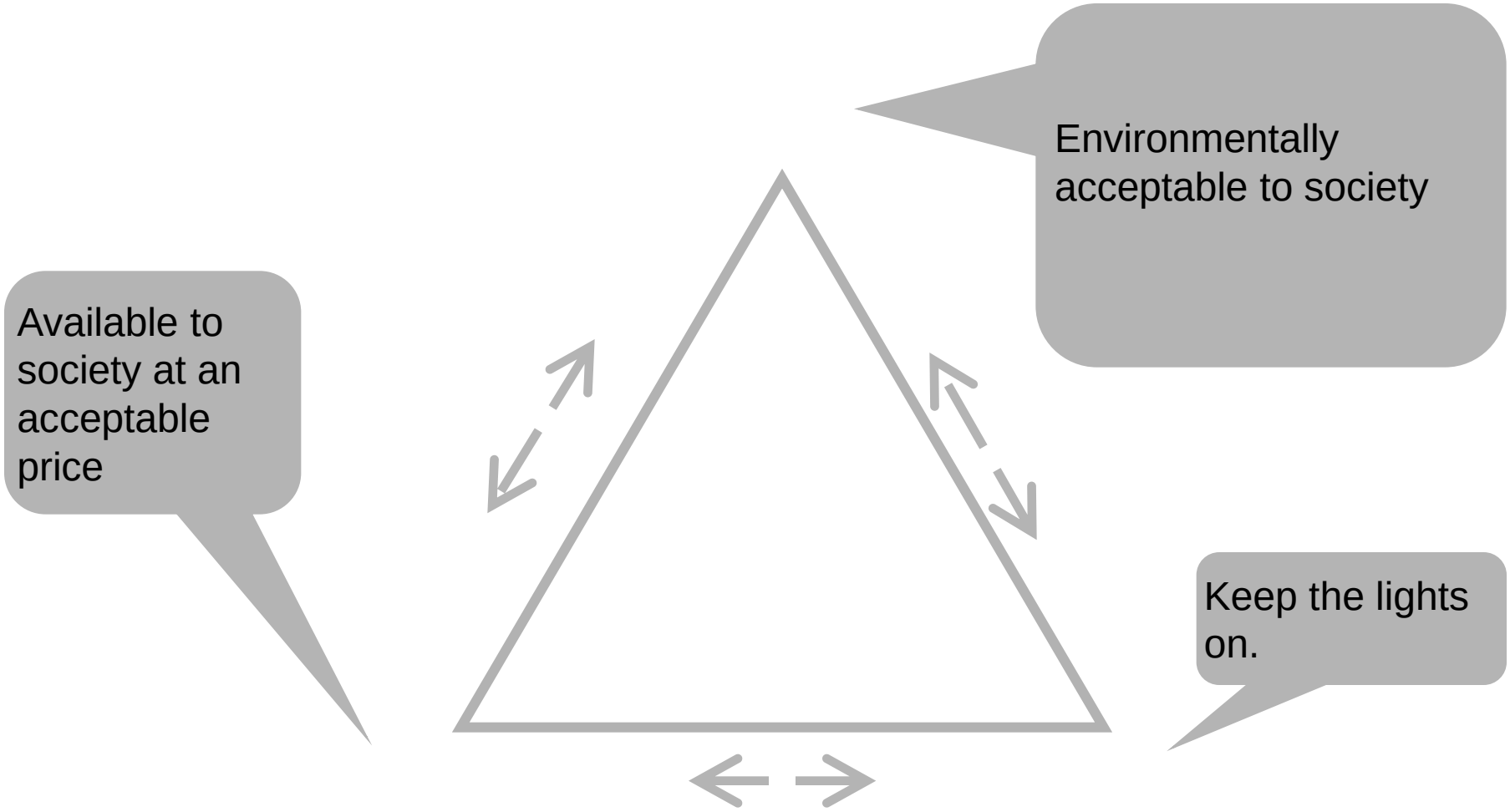
Important issues for fossil power plants for the 21st Century

Robin Irons

The Trilemma



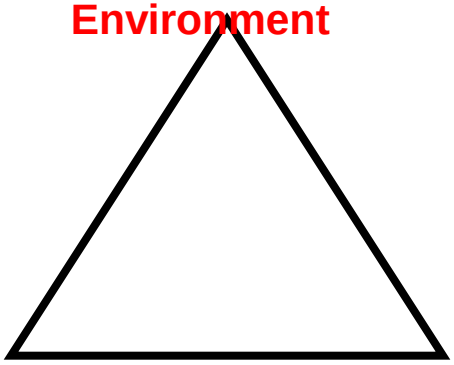
The range of technologies deployed in the market is much broader than ever before

- Wind
- Hydro
- Biomass
- Marine

- Heat Networks
- CHP
- Micro-CHP

- Energy Efficiency
- Insulation
- Smart Metering

- Nuclear
- Carbon Capture and Storage



Changed Marketplace 1 Technologies

Market now has significant penetration from

Nuclear

On-shore wind

Off-shore wind

Photovoltaics

Coal

Gas

Biomass

Future possibilities

Tidal (stream or barrage)

Bulk Energy Storage

Research portfoilos in energy therefore broader than they would have been historically. Fossil plant remains important but is only one topic among many…

Changed Marketplace 2 Utilities/OEMs

Increasingly international

Many operate in multiple regions

Local market drivers and needs differ

Some markets hungry for new, baseload, capacity, others are driven by high degree of intermittent renewables.

Increasing breadth of portfolio (OEMs)

Often cover a range of products (nuclear, conventional, renewable, infrastructure)

Investment decisions taken against a broader background. Is it more advantageous to build a wind turbine in Country X, or a new CCGT in Country Y? Should R&D funds be put into improved steam turbine efficiency or new techniques for nuclear construction?

Power System

Either the instantaneous production of power must equal the instantaneous consumption, or we need to store power in the system

At present, there is little storage in the UK (and most national) systems.

What could the future energy market look like?

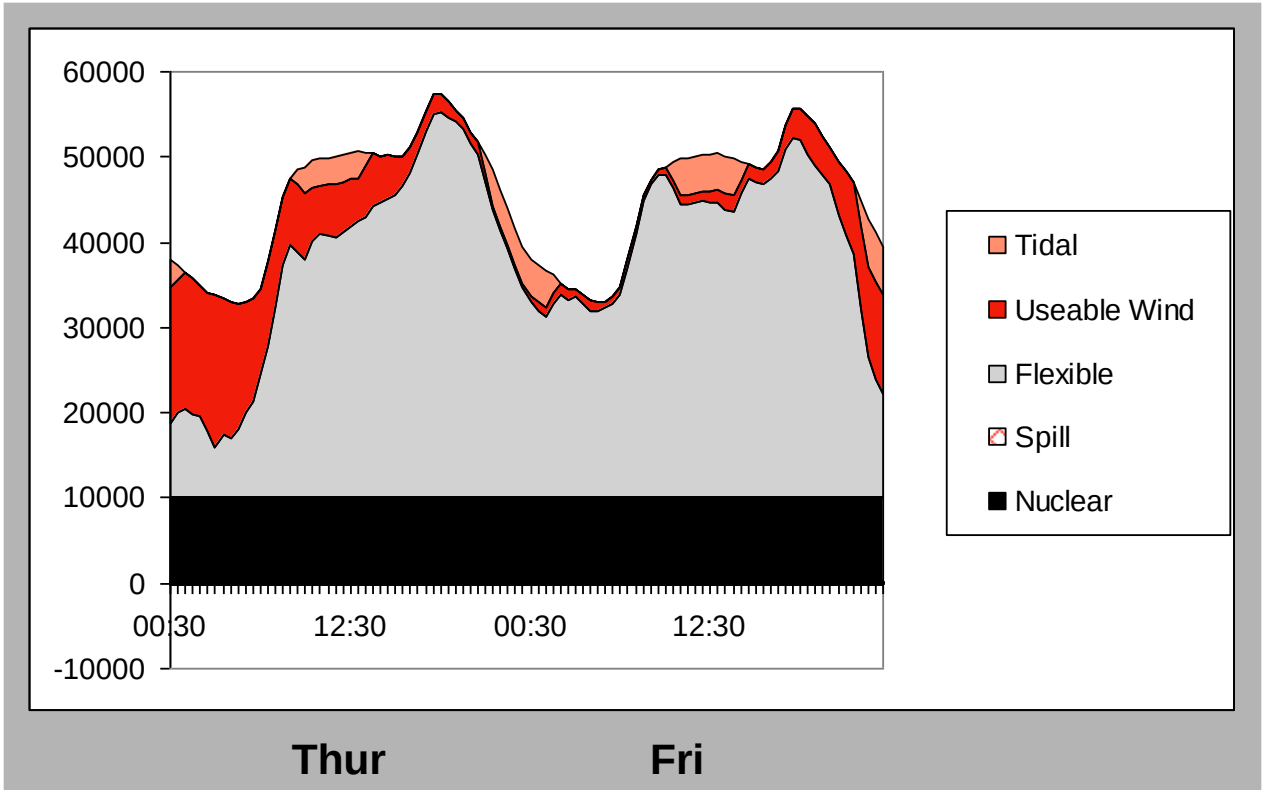
This is the story of a week in the life of the UK system operator in 2025. It is purely illustrative of the issues that will be faced by the electricity and gas system operators, and the utilities providing service to them. However it is based on a realistic simulation of the wind and tidal output onto a system scaled to meet 38% renewables on the system.

