# Potential Role of Combined Cycle Gas Turbines with Carbon Capture & Storage

Low Carbon Technologies for the UK Energy System

Tuesday 7th November at the SCI, London

Den Gammer – Strategy Manager for CCS

# Introduction to the ETI organisation

- The ETI is a public-private partnership between global energy and engineering companies and the UK Government.
- Targeted development, demonstration and de-risking of new technologies for affordable and secure energy
- Shared risk

## ETI members

bp

CATERPILLAR®

EDF ENERGY

Rolls-Royce

Shell

Department for Business, Energy & Industrial Strategy

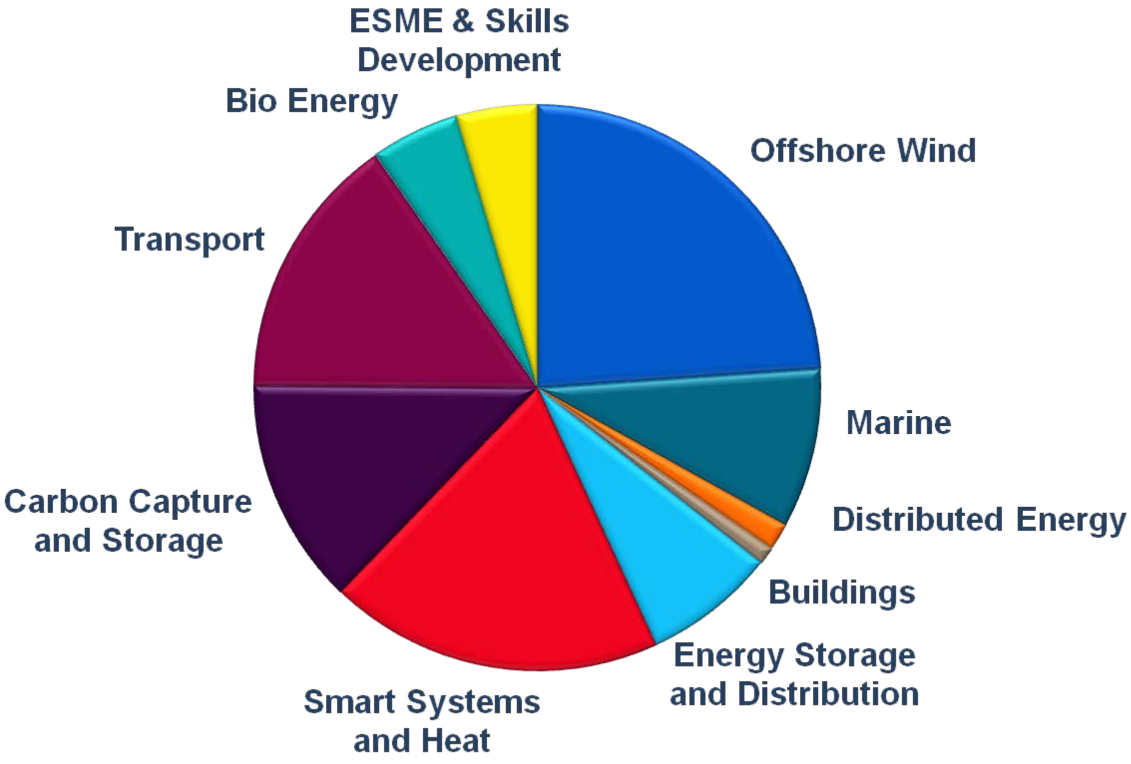
EPSRC Pioneering research and skills

Innovate UK Technology Strategy Board

## ETI programme associate

HITACHI Inspire the Next

# ETI invests in several technology areas





## 9 Technology Programme areas

Delivering...
New knowledge
Technology development
Technology demonstration
Reduced risk

# Presentation Structure

## Introduction to the ETI

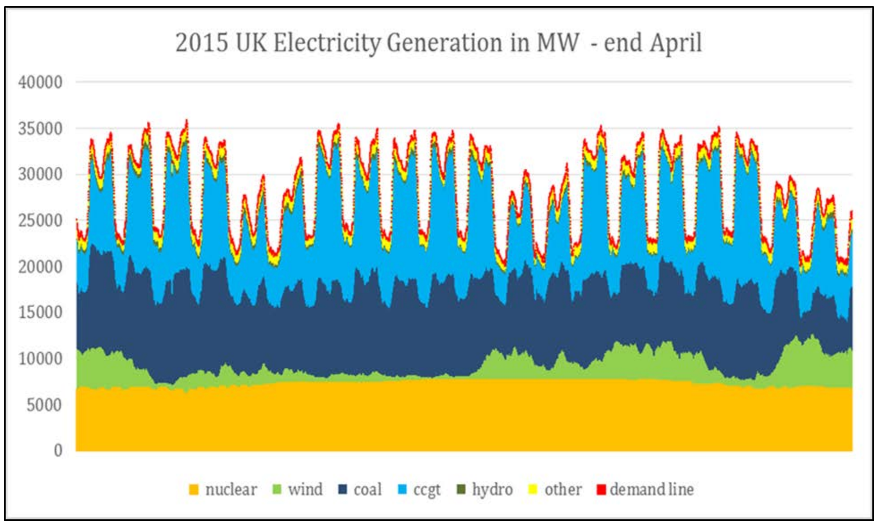
- Large Gas Turbines – prevalence and role in UK power
- Additional plant to add post combustion Carbon Capture and Storage
- Cost, scale and promoting industrial emissions capture
- Performance requirements as renewables increase - 2030
- Alternative oxy –fired and pre-combustion options

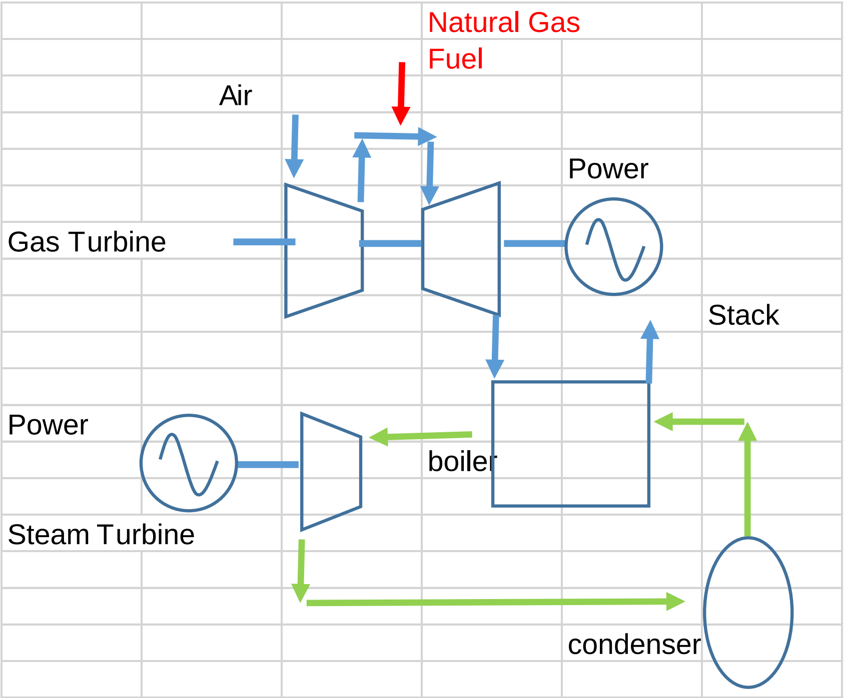
## Conclusions

# The Combined Cycle Gas Turbine

- Large - 700MWe
- Low capital cost - <£750/kW
- Build time 24 months
- Supremely flexible – ramps, stop/starts
- Clean relative to coal, oil, waste combustion

