Doosan Babcock Energy

An industrial perspective on coal R+D

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7 ECCRIA Cardiff 3 Sept 2008

Company update

Nuclear

Thermal

Turbine & Generator

Desalination

Casting & Forging

Construction

- Doosan Babcock Energy Limited is a subsidiary of Doosan Heavy Industries and Construction of South Korea, part of the Doosan Group, and a market leader in gas, coal, nuclear power generation and desalination . Orders in 2007 totalled 7 Bn USD
- Doosan Babcock Energy remains committed to all forms of power generation, including clean coal, nuclear, gas and renewables
- Doosan Heavy offers Pre and Post combustion and Oxyfuel carbon capture technologies
- Doosan Babcock Energy has been designated the Doosan global Centre of Excellence and R+D Centre for Boilers (including Clean coal and Carbon dioxide capture)
- Doosan Babcock Energy's sales territory is Europe, Americas, Southern Africa and China, but its boiler technology is used globally, including recent orders In India and Thailand

A campaign for clean fossil power ?

- **Recognise that despite energy saving measures we will probably need more clean electricity if carbon targets for heating and transport are to be met**
- **Recognise that coal and gas cannot be avoided if people are to have sufficient energy and therefore that widespread implementation of CCS is *urgent***
- **Recognise that while CCS technologies do not need to be invented they need progressive scale up, requiring a number of demonstration projects before wholesale implementation**
- **Seek ambitious programmes for implementation of CCS demonstration*s ie Multiple capture technologies, coal and gas***
- **Ensure all other coal and gas plants are genuinely capture-ready and plan retrofit of CCS onto capture ready plant as soon as reasonable - will require incentives or regulation if C-price not sufficient soon enough**
- **Question whether one UK demonstration is sufficient in the context of 20 GW of new fossil plant in the UK (Conservatives are saying they would support at least 3)**
- **Do not discriminate against coal in favour of gas, such policy simply allows the UK to dodge the issue temporarily**

Content of Presentation

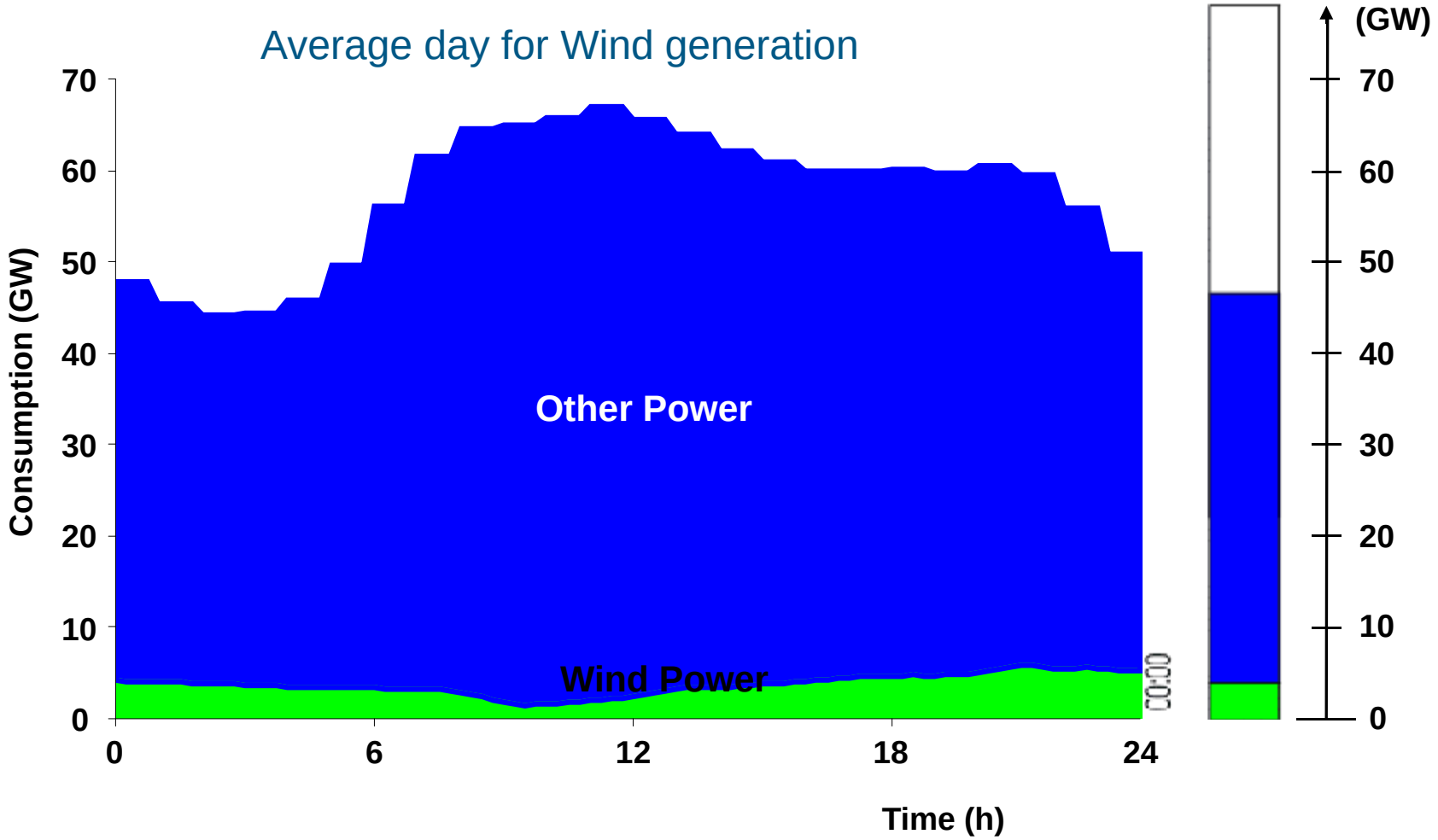
- Importance of clean coal
  - Balance renewables
  - Lower cost low carbon option
  - Avoid further excessive dependence on gas
  - Set a global example
- Status of technologies
- Why are Carbon capture-ready (CCR) power plants and multiple CCS demonstrations needed?
- Current R+D and industrial activities
- Further R+D and Demonstration needs