Scene Setting – It's November 2025 and ...

- 30% of energy comes from wind (circa 45 GW)
- A major build of tidal turbines (8.6GW output on Spring Tides) is complete
- 10 GW of inflexible baseload (mainly nuclear) is on the system
- Remaining plant is mostly flexible gas or coal
- Neighbouring countries are experiencing similar weather so links cannot be relied upon to deliver security

Friday – the way we were

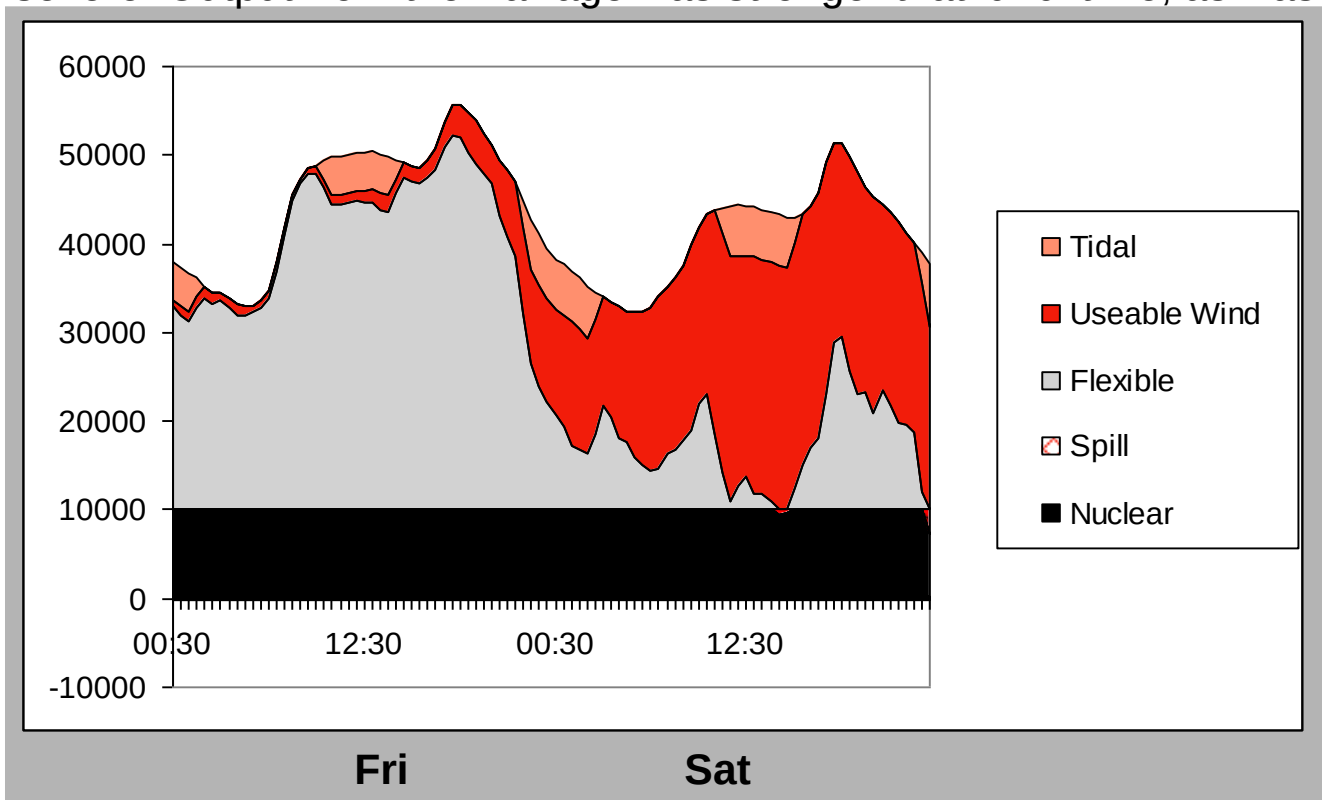
Friday started as a beautifully calm day. There'd been a touch of frost overnight with a bright, almost full moon high in the sky. With little wind much of the plant had been able to run through overnight and it was relatively simple to bring it up to full load for the morning peak, which the tides were just too late to meet now.



During the day nearly all demand was met by thermal plant with nuclear in the baseload. It was just like old times! However wind was picking up by the evening and a strengthening tidal output mean a lot of plant had to be shutdown before midnight

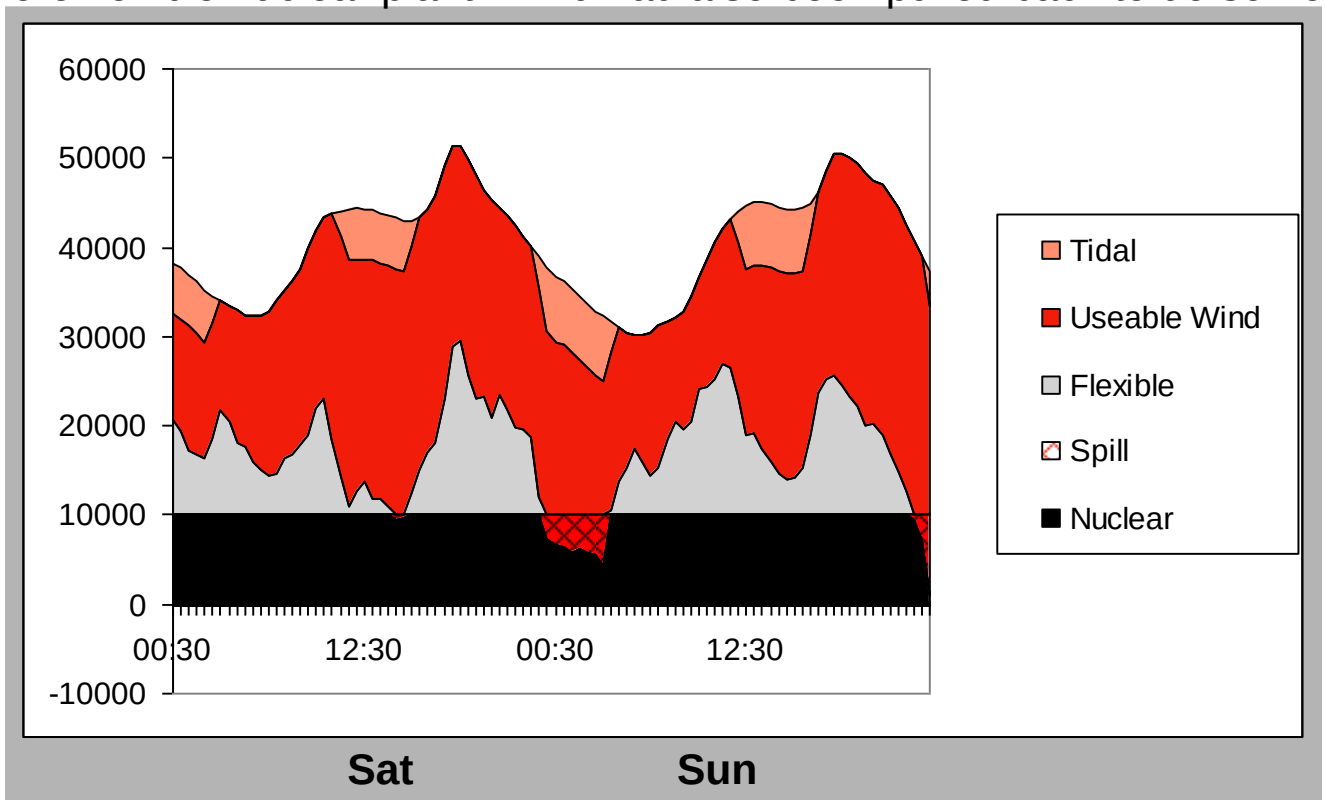
Saturday – the norh wind shall blow

What a contrast to yesterday. The nightshift had had to contend with a short peak in output from flexible plant at 4am as more than 5GW of generation came off the bars with the rising tide. Thankfully it's not full moon yet otherwise the loss of the Barrage output would've been more severe. Output from the Barrage was stronger that lunchtime, as was the wind, meaning that all flexible plant was off the bars by 3pm. Nearly 20GW had to be synchronised for the teatime peak but it all had to be off again by midnight. Fortunately some utilities had built flexible OCGTs which were able to do 3 starts today and stand in reserve the rest of the time.



Sunday – Bad Moon Rising

The situation got worse that night. The nightshift knew the tidal output would be stronger at 7GW but the strengthening wind had caught them off guard and now wind+tidal+nuclear was more than demand. However they managed it by accepting all the pumps bids and shaving some output off the more flexible nuclear plant. Wind had also been pulled back to do some frequency response.