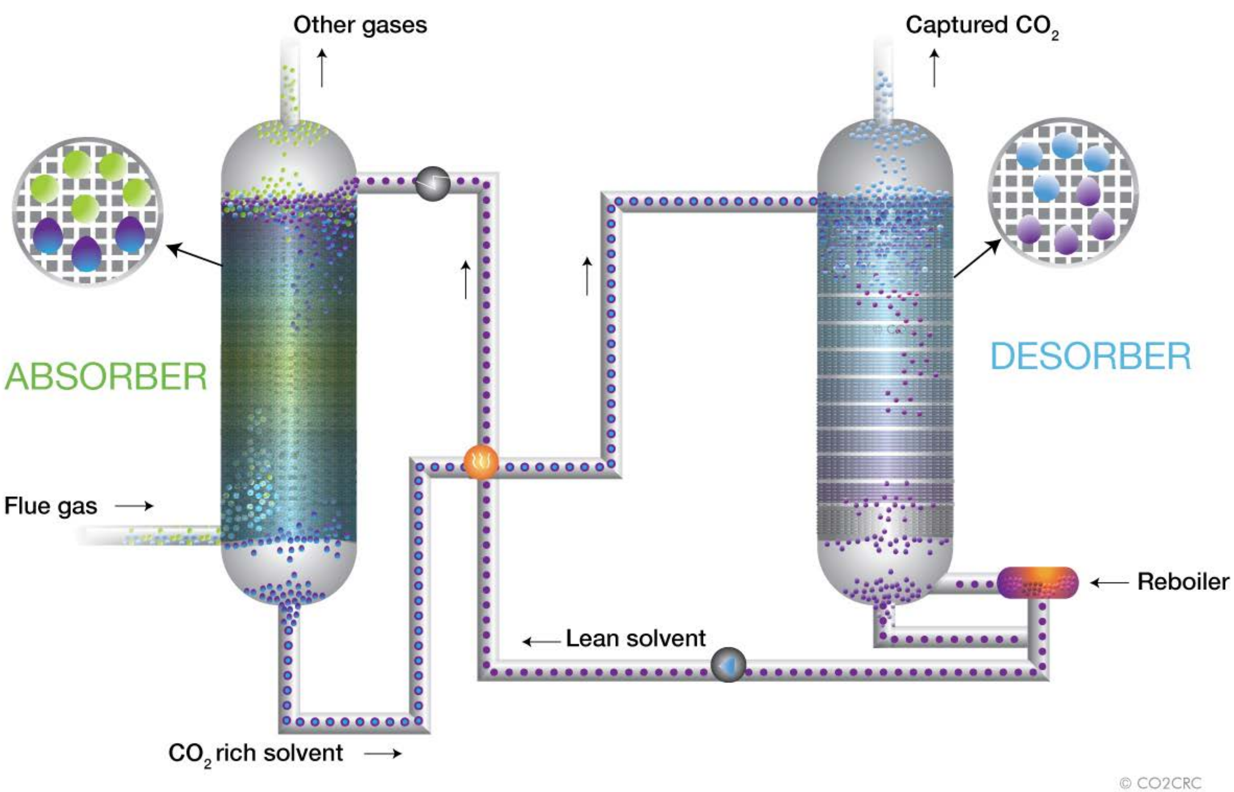
⇨ over a third of UK power capacity




Data : from Gridwatch

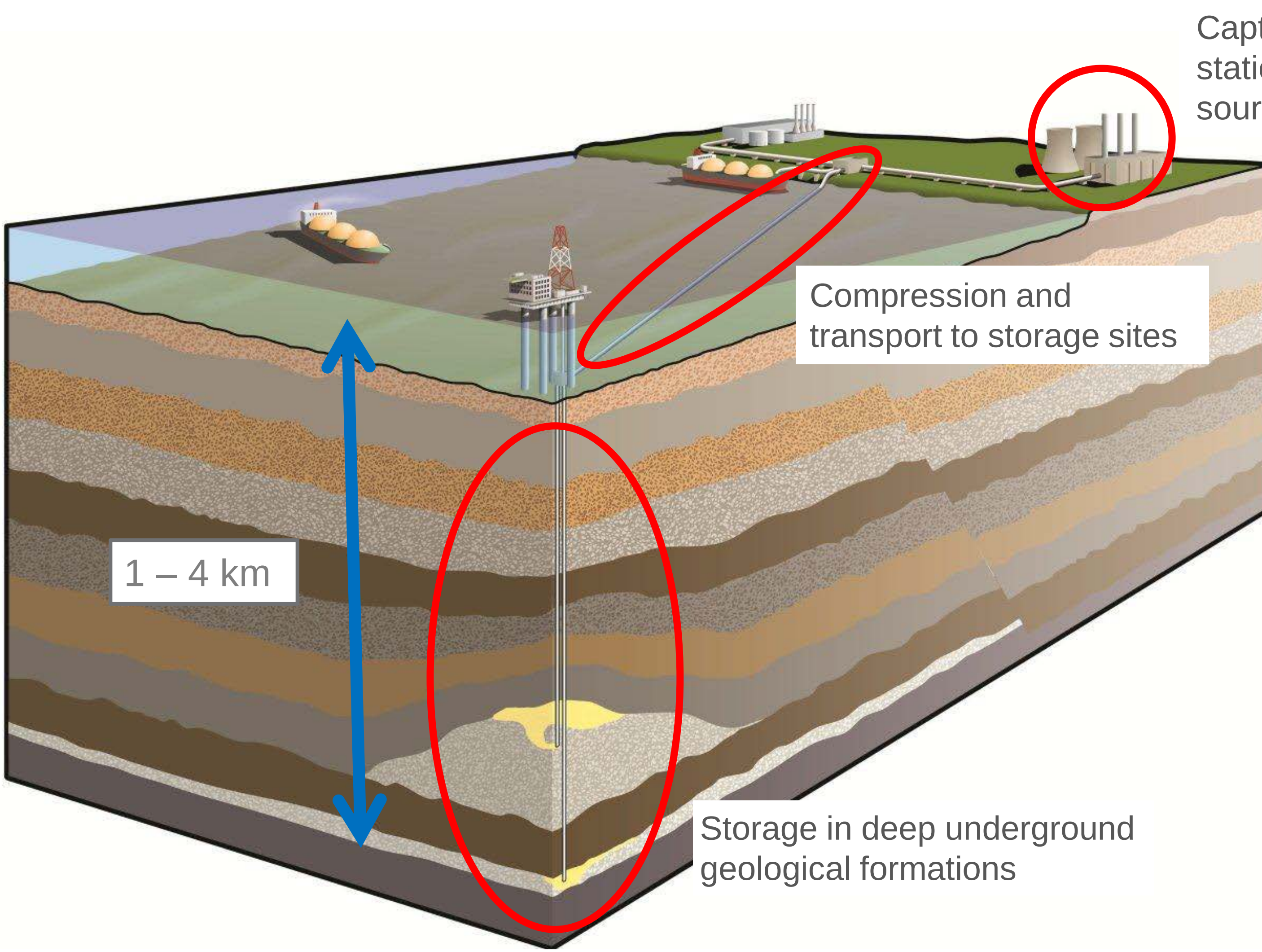
# Capture plants – example post combustion capture

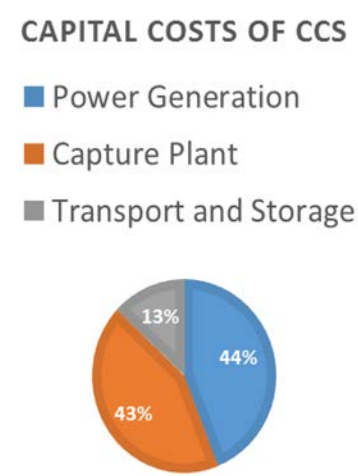



- Enough gas to fill a balloon every few seconds
- Pressure drop is expensive !
- Must remove 5 molecules in every hundred across 2 phases

Pictures Courtesy of CO2CRC

# Additional Plant for a CCS Chain



# Capture plants – economics

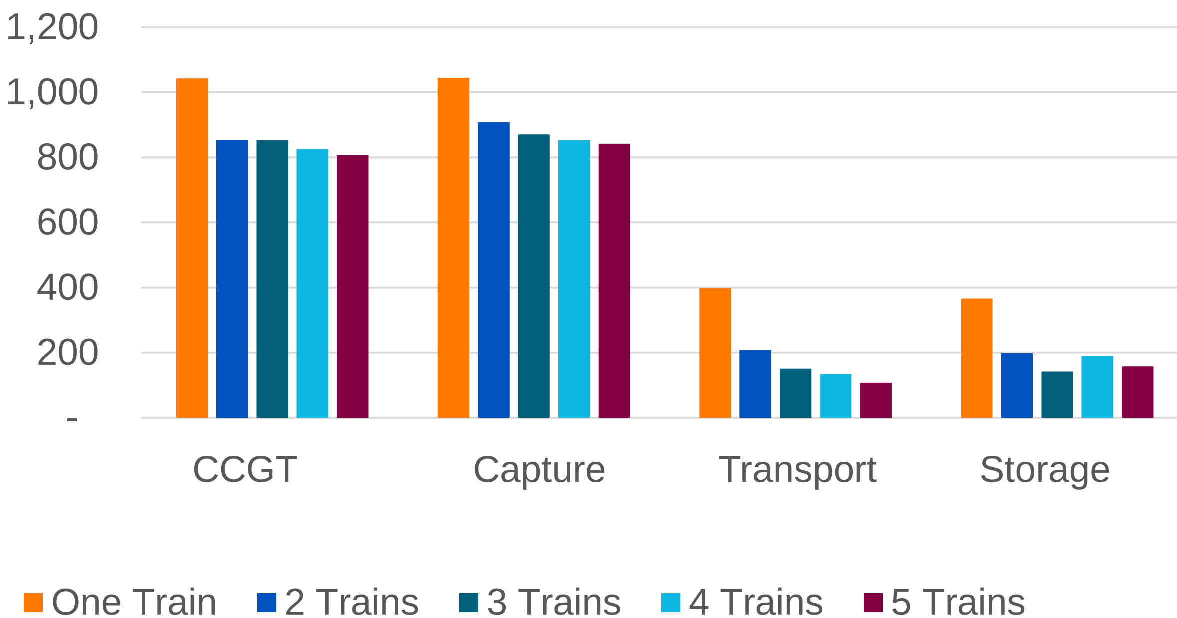
| Additional Cost for CCS | CCGT | CCGT/ CCS |
|---|---|---|
| | | |
| Capital Cost /kWnet , £ | 550 | 1240 |
| Efficiency LHV,% | 58.8 | 49.9 |
| Levelised Cost of Electricity (LCOE), £/MWh | 48 | 70 |
| Levelised cost at 40% Load ,£/MWh | 70 | 119 |
| Levelised cost of Fuel Only ,£/MWh | 34 | 40 |


- 17 large scale CCS plants in operation
- CCGT with CCS proven at Bellingham ,USA . Closed
- New power stations fitted with CCS are all COAL
- Capture from steel, ethanol, H2 – all demonstrated at scale.
- Natural Gas cleaning – Sleipner 1996 !

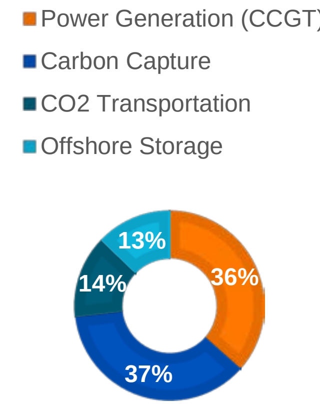
Discounting at 10%, with a 20 year lifetime for gas plant and 30 years for coal plant. Costs are for mature “nth of a kind” plant and include a contingency of 25%. The plants run with an 85% load factor. Gas at £265/te and coal at £65/te. Carbon at £0/te

# Breakdown of Investment

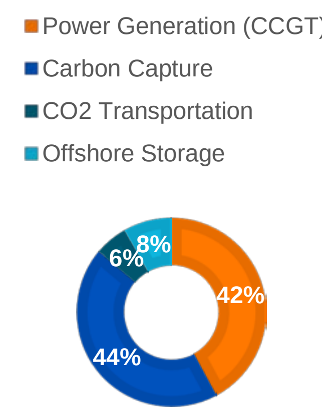
Investment breakdown, £/kW vs. No. of Power Trains