Flexible fossil power needed to provide power on demand to balance intermittency of renewables and variations in demand

Germany,

April 13th, 2007

Average day for Wind generation



Sources: VdN, UCTE

Relative costs of electricity generation (£/MWh)

- Recent evidence to the House of Commons Select Committee on Environmental Audit Committee by EON UK, a major developer of windfarms (onshore and offshore), gas-fired power stations and the proposer of the Kingsnorth clean coal project, quoted the following relative costs-of-electricity generation (£/MWh):

£/MWh		Excluding cost of Carbon Allowances	Including Cost of Carbon Allowances €20/te	Including Cost of Carbon Allowances €40/te
CCGT (gas)		44.3	51.8	59.3
Coal		41.7	56.4	70.8
Coal + CCS		67.7	69.2	70.7
Nuclear		38.6	38.6	38.6
Onshore Wind		75.0	75.0	75.0
Offshore Wind		107.0	107.0	107.0

Coal Forum Scenarios for UK – “Pessimistic for coal”

Scenario assumes

- **No new coal by 2016**
- **10 GW of opted-in coal plants close in 2016**
- **No CCS demonstration**
- **All new fossil plant are gas**

Outcomes of model

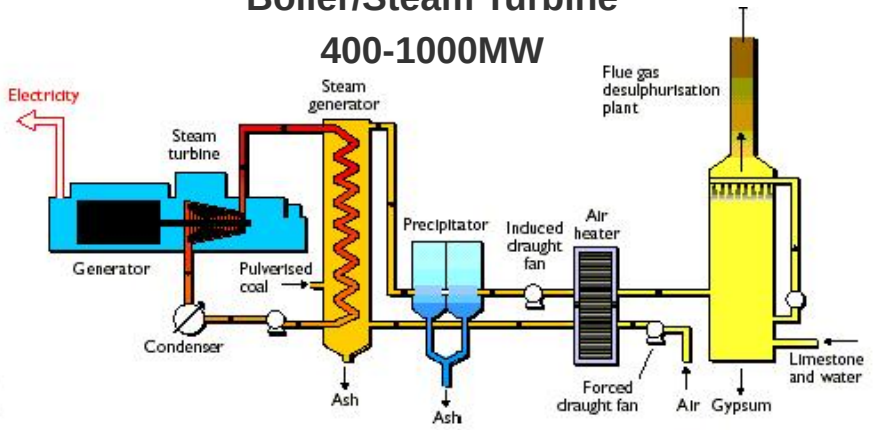
- **Generation capacity gap unless a further 2GW of Gas CCGT built by 2012 and 15GW by 2016 on top of 12 GW planned/under construction**
- **75% dependence (GW) on gas during a cold still spell in winter (cf 36% now)**
- **54% of generation (TWh) from gas, 17% from renewables in 2016**