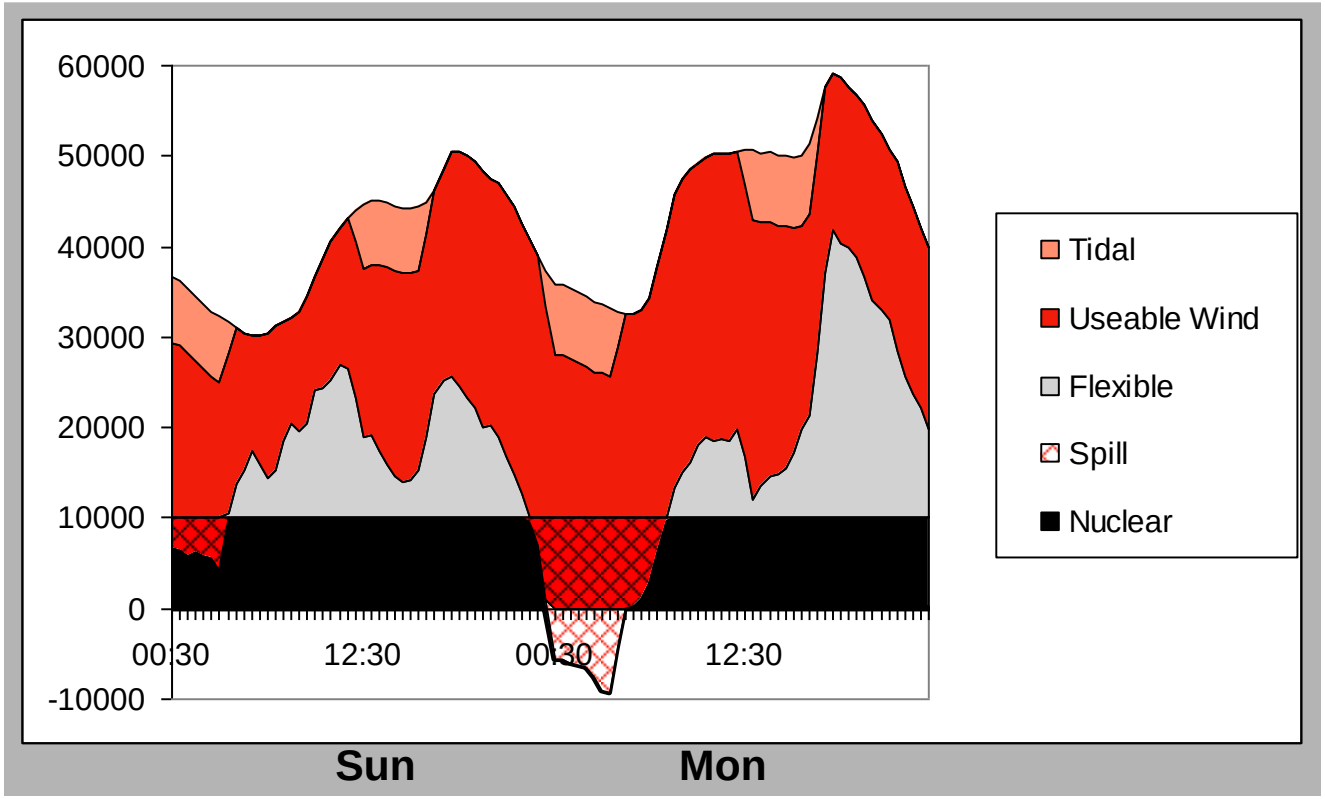


The daytime was little better, 10GW of thermal plant had had to double two-shift around the tidal output. They had charged a pretty penny for that, but delivered little energy over the day! It looked like Monday would be similar too!

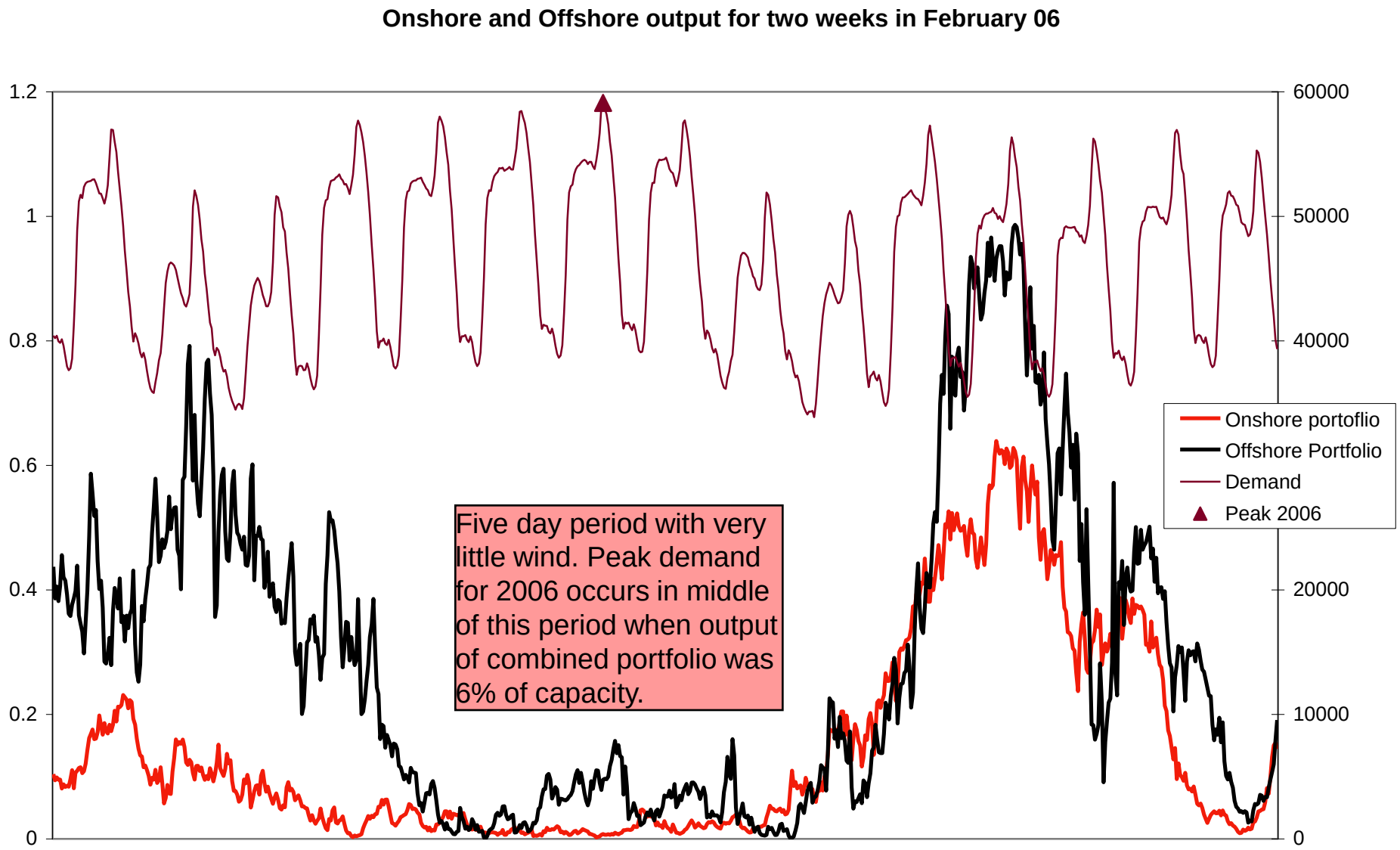
Monday – from free power to business as usual

By midnight it was already clear this was going to be one of the most difficult days to manage. Wind had picked up to 35GW, nearly 80% of capacity, and tidal wanted to dump a further 7.5 GW on the system and needless to say, nuclear did not want to come off and poison their reactors for 2 days, so there was 53GW to meet 33GW demand!! Wind was forced to halve its output. Teatime was even worse. Tidal couldn't stretch its output any further and a weakening wind now meant 30 GW of thermal had to be synchronised for the peak, 20 GW between 3-5pm.

Most of it was off again after 4 hours generation.