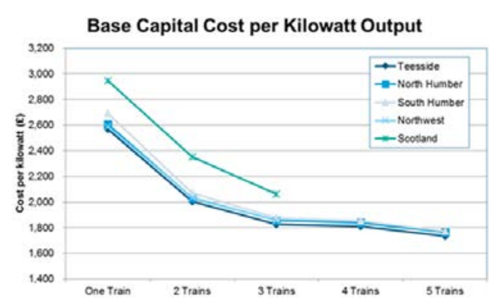

## 1 TRAIN OVERALL CAPEX



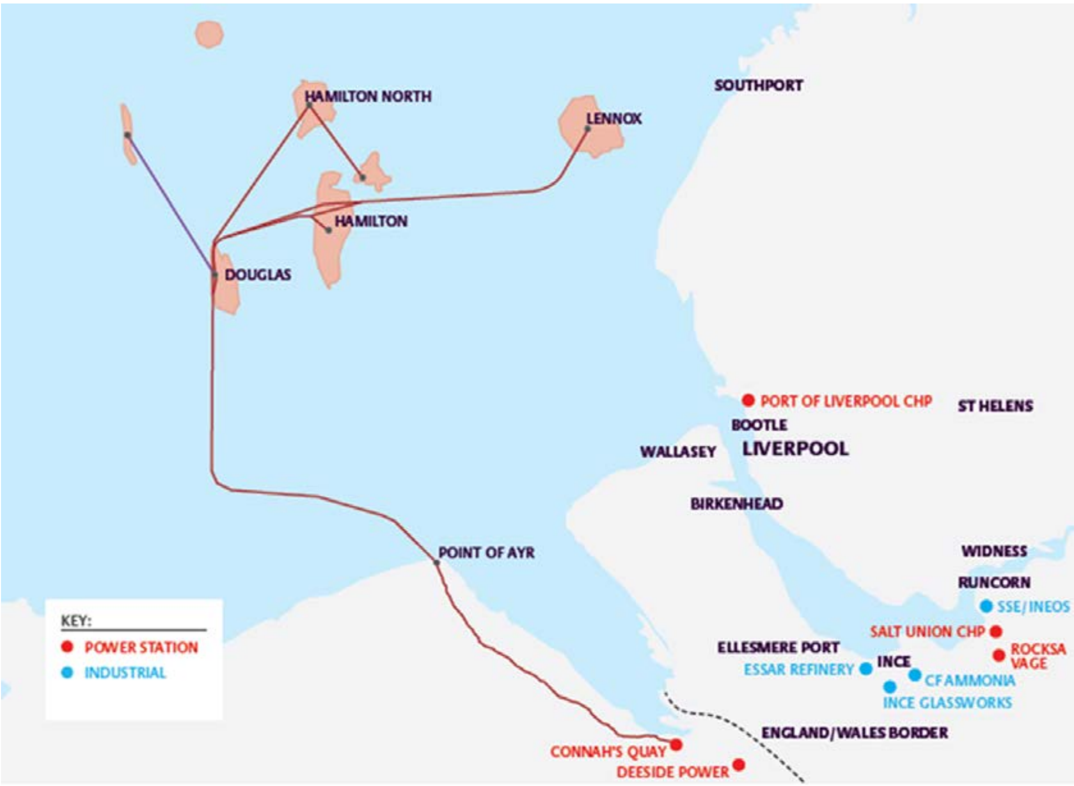

## 5 TRAINS OVERALL CAPEX




Scale helps – Each train about 2MT/a $CO_2$



# CCGT/CCS builds transport and storage at scale – admits industrial emitters




- CF Ammonia – 0.33Mt/a -$CO_2$ Transport and storage costs to Hamilton Store - £324M
- Single GT Connah's Quay - 1.5Mt/a $CO_2$ Transport to Hamilton Store - £255M
- CF Ammonia – 0.33Mt/a – $CO_2$ Transport and storage to Connah's Quay - £56M or 37/te plus rent

# Pitching CCGT/CCS into the future fleet

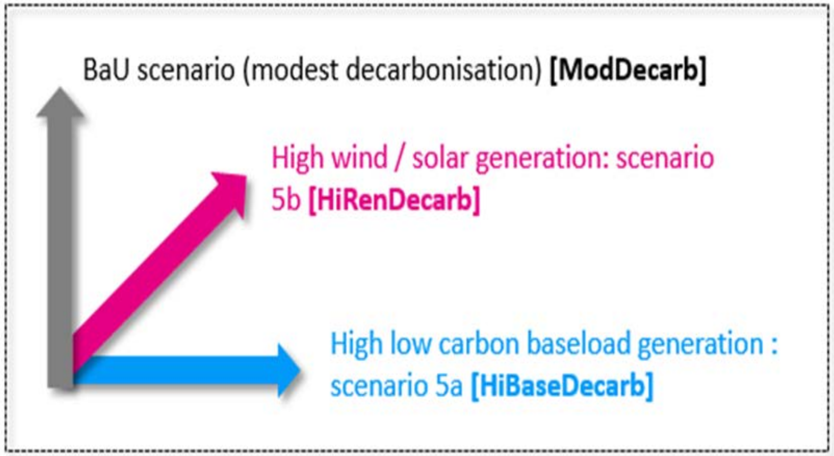
- Selected three "fleets" for 2030 and 2040
  - Modest Decarbonisation effort – BaU
  - High Renewables
  - High Nuclear/ Some CCS - high "baseload"

- Run half hourly despatch model – Plexos in Wholesale Market Mode

- Despatch on short term cost basis

- Extract
  - stop/start requirements
  - ramp rates etc
  - total gas use

- Investability - Plexos in Asset Evaluation mode - Annual revenue, then back-check investability

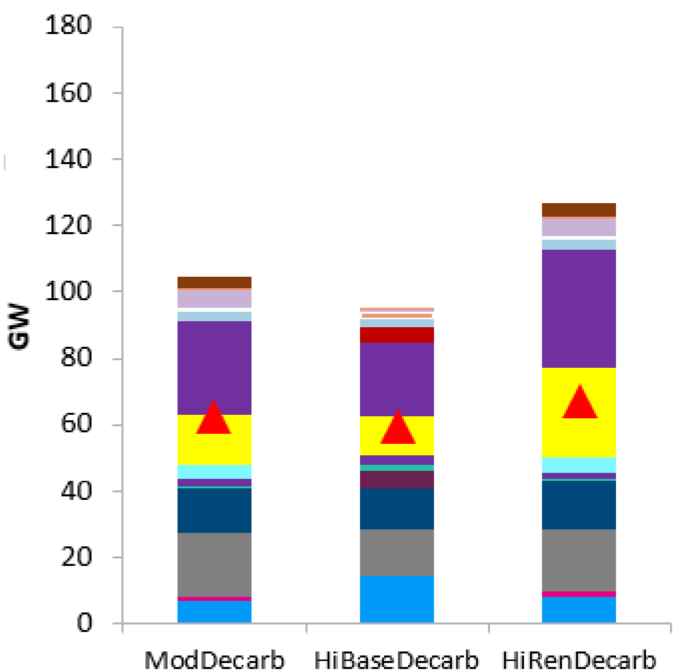


# Three Fleets – all meet peak demand, similar supply/demand tension

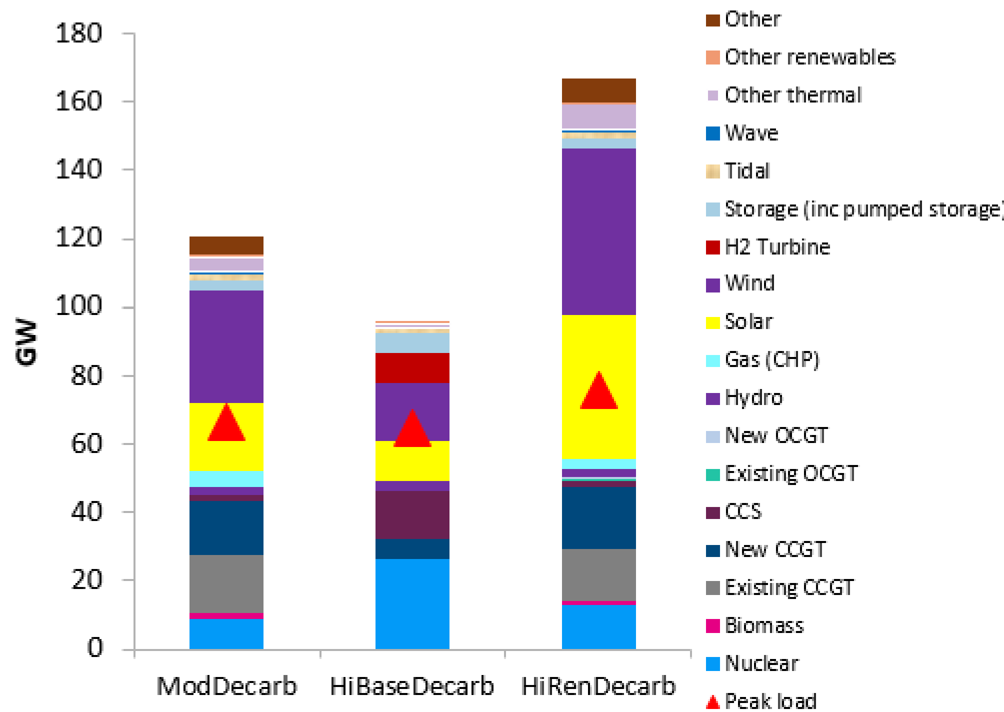
| Scenarios 2030 | GB time weighted price (£/MWh) | Carbon intensity (gCO2/kWh) | Carbon Price £/te |
|---|---|---|---|
| ModDecarb | 57.4 | 130.6 | 35.2 |
| HiBaseDecarb | 56.0 | 50.2 | 44.2 |
| HiRenDecarb | 60.4 | 82.3 | 44.2 |

| Scenarios 2040 | GB time weighted price (£/MWh) | Carbon intensity (gCO2/kWh) | Carbon Price £/te |
|---|---|---|---|
| ModDecarb | 69.4 | 127.3 | 41.3 |
| HiBaseDecarb | 46.2 | 15.3 | 119.3 |
| HiRenDecarb | 69.9 | 69.3 | 119.3 |

**2030 supply and demand**




**2040 supply and demand**



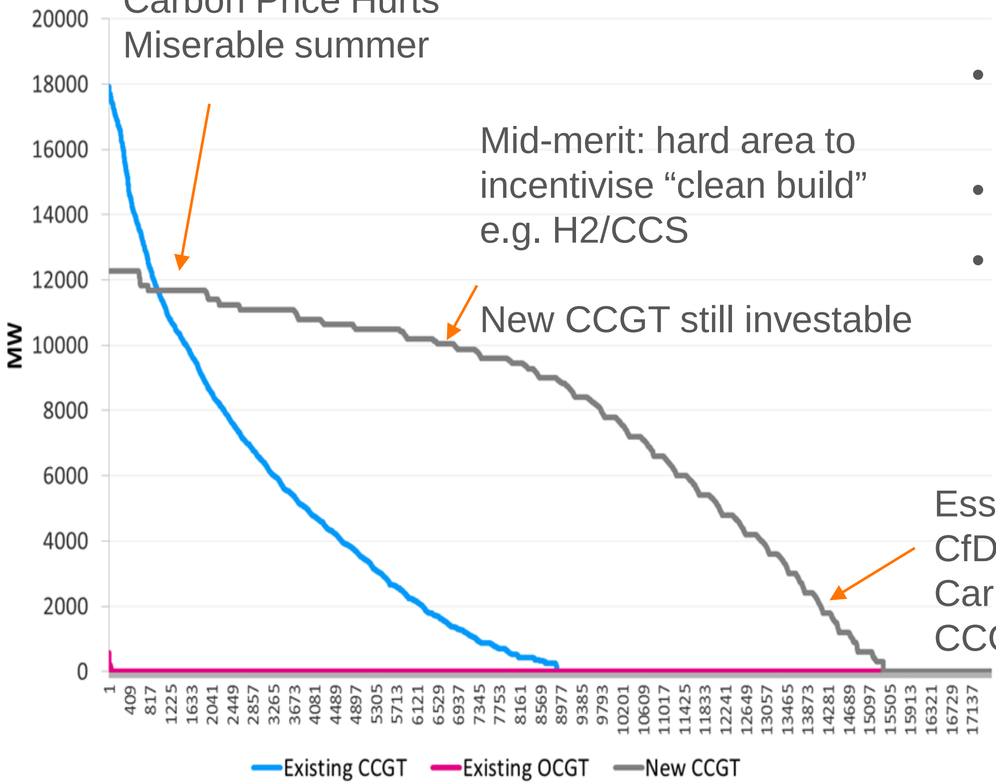
# Despatched Gas Fired Fleet Profile - 2030