Clean Coal Technologies available now

- Higher efficiency / lower emissions than current coal, better than LCPD standards
- Lower cost electricity than gas or renewables
- Suitable for UK or imported coal
- Suitable for Carbon Capture and Storage (CCS) - 90% capture
- ASC Pulverised Coal offers Capture-Ready Retrofit options
- IGCC offers Hydrogen options
- 95% of current orders are for Pulverised Coal

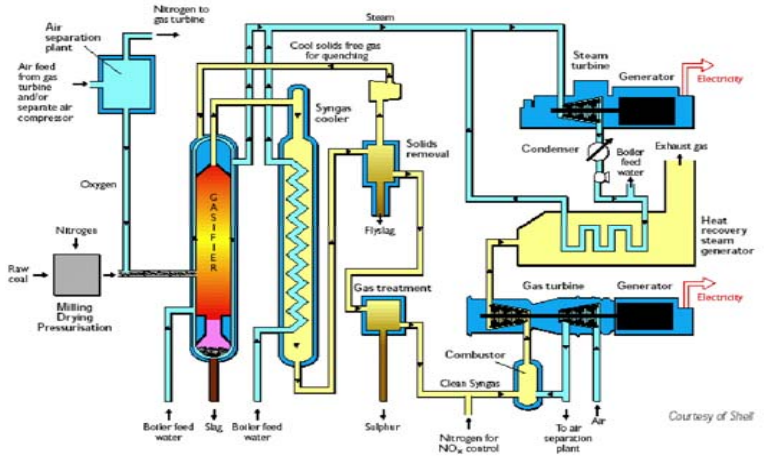
Advanced Supercritical Pulverised Coal Boiler/Steam Turbine

400-1000MW



Integrated Gasification Combined Cycle

250-900MW



Courtesy of Shell

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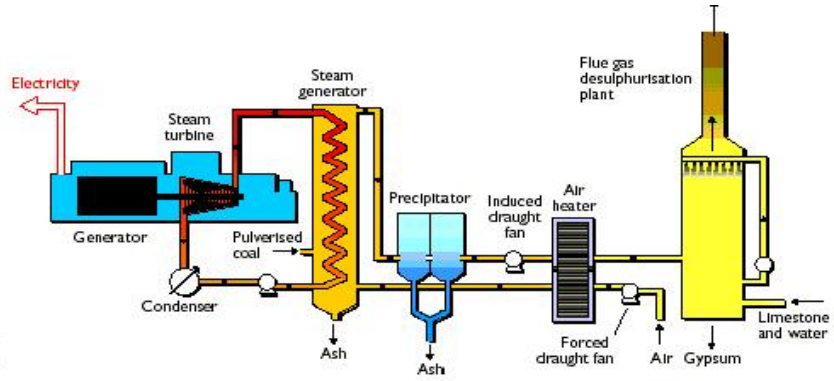
Carbon-Abated Clean Coal Power Plant

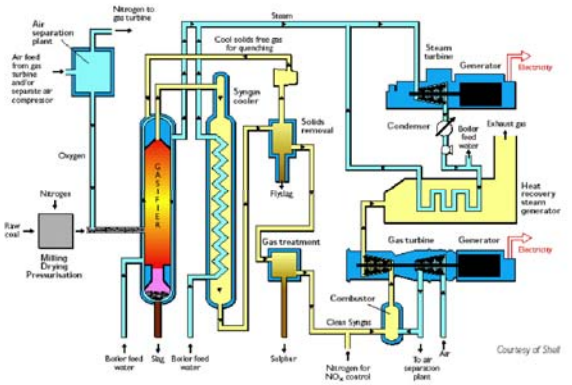
Advanced Supercritical Pulverised Coal Boiler /Steam Turbine 350-1000MW



