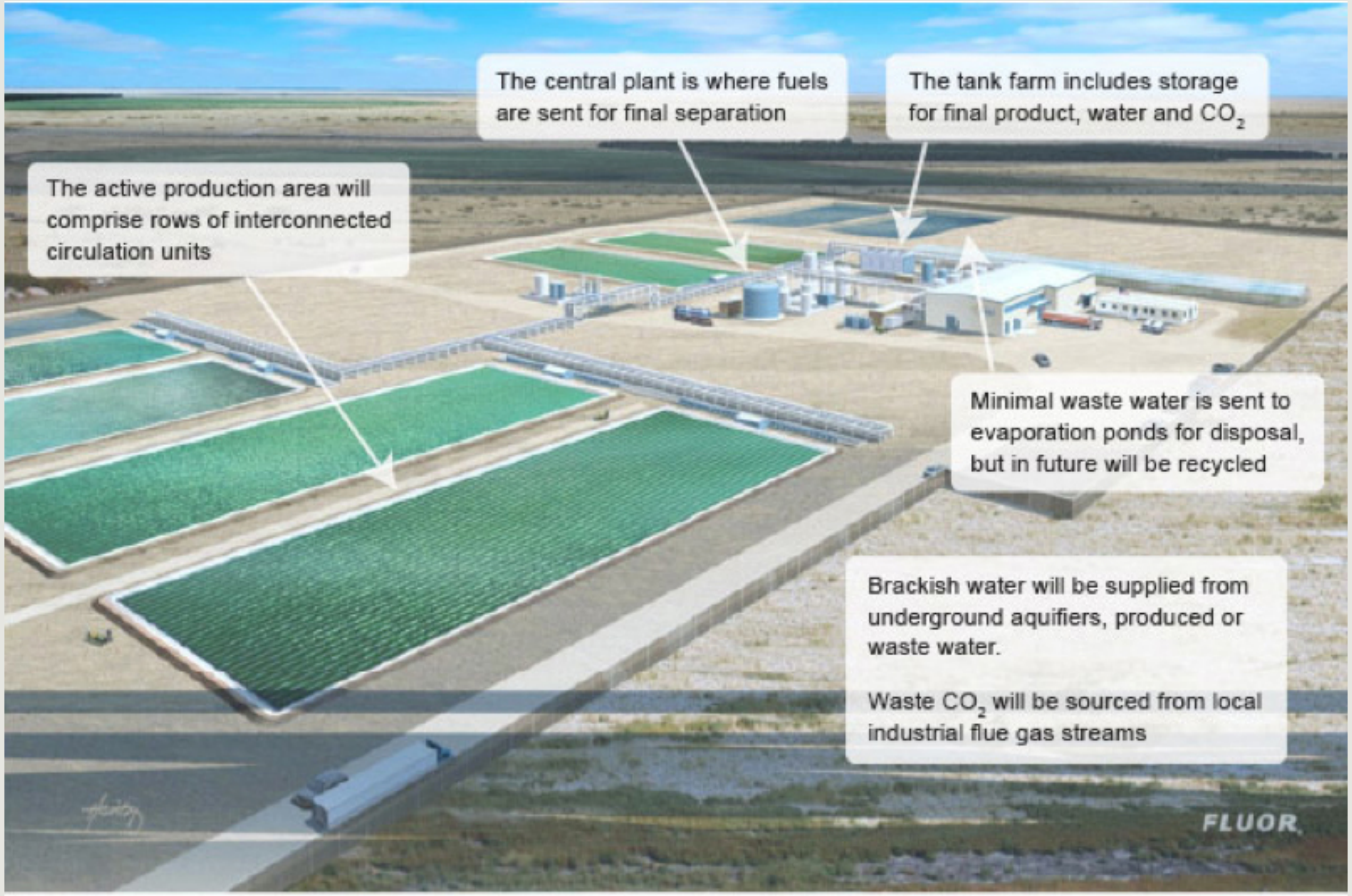
Biomass to liquids



Cool Planet

- Pyrolysis of waste wood to create liquid fuels and biochar
- Low cost feedstock
- No incremental land demand

Biomass to liquids



Joule Unlimited

- Brackish water
- Engineered cyanobacteria
- CO2 injected
- Tailored longer chain hydrocarbons are output
- Land that is used can be desert