Highest Demand is often at time of lowest wind availability



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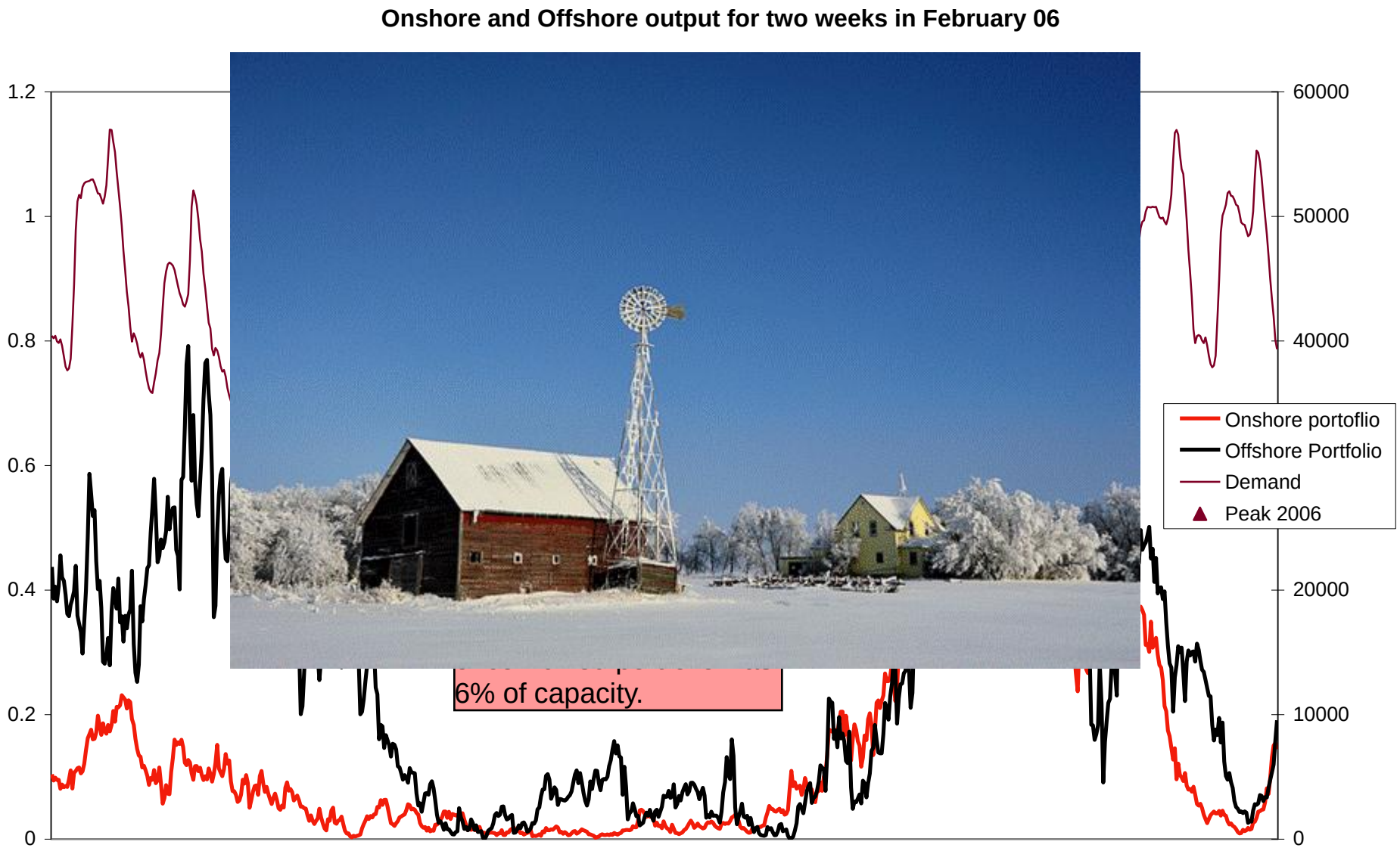
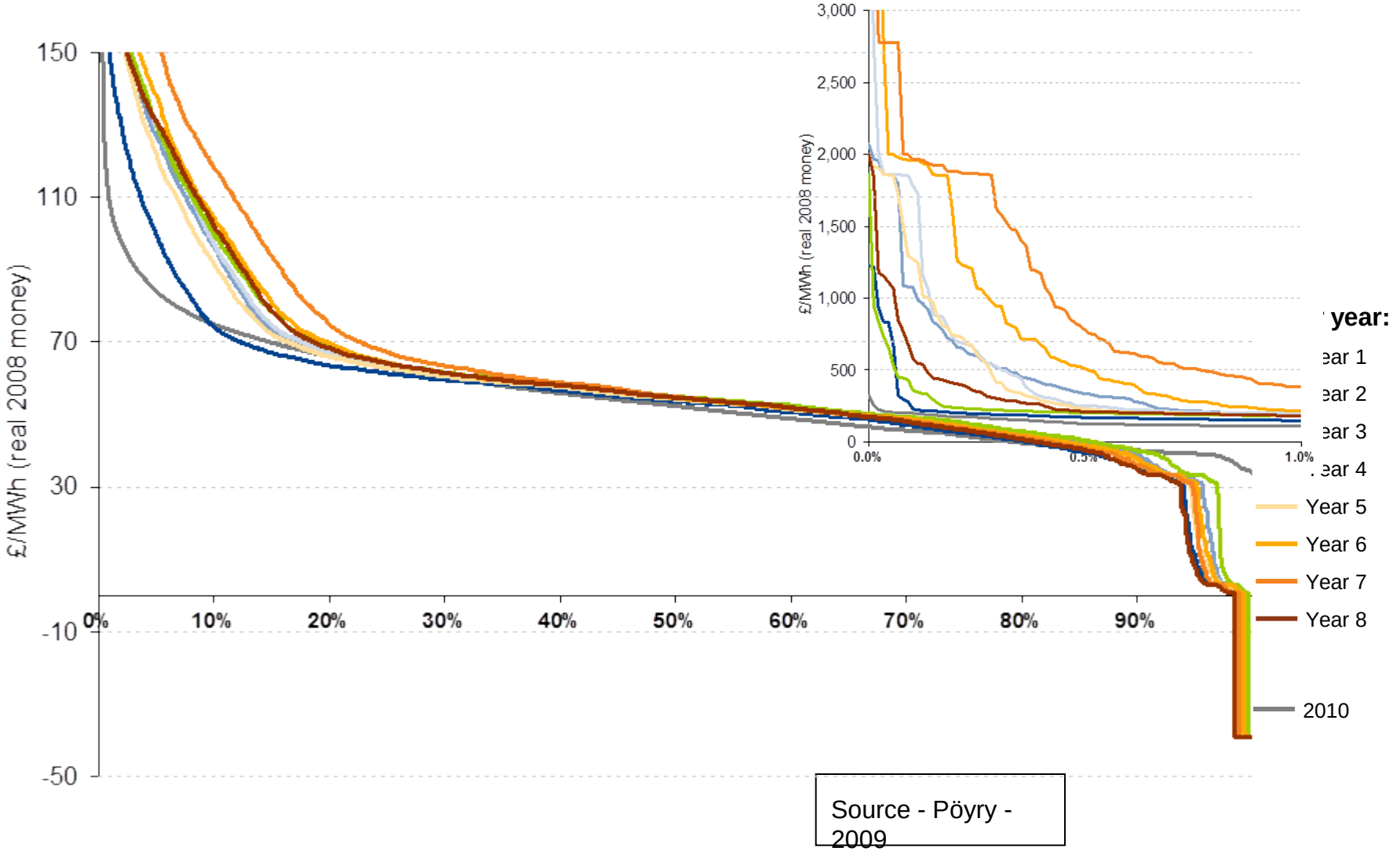


So what are the pressures on market price?



Source - Pöyry - 2009

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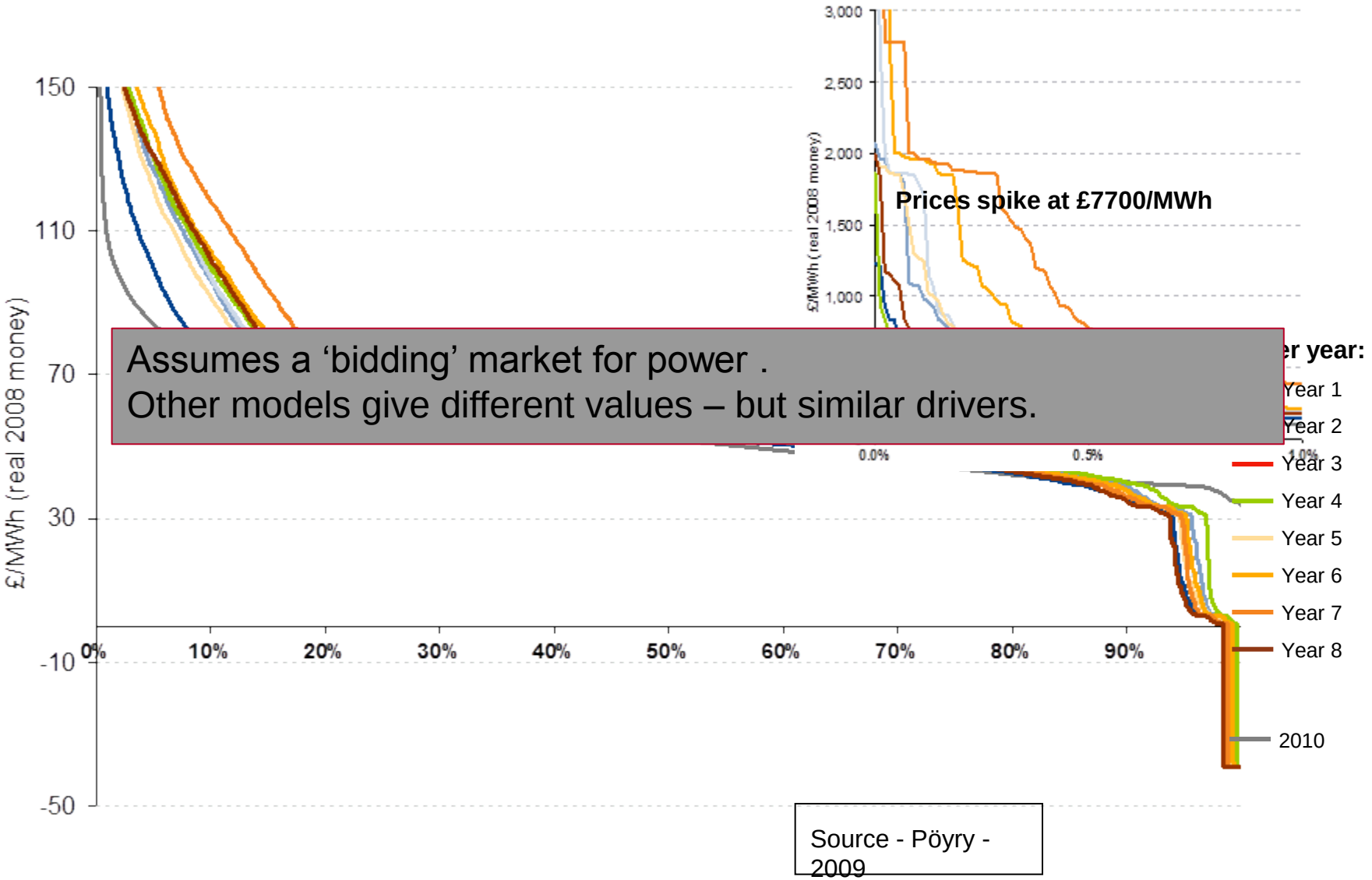

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Implications

A large amount of fossil plant (or other flexible generation or energy storage) is essential for a workable system

That plant will not run for a significant proportion of the time, if other generators are available at lower (marginal) cost.