“BAU” – Modest Decarbonisation Case (NG FES)

Low Load
Capacity Mechanism Incentivises
Carbon Price Hurts
Miserable summer

Mid-merit: hard area to incentivise “clean build” e.g. H2/CCS

New CCGT still investable

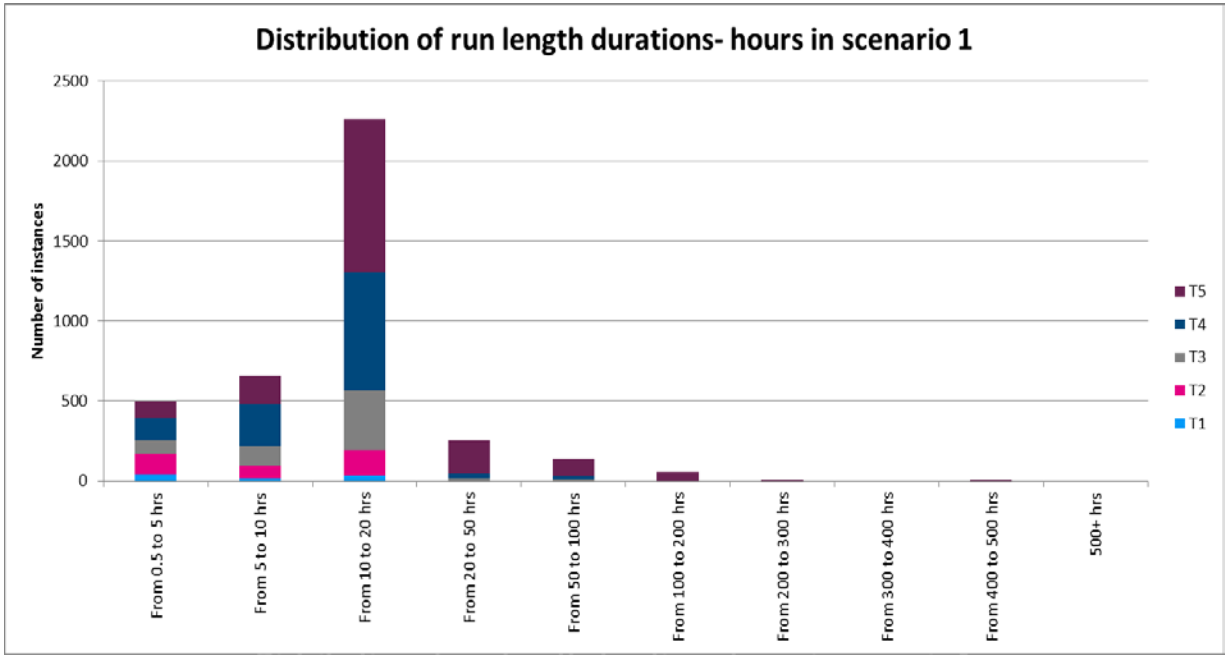



Half hours producing shown load

Essentially Baseload, but “spiky”
CfD Incentivises
Carbon price helps clean plant
CCGT/CCS investible

- 4GW ‘baseload’ taken by CCGTs (plus CHP not shown) – opportunity for CCS
- When added into model, 3GWe CCS was despatched, displacing GTs
- Flexible despatched MWh exceeded the Baseload MWh
- Long tail of older plant ave 16% Load Factor
- “New” Post 2016 fleet ave 58% Load Factor

# Agility is needed in mid-merit plant, 2030



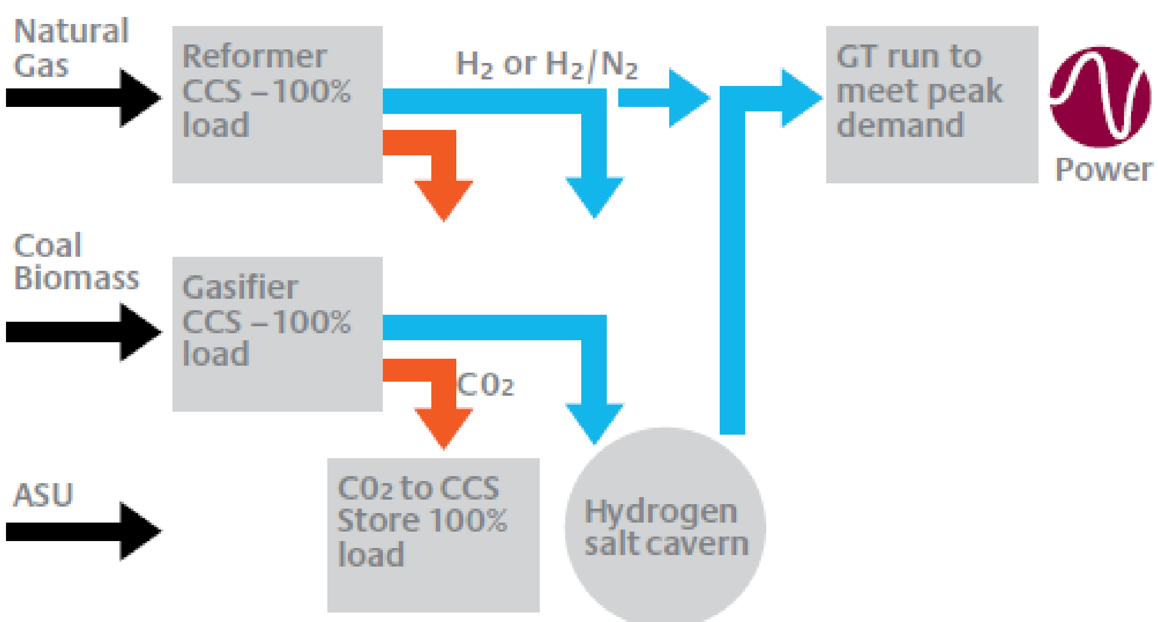

The "best" plants

- Capture the ramping market
- Have the highest number of hot starts – 3 times those of older plants (80-150 starts/a)
- Have a lower number of cold starts – half those of existing GTs

| Efficiency buckets (HHV basis) | Low end | High end |
|---|---|---|
| T1 | 26.4% | 49.5% |
| T2 | 49.6% | 50.0% |
| T3 | 50.2% | 50.9% |
| T4 | 50.9% | 51.8% |
| T5 | 51.8% | 53.8% |

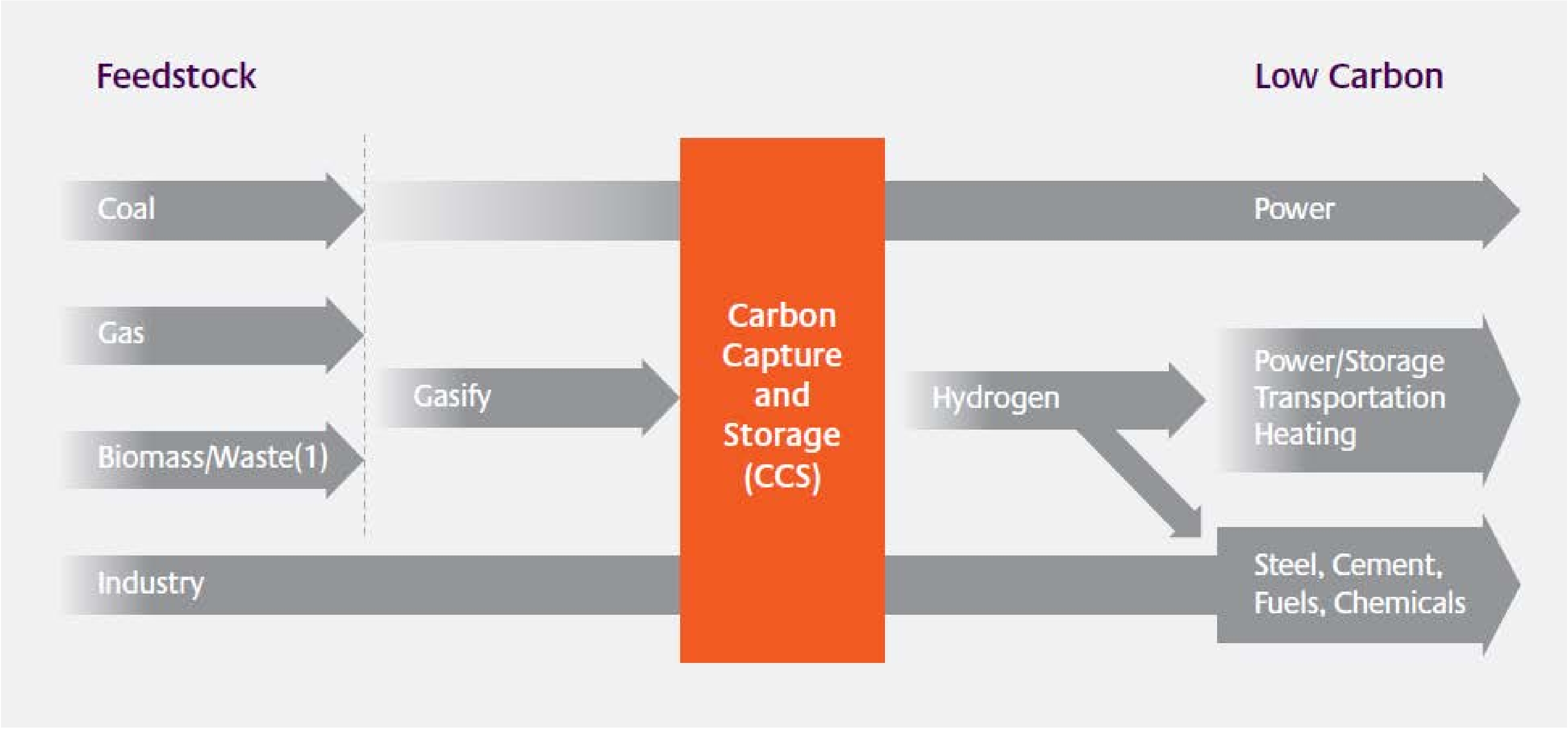
# Using H2 storage to maximise use of CCS investment