How these technologies could reduce UK space needs

Joule

- Joule 14% photosynthesis efficiency claimed possible
- Similar to current solar panels
- Liquid fuel from high solar area for current UK needs would need land area roughly equivalent to 4% UK
- Because liquids can be cheaply shipped, can be from deserts elsewhere in the world

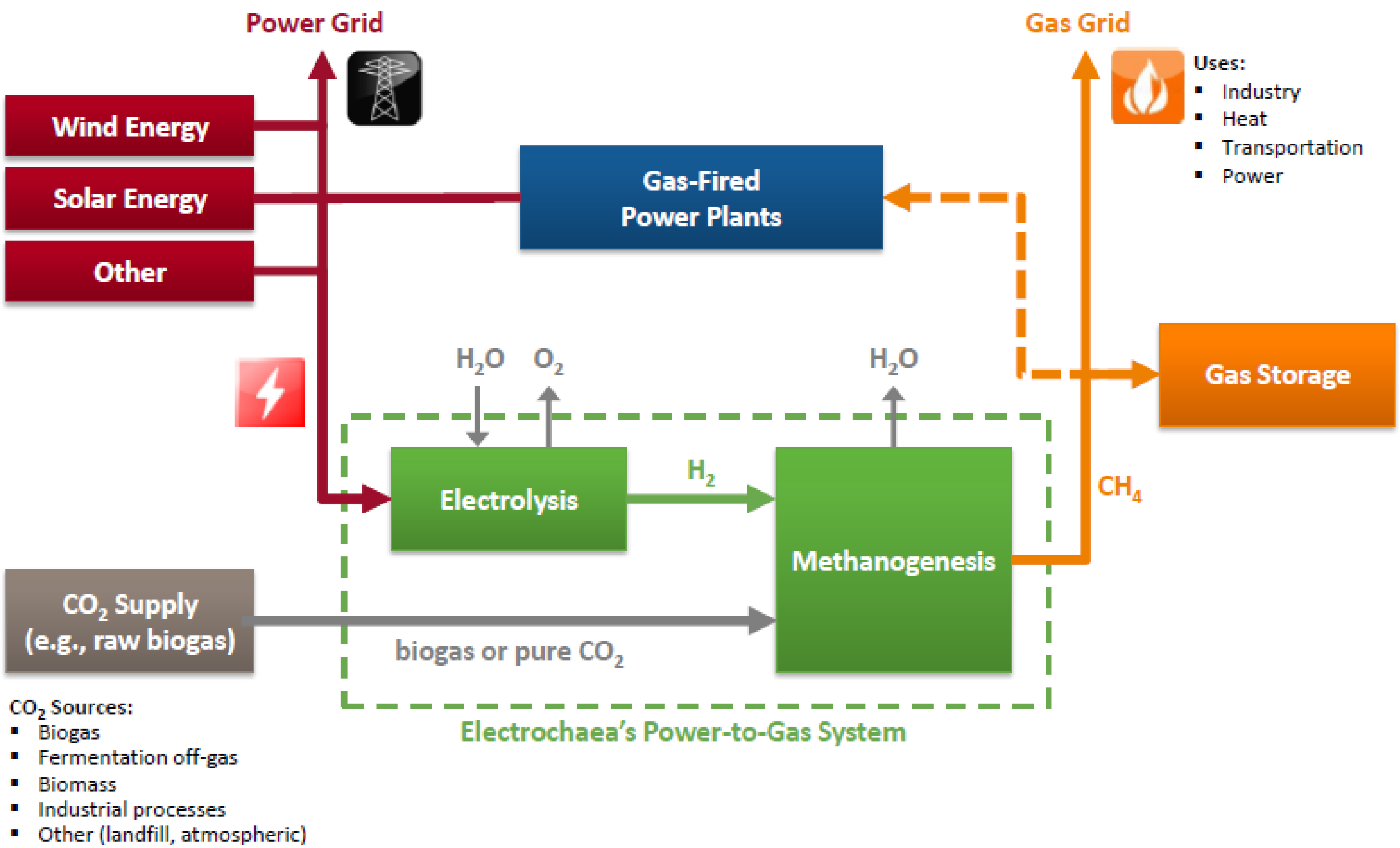
Cool Planet

- Waste wood is only approximately 1% efficient as photosynthesis converter to energy
- So needs much more space than PV
- But tropical production of Cool Planet liquid fuels will also produce biochar as a soil improver

Storage – the real problem

- Diurnal storage useful for countries with reliable sun. (But not enough for rainy seasons)
- Diurnal storage virtually useless for UK. Wind not predictable. Sun occurs at wrong time of year. Total storage capacity today about 2 minutes of electricity use
- Critical need is for seasonal storage – converting energy in one month and having it ready for use six months later