Inflexible plant will be highly penalised in the market. It cannot benefit from high power prices (short-lived) and may be compelled to run at times when the power price is negative.

Power Plants

Amongst the world's biggest chemical engineering plants –
each 500MW unit can process up to 40Mtonnes per year (fuel plus air) .

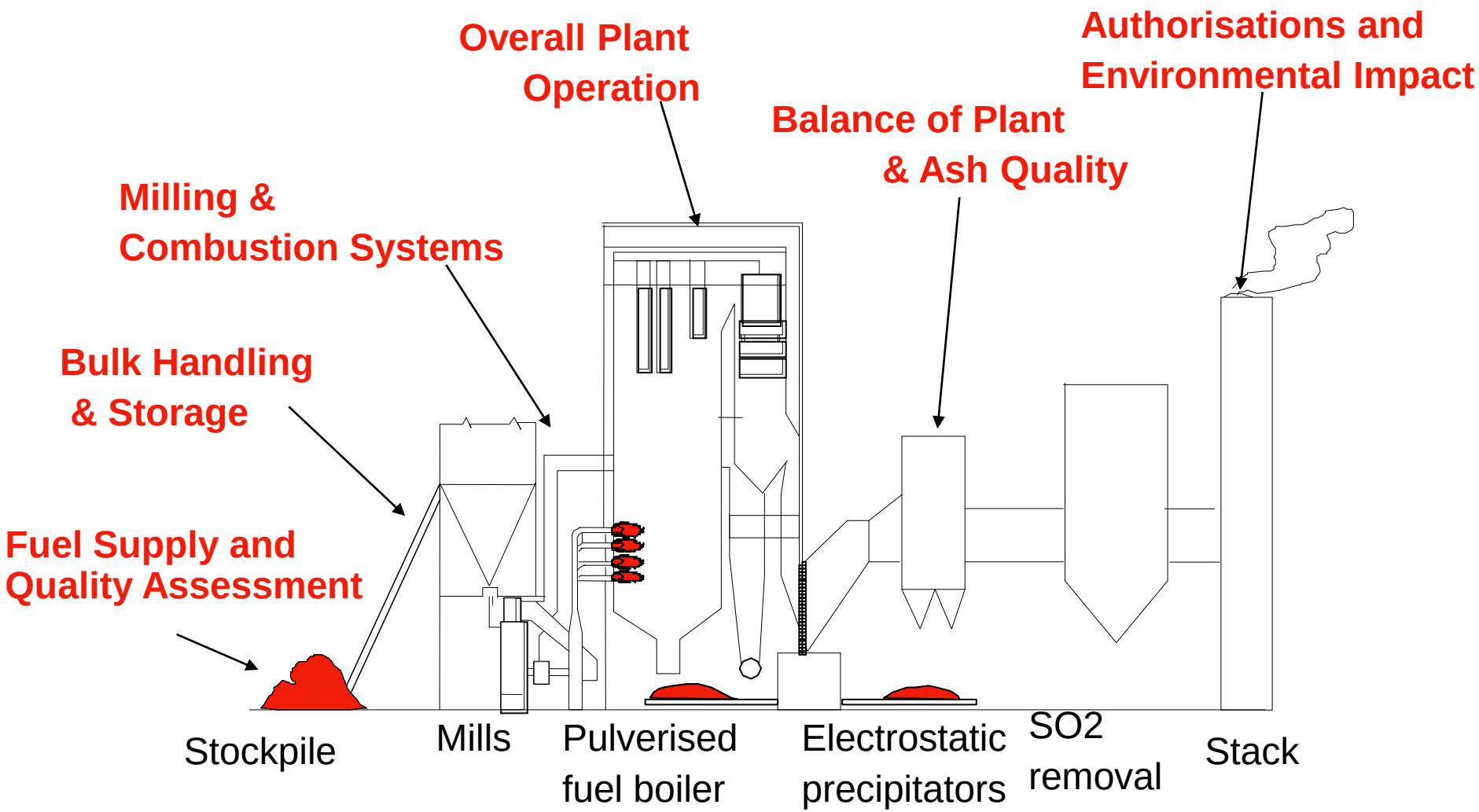
Have very different drivers from most chemical plants - they need to be capable of frequent starts/stops and part-load and flexible operation.

Need to be efficient – or they are too expensive to operate.

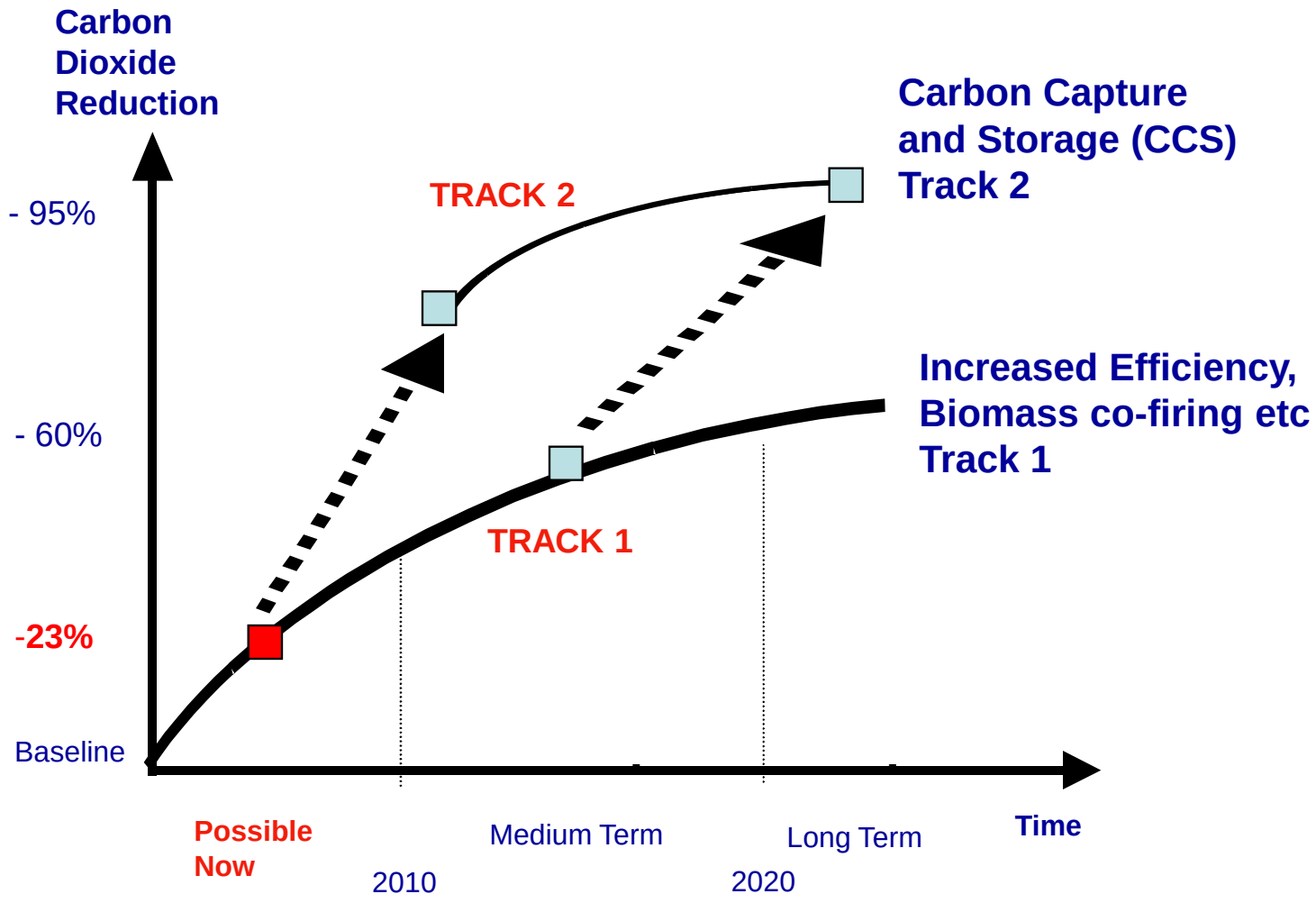
Need to be flexible – or they cannot exist in the real commercial world.

Have a significant tension between high efficiency and high flexibility.

A Coal-fired Power Plant



CO_2 abatement from coal – twin track approach



Source: IEA

Power Plants

Design life 25-40 years
Need to be robust to market conditions over that full period
Some plant requirements will be clear at the design stage
Others will become clear as circumstances change.

Power plants do not get built if it is clear that they will not recover their costs.

Flexibility

Components come to temperature quickly. Thin, light components.