## Power station configurations using $H_2$ storage



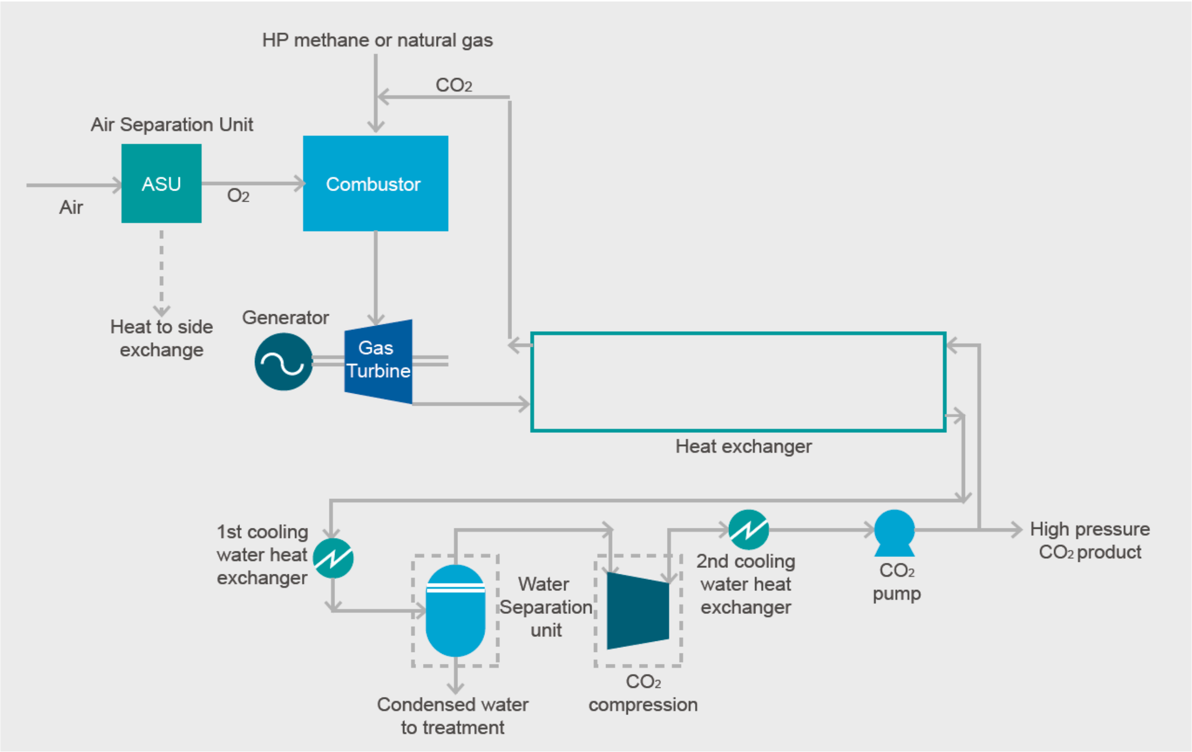

UK salt beds are not widespread
but are situated in good locations

# Multiple opportunities for CCS



# Pre – combustion and Oxy Combustion (NET Power)

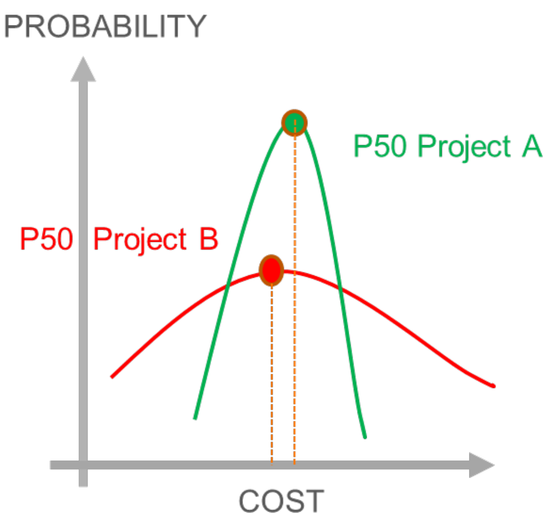
- New power cycle designed with $CO_2$ capture in mind – no steam cycle.
- New Combustor and Turbine type – high pressure/medium temps ( 300 BarG, 1180 oC)
- High level of heat recuperation, high outlet pressure of turbine (~ 30 BargG)
- Target 58.9% efficiency , same capex as unabated CCGT

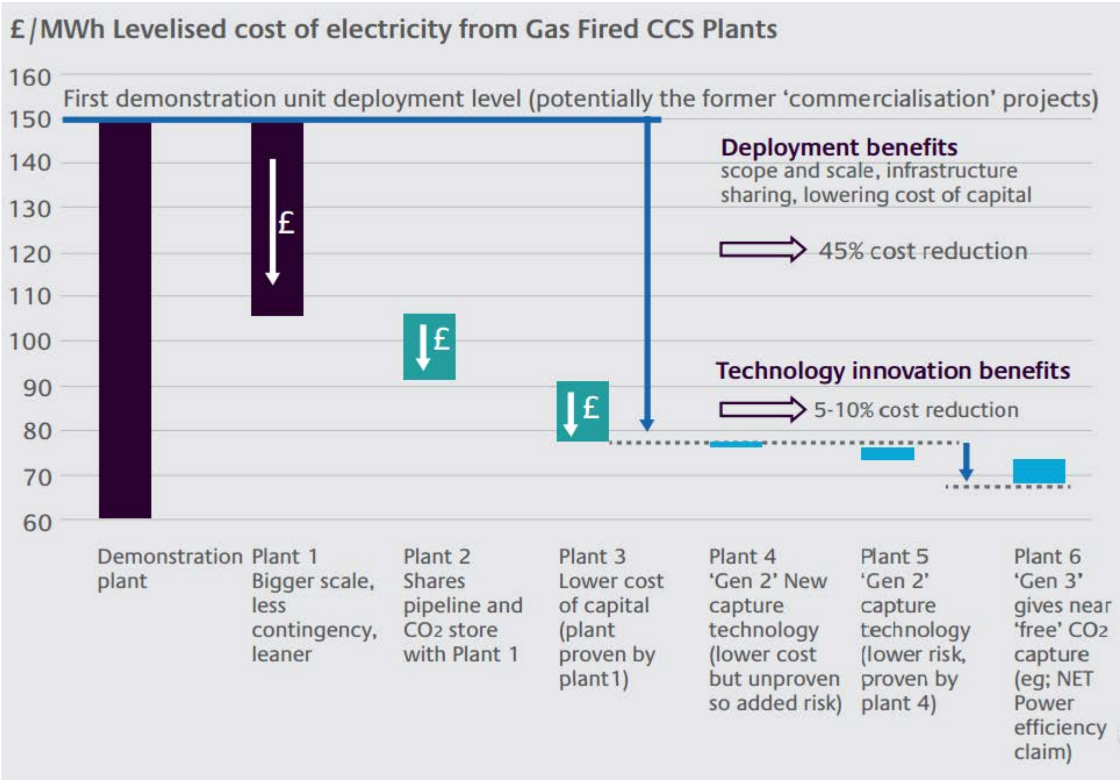



- High pressure means
  - small !!
  - $CO_2$ pumpable
- Oxy –firing means
  - $CO_2$ /$H_2O$ only (ish)
- 50MWth unit under construction, Texas

# Cost reduction – Key drivers

- Scale
  - reduce infrastructure cost/MW
- Location
  - minimise overall connection costs
  - Clustering to further enhance benefits of scale
- Technology
  - Use of proven technologies reduces risk and cost of capital

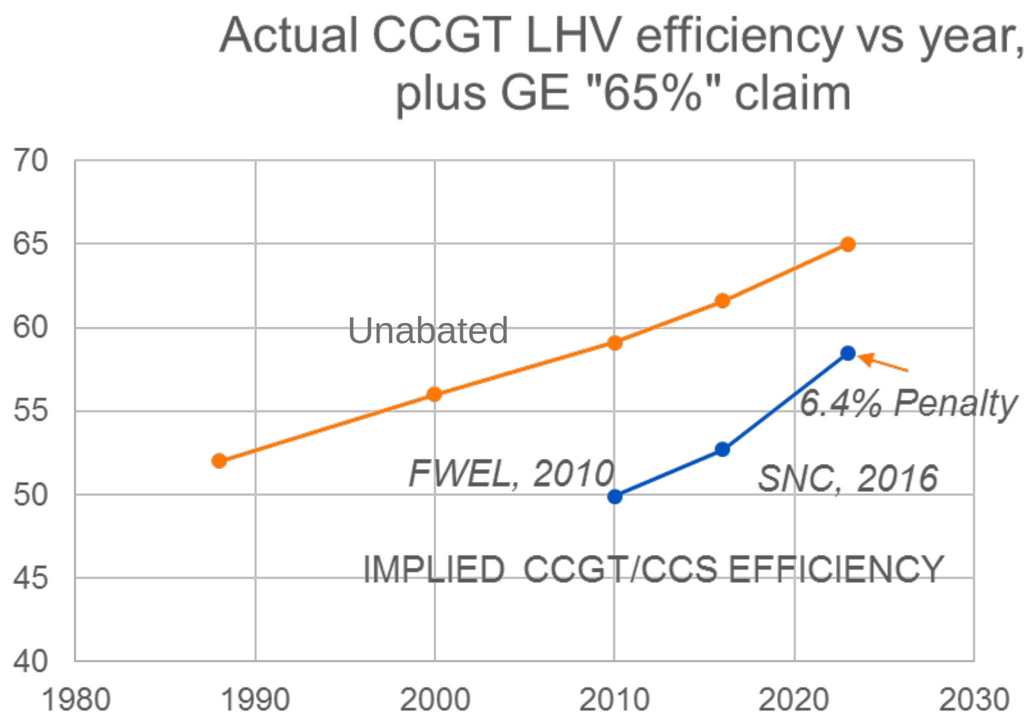



From 'ETI Insights Report 'Reducing the Cost of CCS'
http://www.eti.co.uk/insights/reducing-the-cost-of-ccs-developments-in-capture-plant-technology

# CCGT/CCS – Performance & Cost Trajectory

- Large increase in scale of GTs since 2010
- Both cost and efficiency improvements
- Post combustion capture energy penalty is also reducing
- Capital cost of capture – expecting 20% reduction post PetraNova, Sask Power



# The Clean Gas Project

### 2016/2017

- ETI develops concept – large scale, first commercial gas with CCS plant, without capital subsidy

### Mid 2017 onwards

- Clean Gas Project transferred to OGCI Climate Investments
- Announced at OGCI CEO's meeting, 27$^{th}$ October 2017

# Conclusions - Energy Mix - a team


## BASELOAD

- Bullet Proof
- Dependable
- Large

Nuclear, Coal /Gas
CCS


## RESPONSIVE

- Ready for action
- Flexible Role
- Multiple Skills

Gas or gas/CCS,
Diesel


## INTERMITTENT

- Clean
- Less predictable
- Low operational cost

Wind, Solar

# Key Messages

CCS offers system wide benefits to the UK energy sector

- Provides clean power on demand from customers.
- Abates emissions from power and industry, and through $H_2$ can tackle transport emissions and smaller local emissions
- In combination with biomass, can create “negative emissions”
- Cost advantage – without CCS, energy would be more expensive in the UK - 2050 system costs up £30Bn+/a, electricity up 2p/kWh.