Power-to-Gas: System Overview



Source: Adapted from ZSW, *Erneuerbares Methan aus Ökostrom*, April 2012

Electrochaea

Power-to-gas

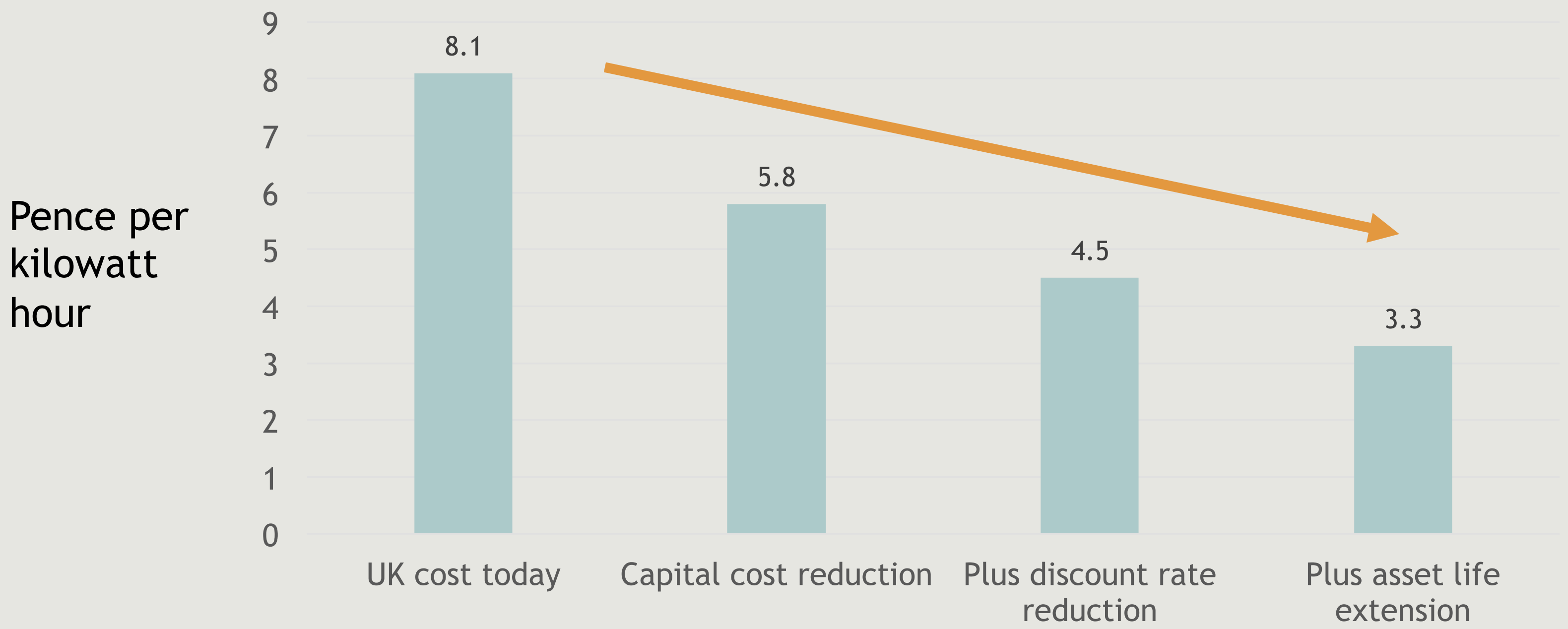
- Wild swings in availability of wind and solar power. Must be stored for minutes or months
- Electrochaea technology uses spare wind for electrolysis, followed by creation of methane by merging H2 with CO2
- Needs point source of CO2. Biogas source is best from anaerobic digestion. But could work as carbon capture technology from cement plants or even CCGT.
- First plant is at Copenhagen sewage works

Policy

- The UK approach to decarbonisation is almost insane
- Avoids R+D, ducks the dilemmas on technology choice
- Crucially, tries to run a free market in electricity generation at the same time as spraying subsidies across low carbon sources

→ Building very long asset life projects at the minimum possible cost of capital requires an utterly reliable price for electricity (and transport fuel and heat). Impossible within a free market structure. Nationalisation of energy supply is a prerequisite for fast decarbonisation

Getting solar PV down to 3.3 pence per kilowatt hour by 2020



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