Minimise transients optimise and maintain heat transfer surfaces

Reduce integration – simple once-through systems are easier to start-up and shut down.

Re-optimise performance – aim for ‘good’ performance across a range of operating conditions, rather than a system with a single high efficiency operating point.

Consider local heat or energy storage. Minimise start-up time.

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Combustion issues in low-carbon fossil power plants for the 21st Century

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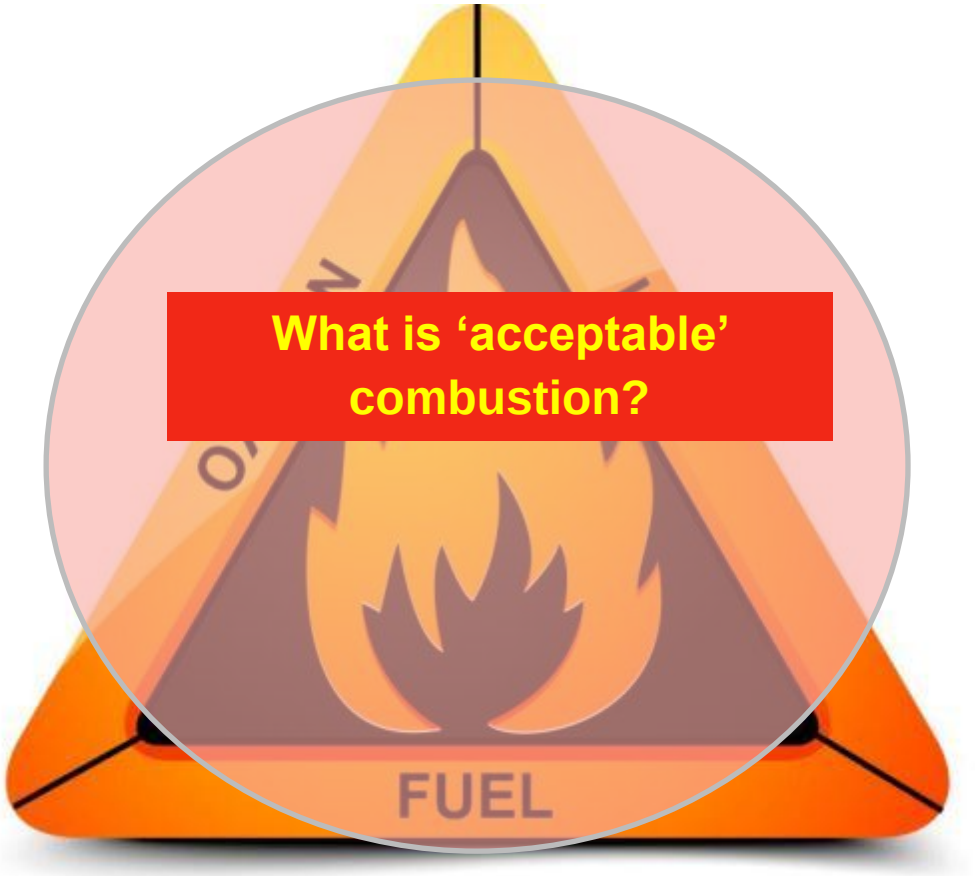

Low-carbon fossil power plants for the 21st Century
Whats New in the 21st Century?

Combustion

Fuel

Comburent

Heat

Acceptability

Emissions

Materials

Flexibility

The Fuel Diet

UK Coal Market 2012

Coal Source	Mte	Domestic total
UK Deep*	6.2	
UK Surface	10.2	**16.8**
UK Other	0.4	
		Import Total
Russia	18.3	
Colombia	11.9	
USA	10.5	
Australia	2.3	**44.8**
EU (includes trans-shipment)	0.7	
RSA	0.6	
Canada	0.1	
Other	0.4	

* NB: data includes Daw Mill – Closed after fire in early 2013

Source UK Coal website

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The UK Coal basket is as broad as ever and fuel of choice varies rapidly with regulation, politics and economics

* NB: data includes Daw Mill – Closed after fire in early 2013

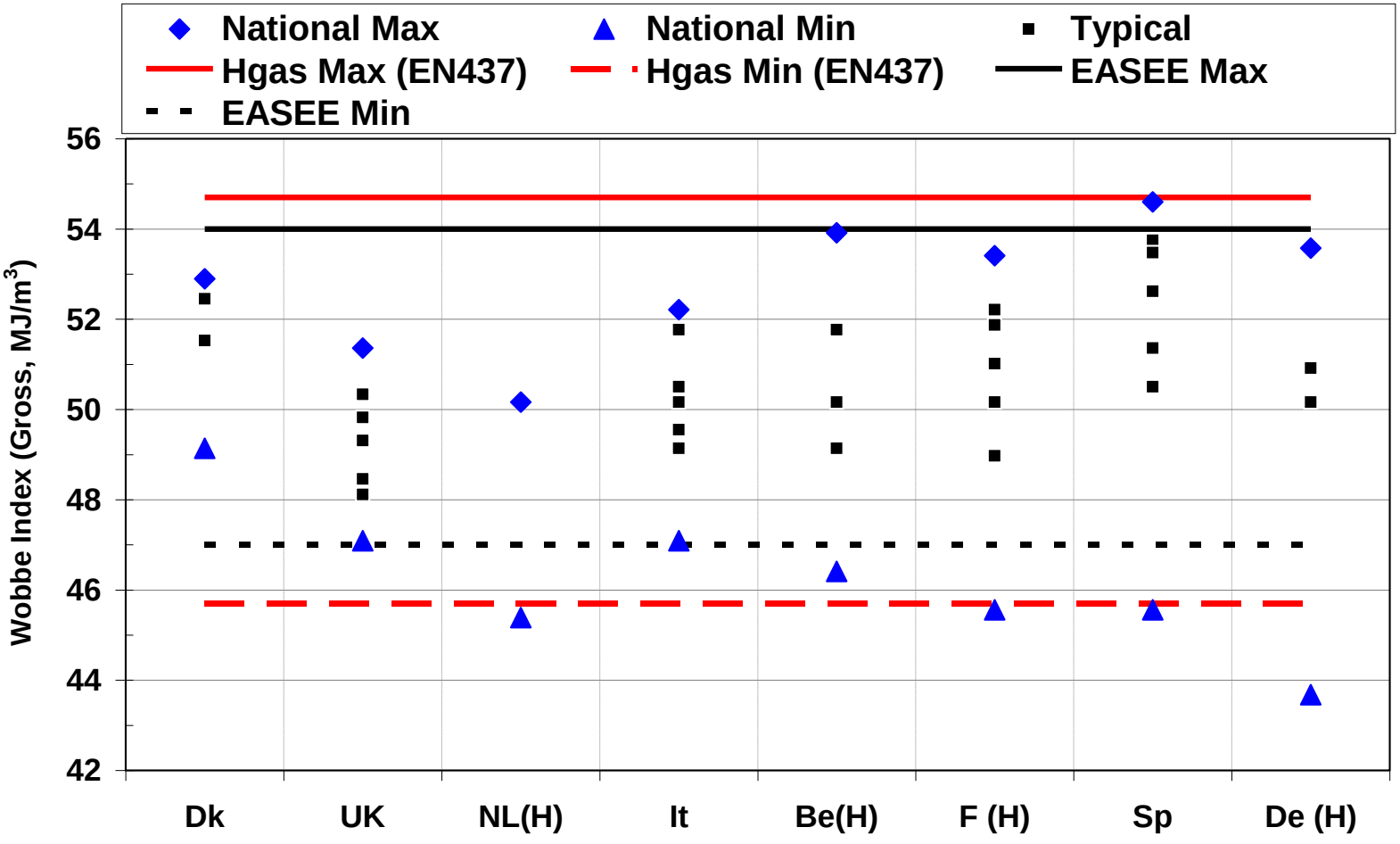
Source UK Coal website

New Biomass plants – E.ON's Blackburn Meadows

- 30MWe
- CHP
- Waste Wood
- Fluid Bed Combustion
- NE of Sheffield

But at least natural gas is easy isn’t it? It’s just methane…..