- Best Available Technology *now 46/47% efficient (290 bar/600C/610C), cf 35%*
- Advantages are proven Availability (>95%), Load Flexibility (20-100%) and wide fuel range (inc Biomass cofiring up to 20%)
- Matches any other coal technology for emissions, easily meets LCPD limits
- Can be built now, designed to be “capture ready” and fitted with economical CO_2 capture when CCS is possible
- Can be retrofitted to existing UK stations
- Technology of choice for vast majority of new build orders
- Doosan Babcock building 2 x 800MW ASC in Germany and tendered for Kingsnorth

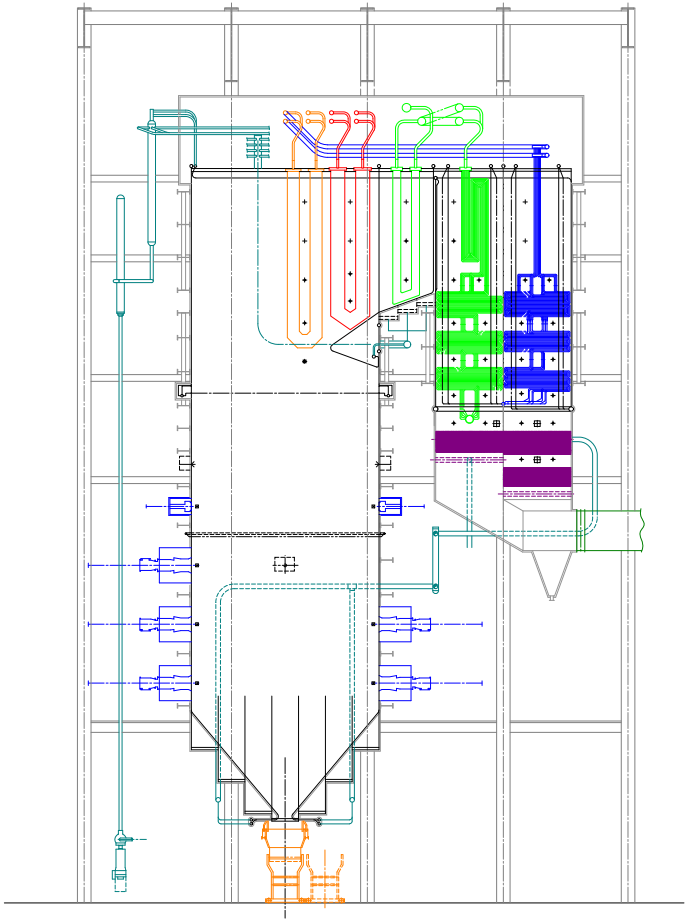
Integrated Gasification Combined Cycle (IGCC)

Integrated Gasification Combined Cycle 250-900MW



- New technology for New-Build claimed attractive because of potential for hydrogen generation and CO_2 capture
- Total of 4 units in operation worldwide on coal and some plans for further plants
- Challenges are poor availability, high cost, lack of flexibility, lack of EPC guarantees
- Latest designs attempt to improve availability with consequences on cost and efficiency
- Main challenge for CCS is the GT (has to fire natural gas, syn gas and hydrogen in turn)
- IGCC projects are being developed in UK, Europe and USA, some with CCS, but few are certain to go ahead. Futuregen on hold.
- Powerfuel were proposing to build a capture ready IGCC at Hatfield