Key issues

- New business models and financial solutions, for complex projects required.
- De-risked storage is needed, through new appraisal activity
- Cheaper capture technology, through demonstration projects

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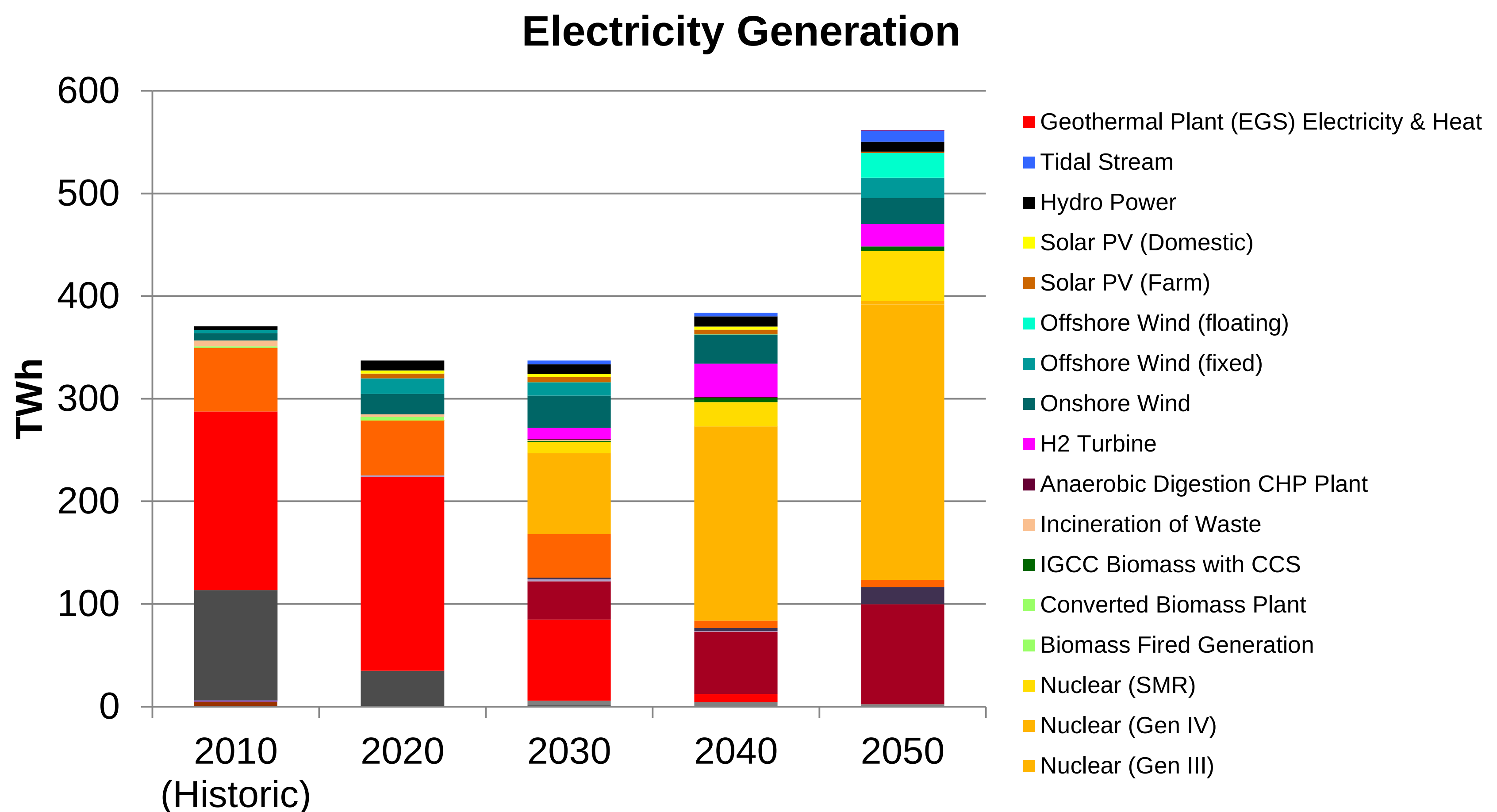
For more information about the ETI visit www.eti.co.uk

For the latest ETI news and announcements email info@eti.co.uk

The ETI can also be followed on Twitter @the_ETI

ETI10 TEN YEARS OF INNOVATION 2007 — 2017

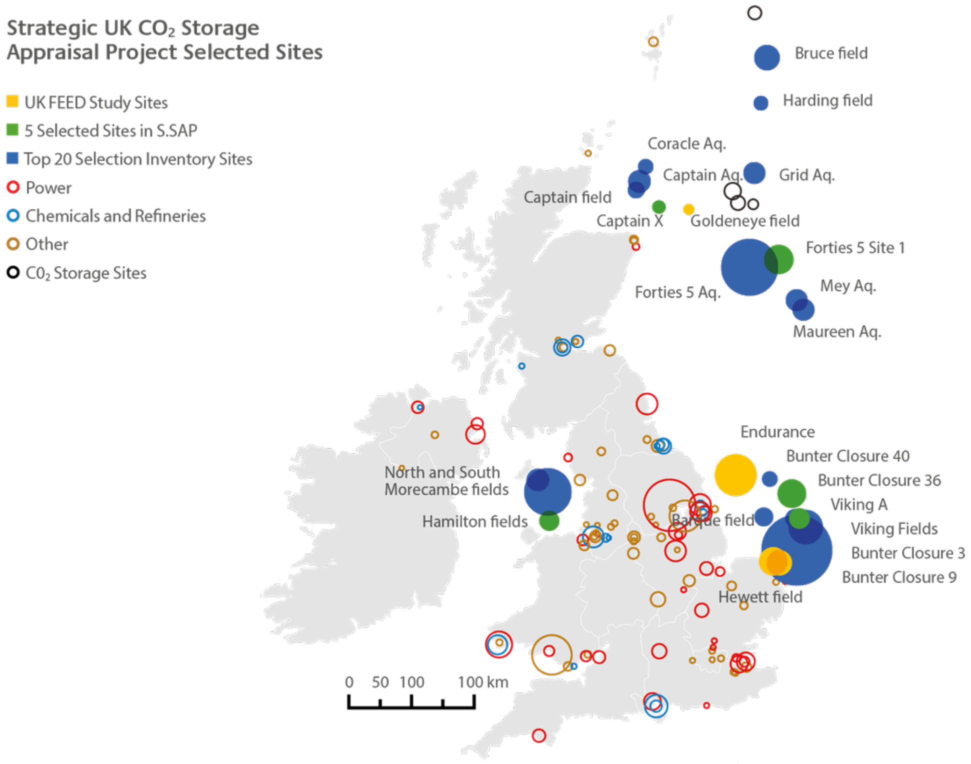
# Spares




ESME v4.1 Database 100sim

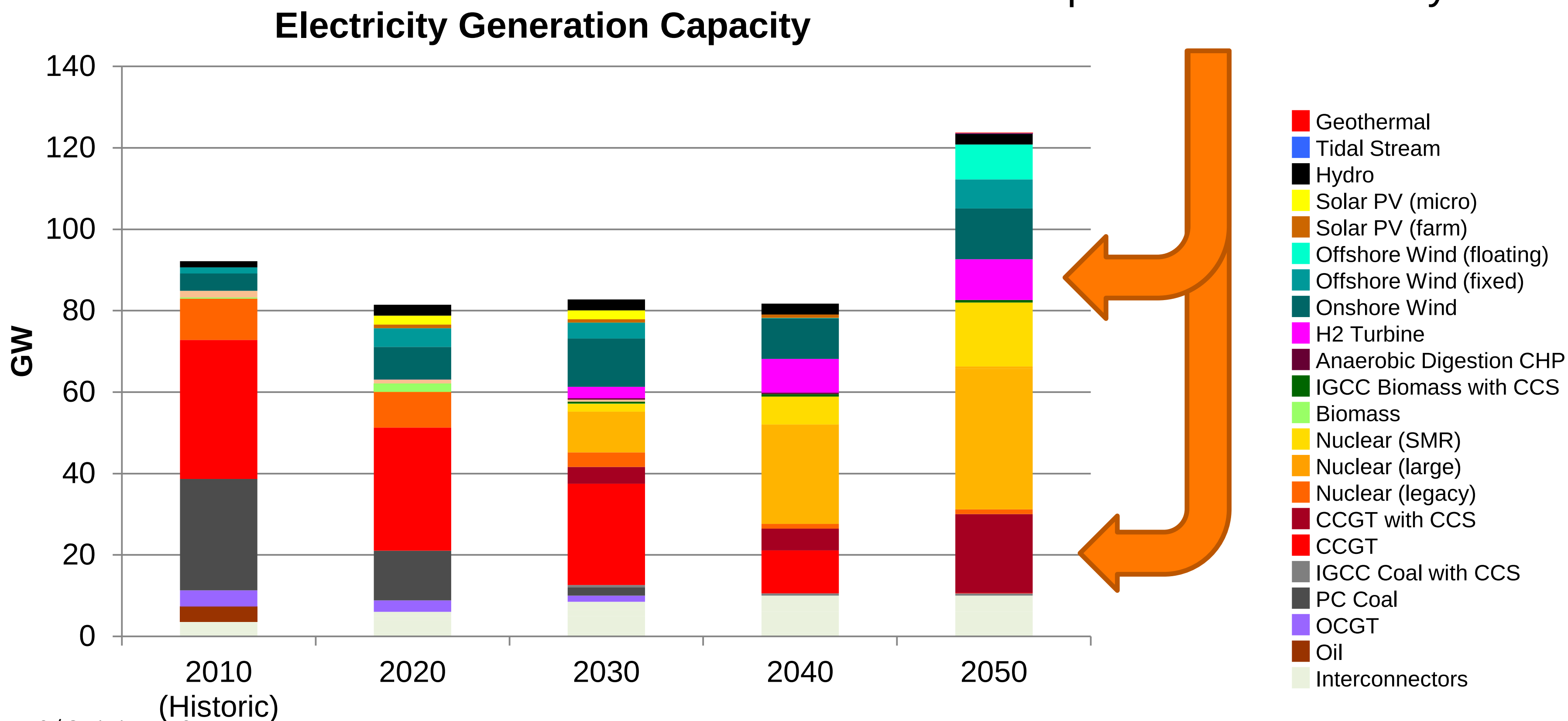
# CO2Stored

- Transfer of ownership from ETI to BGS being concluded, with future use of data permitted by ETI/ESC individuals.