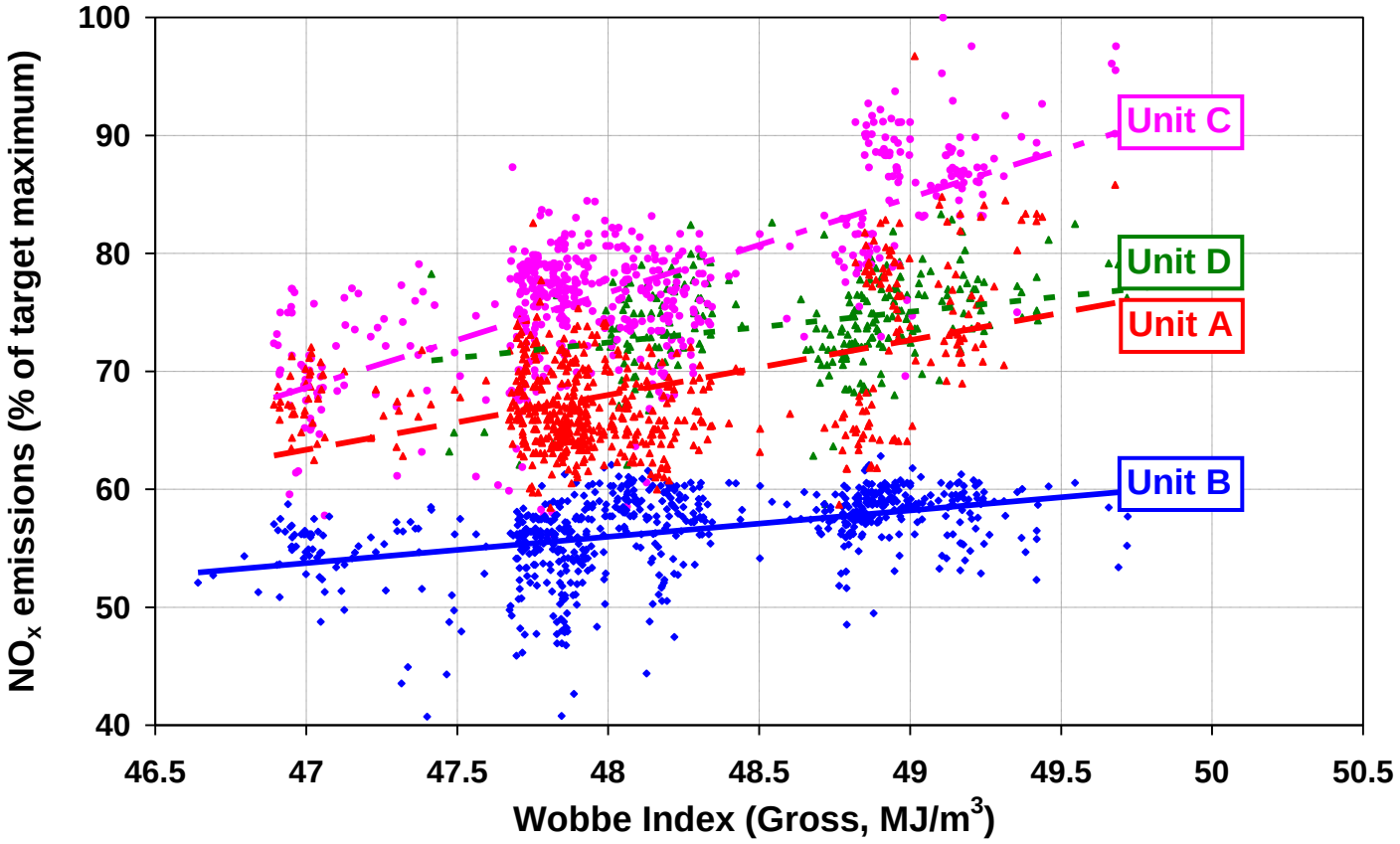
EASEE-Gas Gas Quality Specifications



Wobbe Index = GCV/(Specific gravity)$^{0.5}$

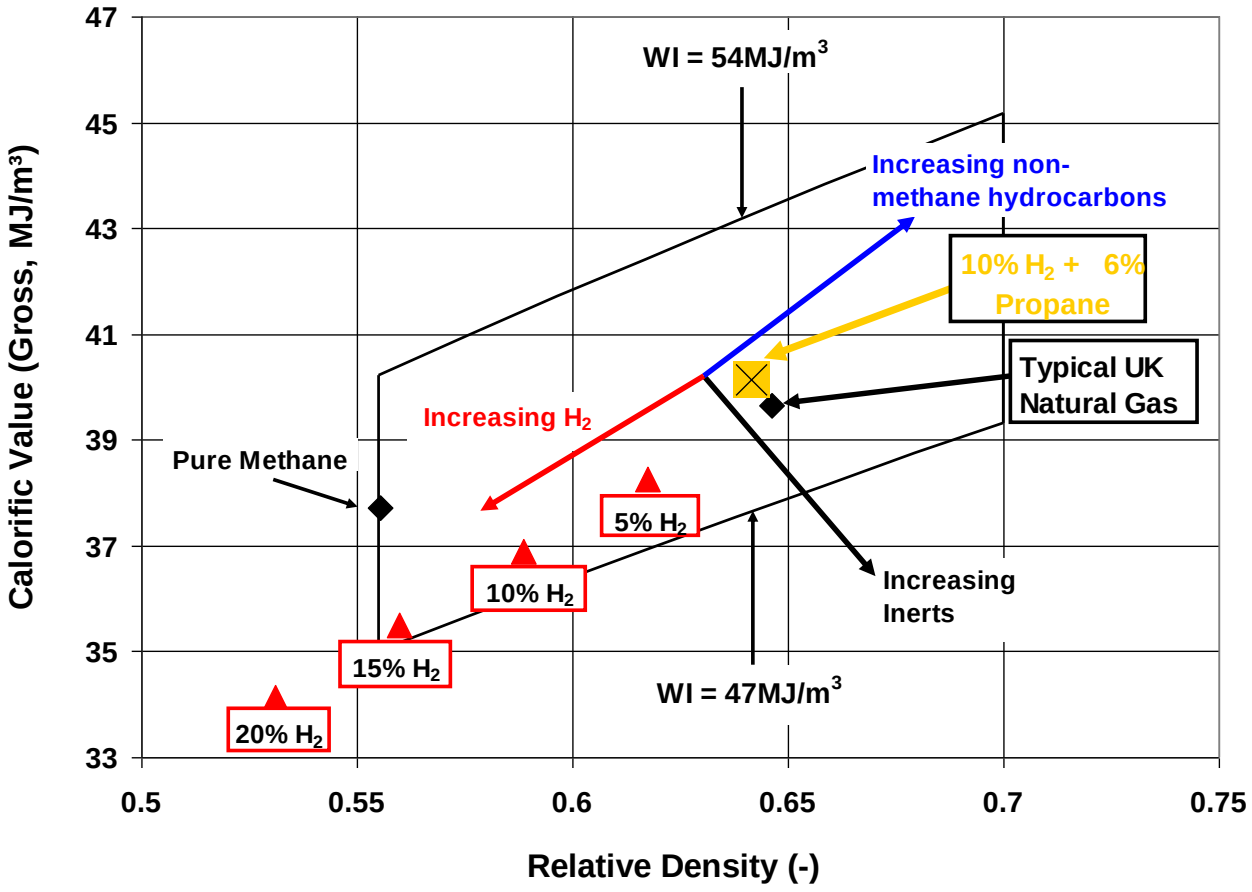
Impact on NO_x Emissions

- Site with 4 GTs of same design
- Increasing trend in NOx emissions with fuel Wobbe Index
- Impact of fuel quality on NO_X emissions varies between the 4 units



Potential for Hydrogen

- Significant amounts of hydrogen can be accommodated within the EASEE-Gas envelope
- This could cause significant issues for gas turbines