800MW 46 % efficiency advanced supercritical boiler

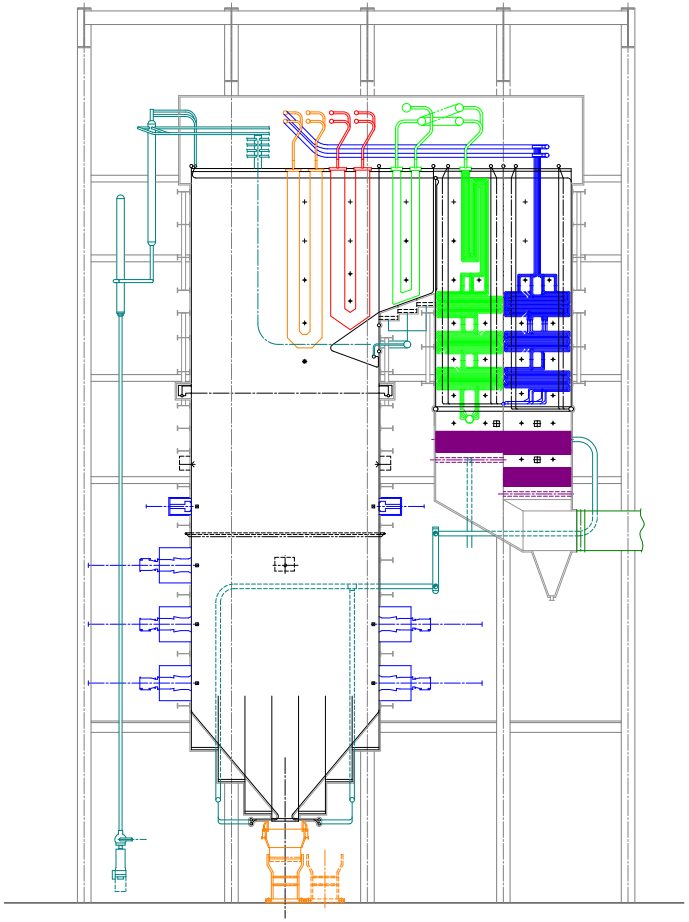


Main Steam	**281bar**
	602.45°C
Reheat Steam	**605 °C**

International traded Bituminous Coal with 3 specified guarantee coals plus 100% oil firing

Boiler Efficiency (100% load LHV)	**95%**
O_2 at economiser outlet	**2.84%**
Boiler HP steam flow	**578.65 kg/s**
Pressure drop (bar)	
HP	**27**
RH	**2.4**
SCR inlet NOx (worst coal)	**<450mg/Nm^3**
SCR outlet NOx (all coals)	**200mg/Nm^3**
CO at econ outlet	**<200mg/Nm^3**

800MW 46 % efficiency advanced supercritical boiler



Main Steam	**281bar**
	602.45°C
Reheat Steam	**605 °C**

Ordered in Germany

Suitable for UK (eg for Kingsnorth, Tilbury, Longannet)

Can be designed capture ready

Suitable for new build or retrofit

Pressure drop (bar)	
HP	**27**
RH	**2.4**
SCR inlet NOx (worst coal)	**<450mg/Nm^3**
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Near Zero Emissions Power plant – CO_2 capture options

Three options:

- **Post Combustion Capture (PCC) –**
  - **Amine or Ammonia scrubbing**
  - **Oxyfuel firing**
- **Precombustion – IGCC**

Numerous studies show these are similar in resulting efficiency and cost of electricity and competitive amongst low carbon technologies

No clear winner but PCC and Oxyfuel needed for retrofit to plants currently being built around the world (including China and India)

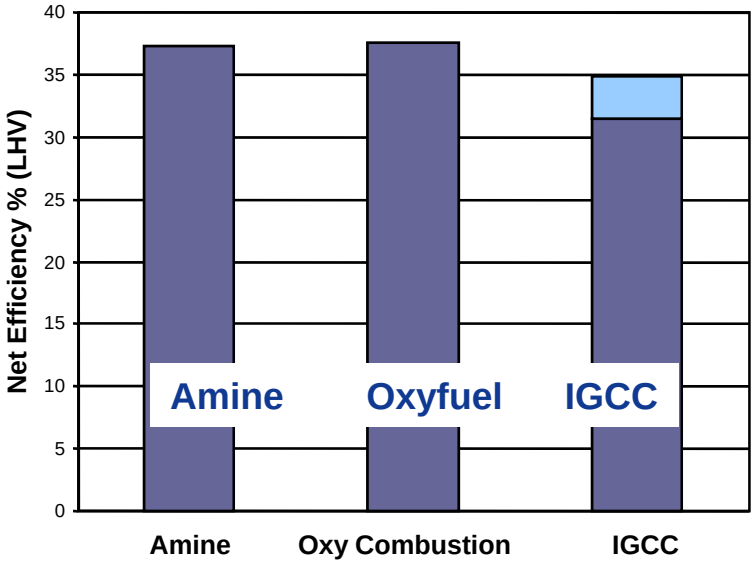
All three capture technologies proved in pilot plants but need scale up and Demonstration on full-size plants