# Expensive – but still competitive

CCS in Power (25% of total) plus CCS in Industry




DB v4.0 / Optimiser v4.0

# Overall Power Costs – CCGT with CCS

- The post Brexit fall in the £/US$ caused an escalation of 3% - 4% alone
- Even with a "conservative" configuration, the capture energy penalty has dropped by more than ~ 2% points since 2010 estimates. Generation efficiency has gained 2% points.
- Overall, levelised costs have not changed significantly since earlier ETI estimates and are in the range :

**LEVELISED COST of ELECTRICITY**

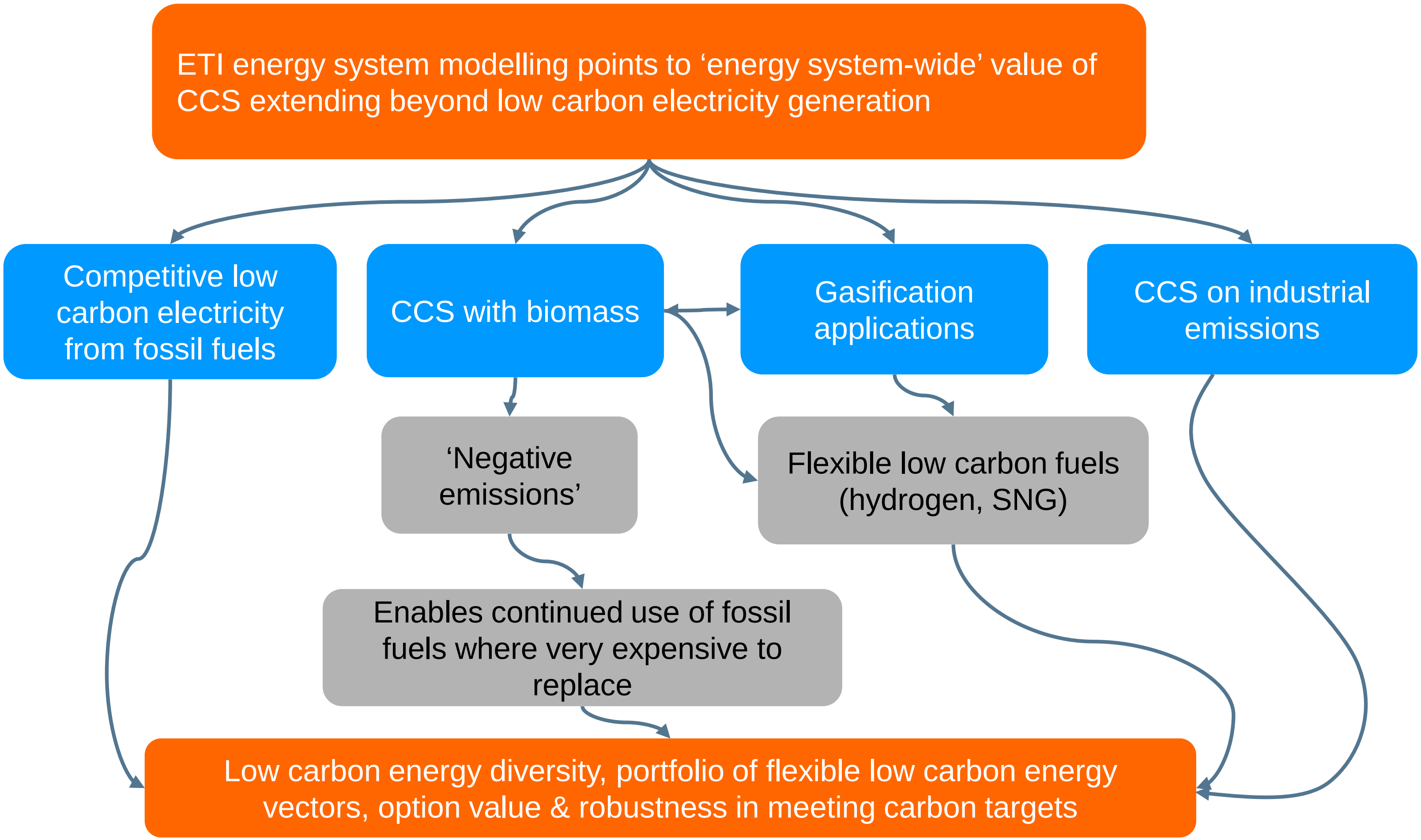
**Range : £/MWh 63 to £/MWh 93**

SIMPLIFIED ASSUMPTIONS

- Discount Factor - 10%
- Gas Prices, p/therm : Lo- 30 Med- 50 Hi- 70
- 5 Train capex
- 25 year life
- Costs, Q1 2016
- Load Factor 90%
- LHV Efficiency 52.7% ( by calculation)
- 100% equity

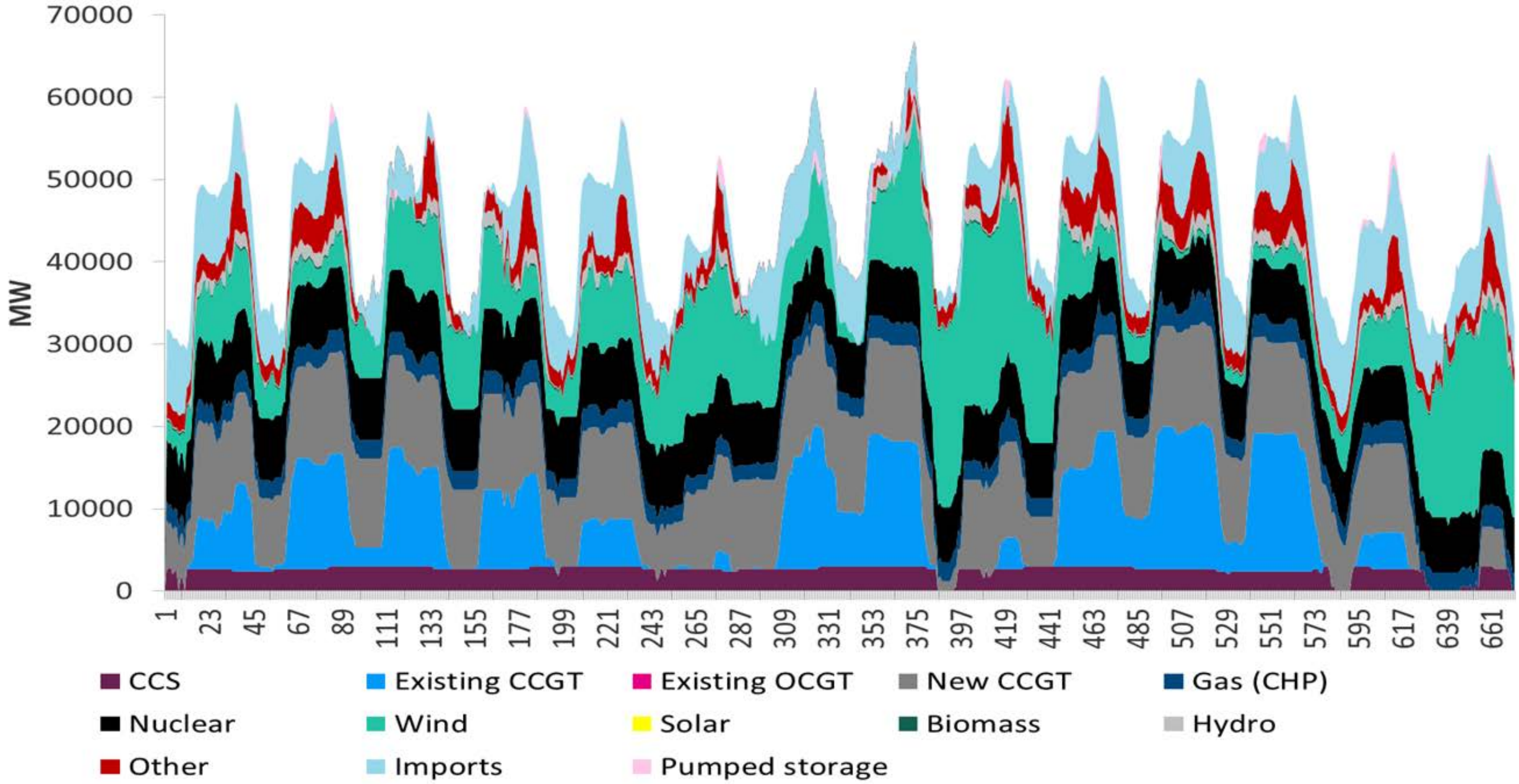
"Conservative": No 2+1 for Steam Turbines, Absorbers, ARU's etc , 316 SS in capture unit , multishaft, HRSG/ST etc sized for full GT flow, energy penalty 7.9% ( 2.99GJ/te reboiler)

# System perspective: CCS is valuable!



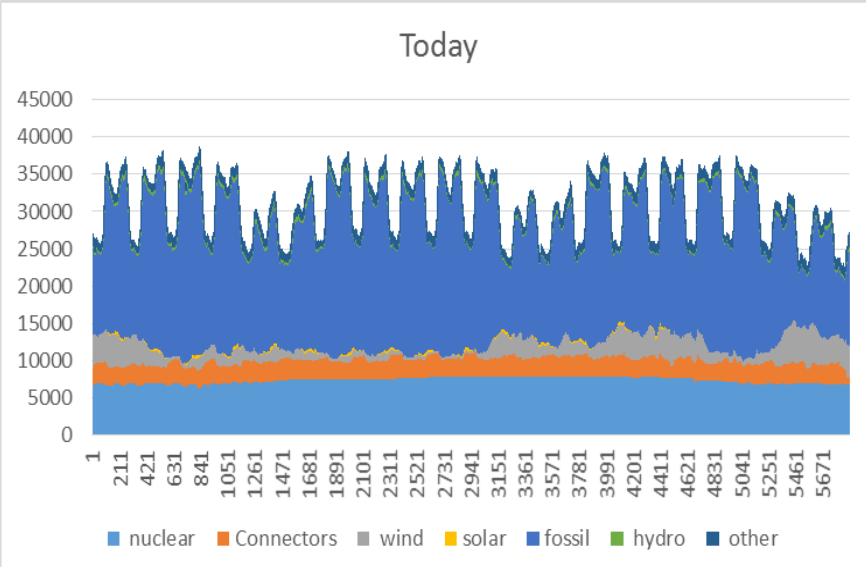

ETI ESME analysis consistently shows doubling of cost of meeting 2050 targets without CCS: 1 – 2% GDP