Black line represents EASEE-Gas quality specification

Combustion Issues in CCS – an Example

Oxyfuel Combustion

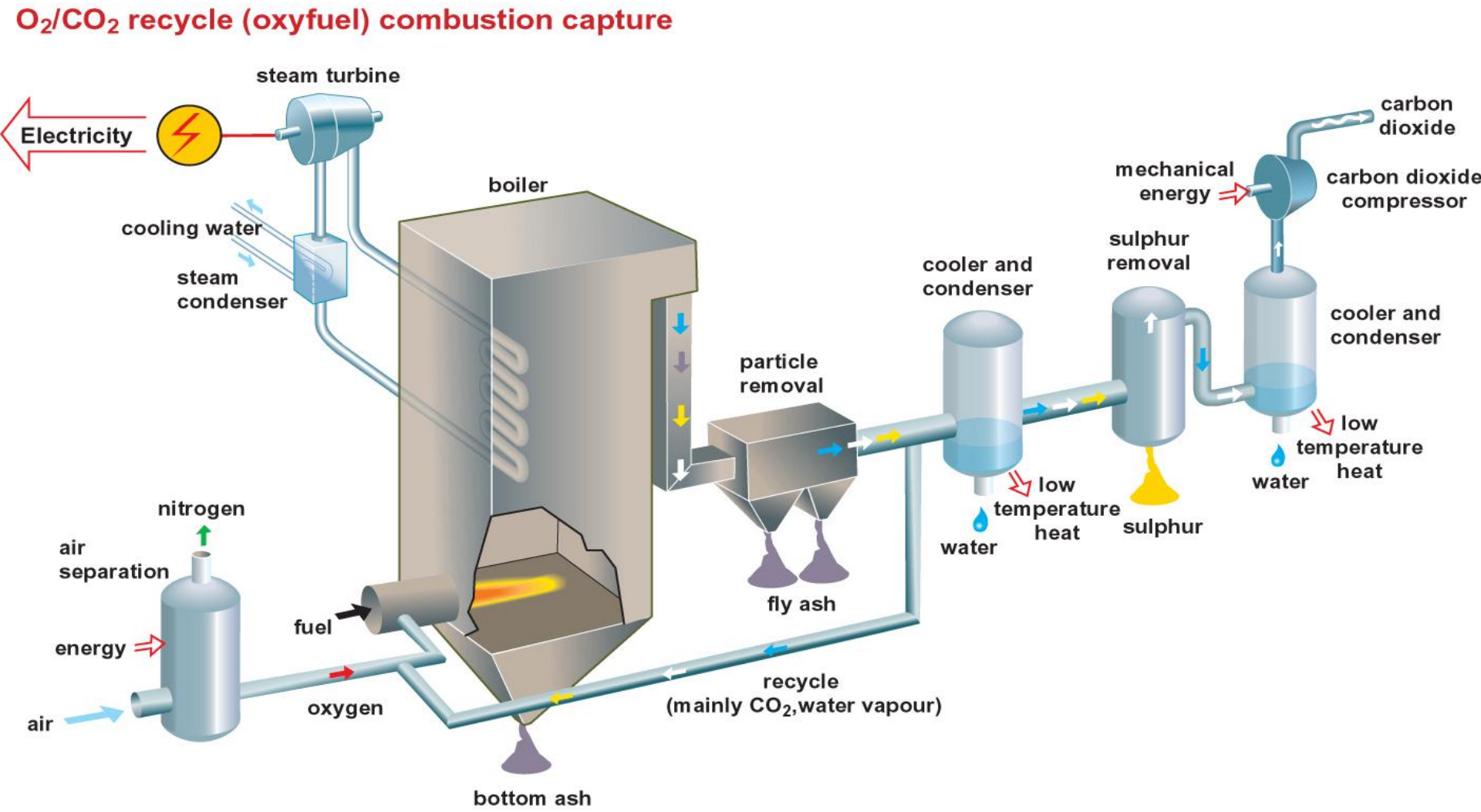


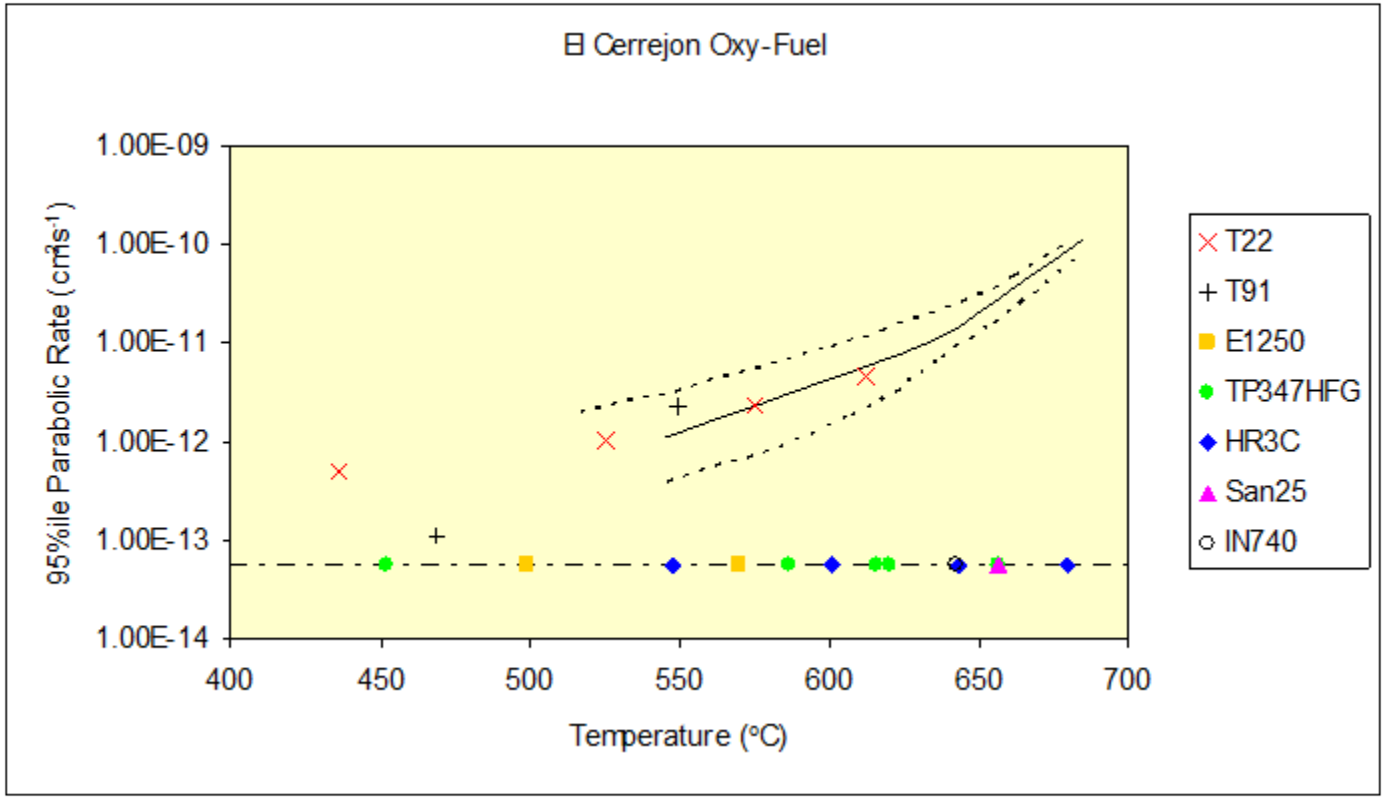
Figure courtesy Vattenfall

Corrosion in Oxyfuel

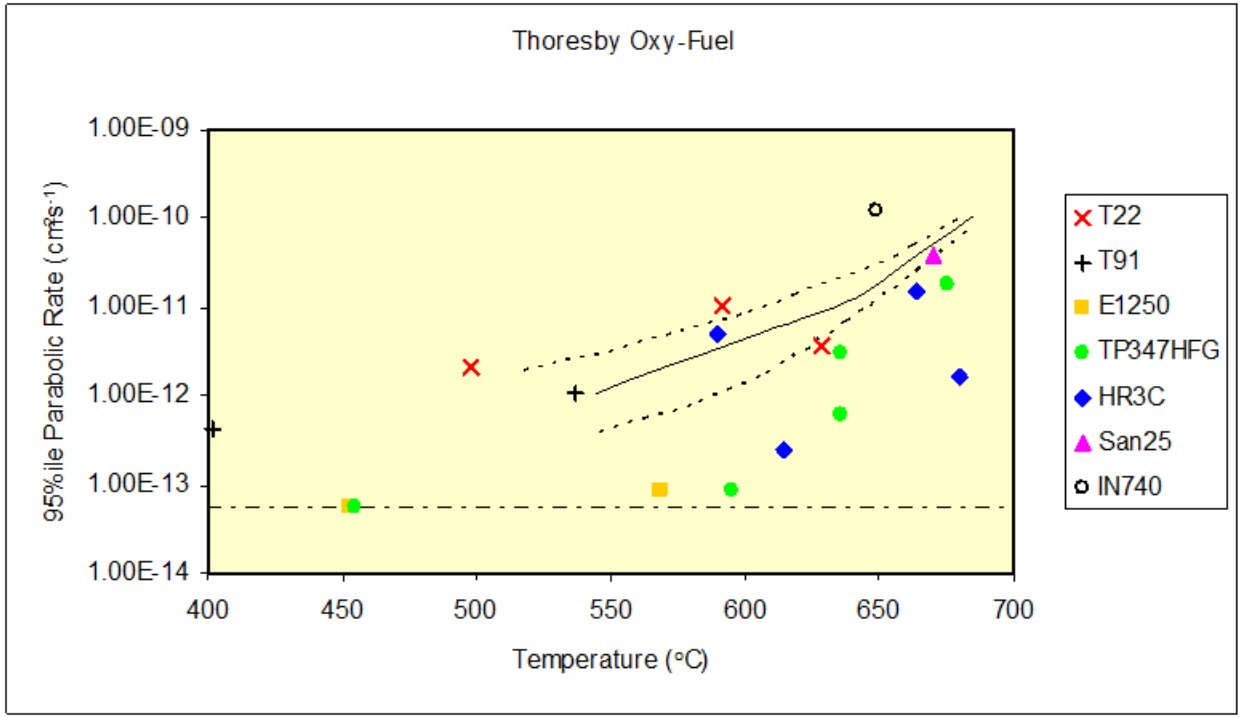
			El Cerrejon	Thoresby
Moisture	%wt AR		5.8	4.8
Ash	%wt AR		8.6	11.8
Volatile	%wt AR		34.8	32.3
	%wt DAF		40.7	38.7
Fuel ratio	(Fixed C:VM)		1.46	1.58
Net CV	kJ/kg AR		27,122	27,393
S	%wt AR		0.58	1.61
	%wt DAF		0.68	1.93
Cl	%wt AR		0.02	0.45
	%wt DAF		0.02	0.54
N	%wt AR		1.42	1.55
	%wt DAF		1.66	1.86

AR = As Received - DAF dry, ash-free

CORROSION - Low-S/Low-Cl



CORROSION - High-S/High-Cl



Emissions – new substances and new regulations

Industrial Emissions Directive

New limits for ‘old’ pollutants

NOx, SOx, Dust (regulatory)

National Ceiling Directive

‘New’ Pollutants

Black Carbon,

PM2.5,

Hg

Medium Combustion Plant Directive

New ‘Old’ Plants

1-50MWth

Reduction Driven by process requirements

NO_2, SO_2, $\mathbf{SO_3}$ (Post combustion carbon capture)

Conclusions

- The fundamentals of fossil-based power generation haven’t changed
- The market-place continues to change requiring new innovations as

  - Fuel composition changes – sourcing/blending/regulation/innovation
  - Emissions constraints tighten
  - Operational requirements mean old plants must operate in different ways
  - New Cycles/configurations come to market.

- All offer new RD&D challenges