Post Combustion Capture selected for (initial) BERR competition, amine scrubbing likely to be picked if nothing else because of the terms of the competition

If further Demonsrations are supported then other technologies should be encouraged

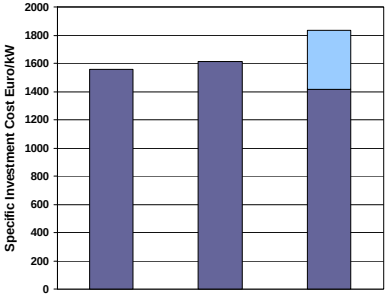
Near Zero Emissions Power plant – CO_2 capture options

Net Cycle Efficiencies (%LHV)



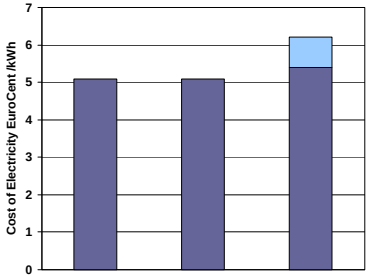
From joint paper with Jacobs at Powergen 2006

Specific Investment costs (Euro/kw)



Amine Oxyfuel IGCC

Cost of Electricity (Eurocents/kwh)



5 -6.2 Euro/kwh for New build, <5 Euro/kwh for retrofit

Amine Oxyfuel IGCC

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Post-combustion Carbon Capture – Flue Gas Scrubbing on Pulverised Coal Plant

Large Scale CO2 Capture Plant

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Scale up of Post Combustion Capture for Coal power plants

HTC	Searles Valley Minerals	2009	50MW	Coal
	CSIRO - Huaneng Beijing	2009	175MW	Coal
Alstom	AEP Oklahoma	2011	233MW	Coal
Alstom	NRG WA Parish	2012	125MW	Coal
(HTC)	Sask Power	2011		Coal
HTC	EPCOR Genese	2010		Coal
HTC & EESTech	Loy Yang	-	60MW	CBM

Target is "Commercialised by 2020"

More than 6 industrial scale demonstrations 60-250MW planned, for operation

2009 -2012

300 - 400 MWe UK Competition demonstration

2014

UK project is a major step up, 2x 800MW commercial units would be a step too far

More than 5 pilot scale demonstrations in the 10 – 30MW range for operation by

2008 - 2012

Powerspan	Basin Electric Beulah, ND	2012	120MW slipstream	Coal
MHI	E.ON Germany	2010	6-25 MW	Coal
Fluor	E.ON Wilhelmshaven	2010		Coal
Cansolv	E.ON Heyden	end 2009	10MW approx	Coal
Alstom	Karlshamn	2008	5MWe	Oil/gas
	EON/Electrabel/HitachiEuro	2009?		Coal

Many R+D scale – pilot plants using power station flue gases by 2010

Alstom	We Energies	Mar-08	1.7MW	Coal
MHI	Matsushima		0.5MW	Coal
Various	CASTOR Dong	2006	1MW	Coal
ITC	Boundary Dam	2005	0.25MW	Coal
BASF	RWE Niederaussem	mid 2010	0.33MW	Coal
?	RWE Aberthaw	2010	1MW	Coal

Post Combustion Capture for Coal power plants - Doosan Babcock road map

HTC	Searles Valley Minerals	2009	175MW
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Alstom	AEP Oklahoma	2011	233MW
Alstom	NRG WA Parish	2012	125MW
HTC	Boundary Dam	2012	100MW
HTC	Boundary Dam	2011	2x75 MW
(HTC & EESTech)	Loy Yang	-	60MW

Many pilot plant R+D scale – pilot plants using power station flue gases by 2010

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Alstom	Karlshamn	2008	5MWe	Oil/gas