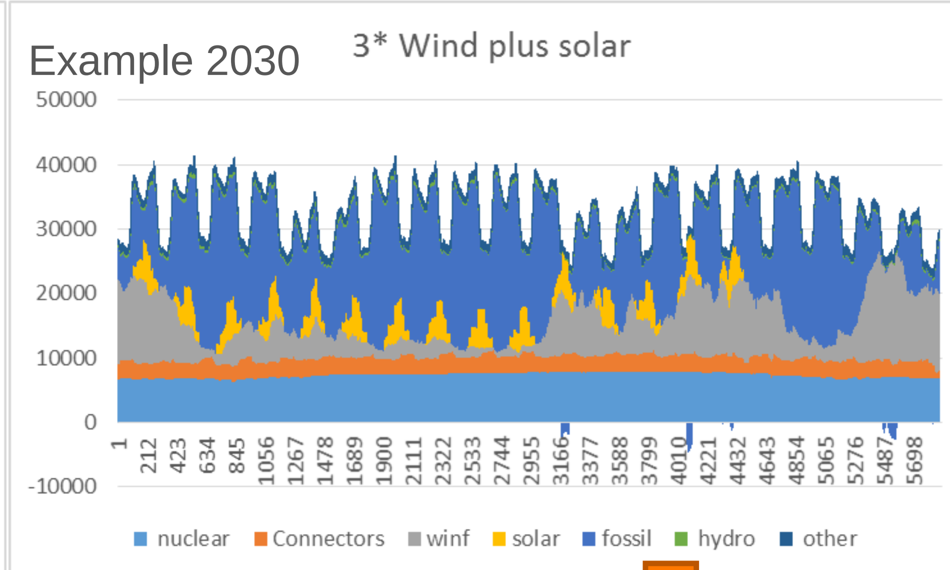
# Dispatch Analysis – 2 weeks in December 2030 – with CCS

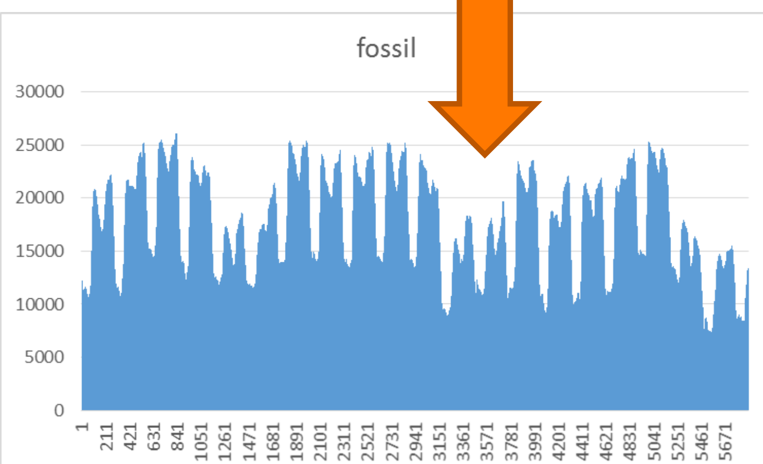



- 3GW of gas with CCS added to the fleet – no consequential reductions in other generating capacity
- CCS operates at near baseload – but reduces output in instances of low demand/high wind

# Change in Duty of Despatchable Plant (“Today” -15 min data from Gridwatch)




Changes

Annual Starts

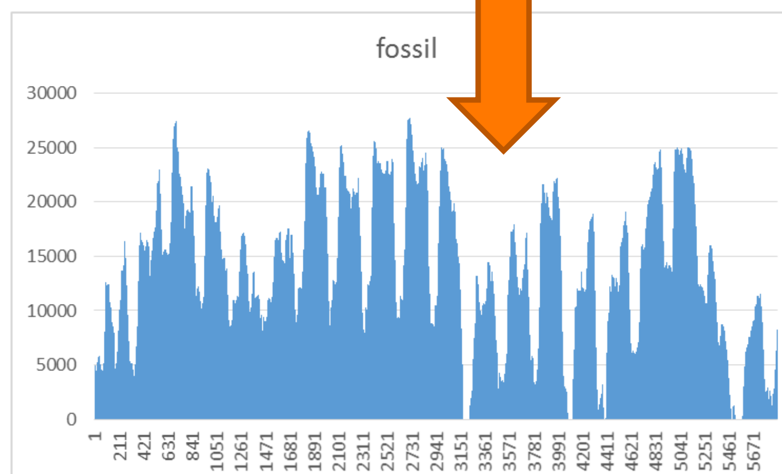
Ramp-Rates

Total MWh

On/Off - Hold

Load Factor

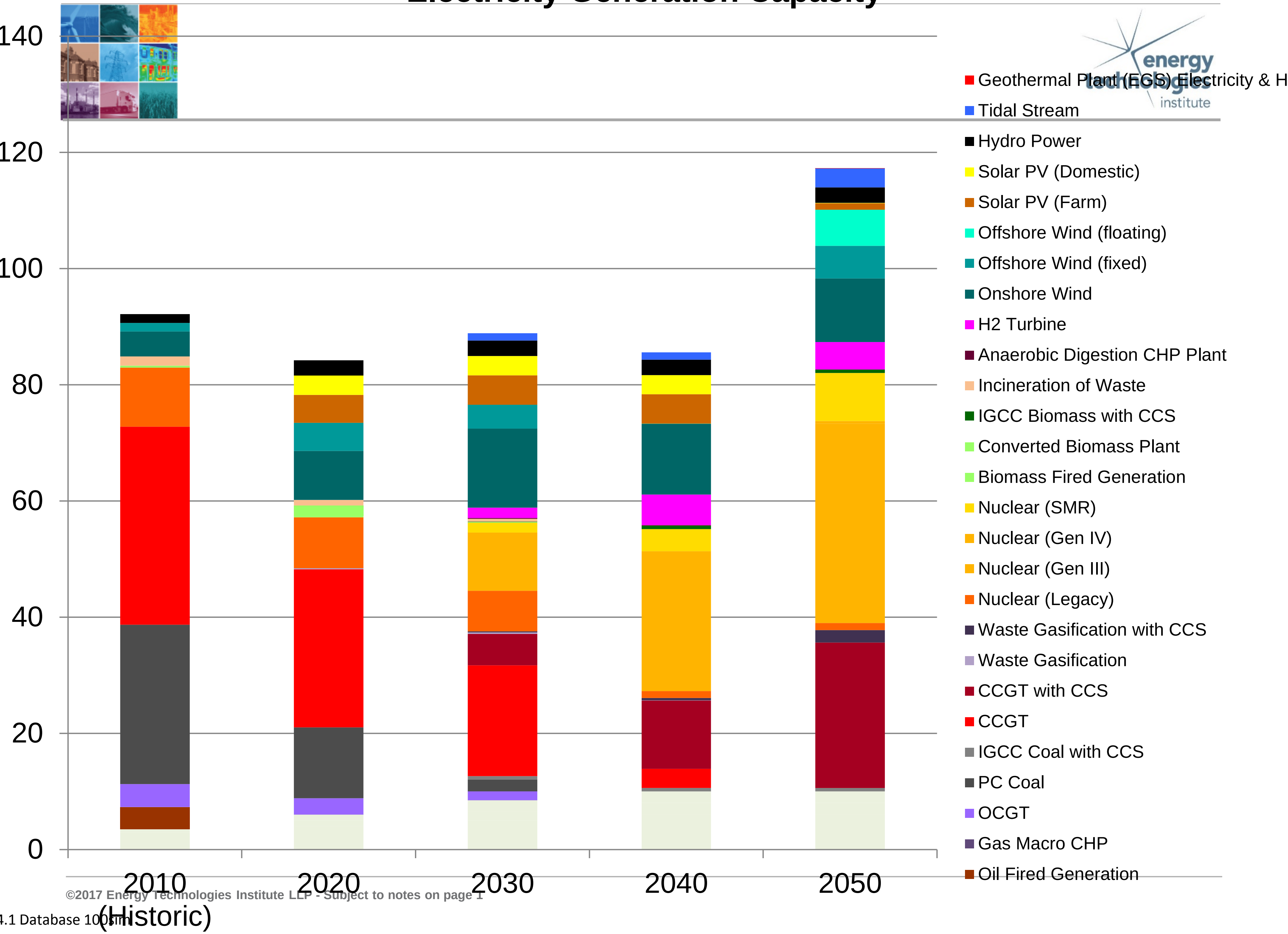
(by sector)



# Plant Performance

| Power Generation | | |
|---|---|---|
| | Per Train | 5 Train Plant |
| **Gross** | 732 MW | 3.66 GW |
| **Efficiency @ Generator Terminals** | 62.0% (LHV) | |
| **Net (Gross minus Parasitic Loads)** | 715 MW | 3.58 GW |
| **Net Efficiency (unabated)** | 60.6% (LHV) | |
| **Steam Abated (Gross Power with Abatement Steam Extracted)** | 691 MW | 3.45 GW |
| **CCGT Parasitic Electrical Load** | 17 MW | 0.09 GW |
| **CC Parasitic Electrical Load** | 52 MW | 0.26 GW |
| **Net Abated (Steam Abated minus CCGT & CC Parasitic Loads)** | 622 MW | 3.11 GW |
| **Net Efficiency (abated)** | 52.7% (LHV) | |
| **Efficiency Loss for CC** | -7.9% | |
| **Carbon Capture & Compression** | | |
| | Per Train | 5 Train Plant |
| **$CO_2$ Purity (Volume Basis)** | 98% | 98% |
| **$CO_2$ Mass Flow (@ 100% availability)** | 221 T/hr<br>1.93 MT/annum | 1103 T/hr<br>9.66 MT/annum |
| **Reboiler Service** | 2.99 GJ/tonne$CO_2$ | |
| **Compressor Service** | 0.38 GJ/tonne$CO_2$ | |

# Electricity Generation Capacity






4.1 Database 100sim