More than 6 industrial scale demonstrations 60-250MW planned, for operation

2009 -2012

300 - 400 MWe UK BERR

Competition demonstration

2014

2 x 800 MWe

New power station/retrofit

Carbon Capture by Oxyfuel firing on Pulverised Coal Plant

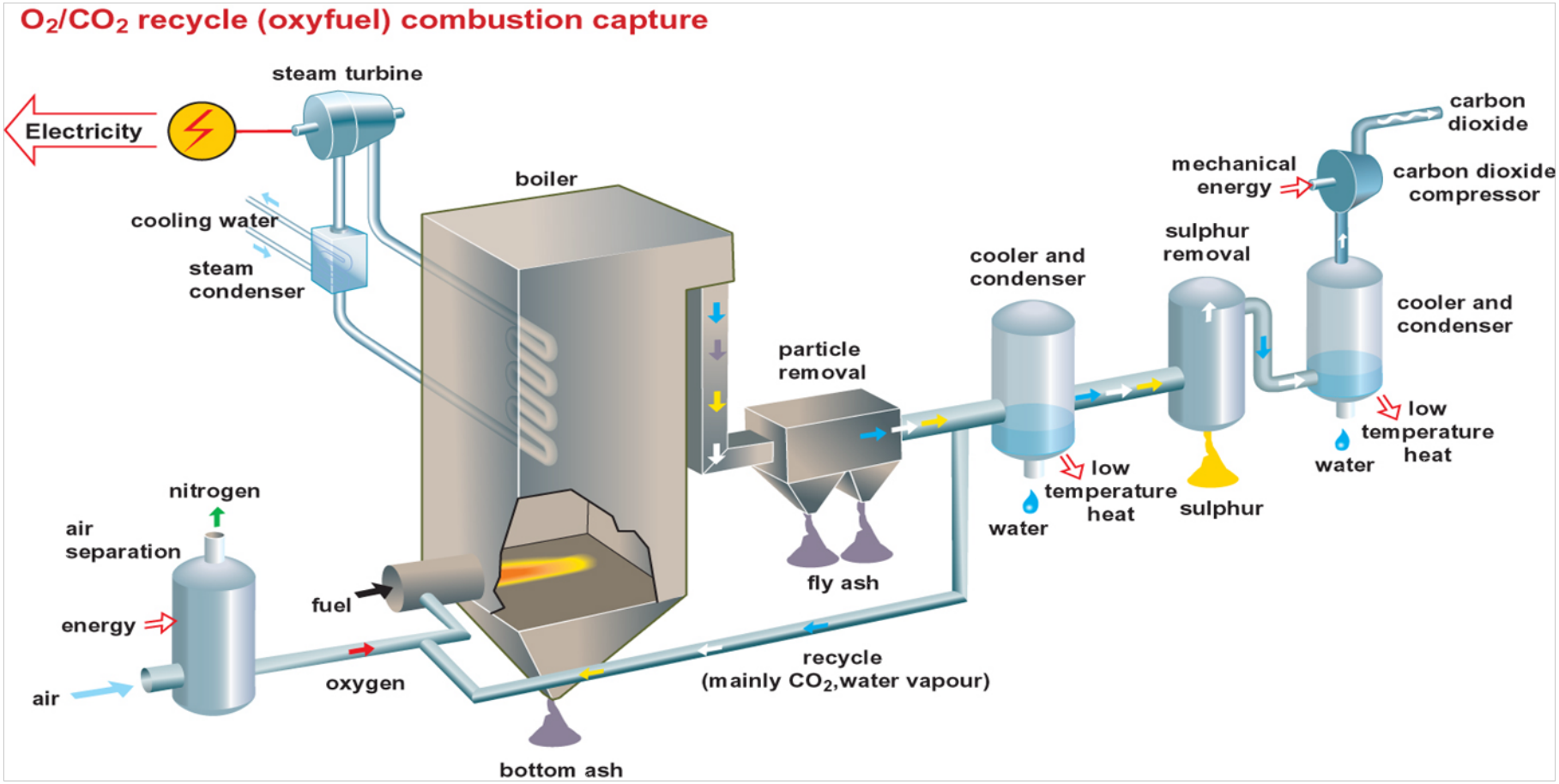

Figure courtesy of Vattenfall

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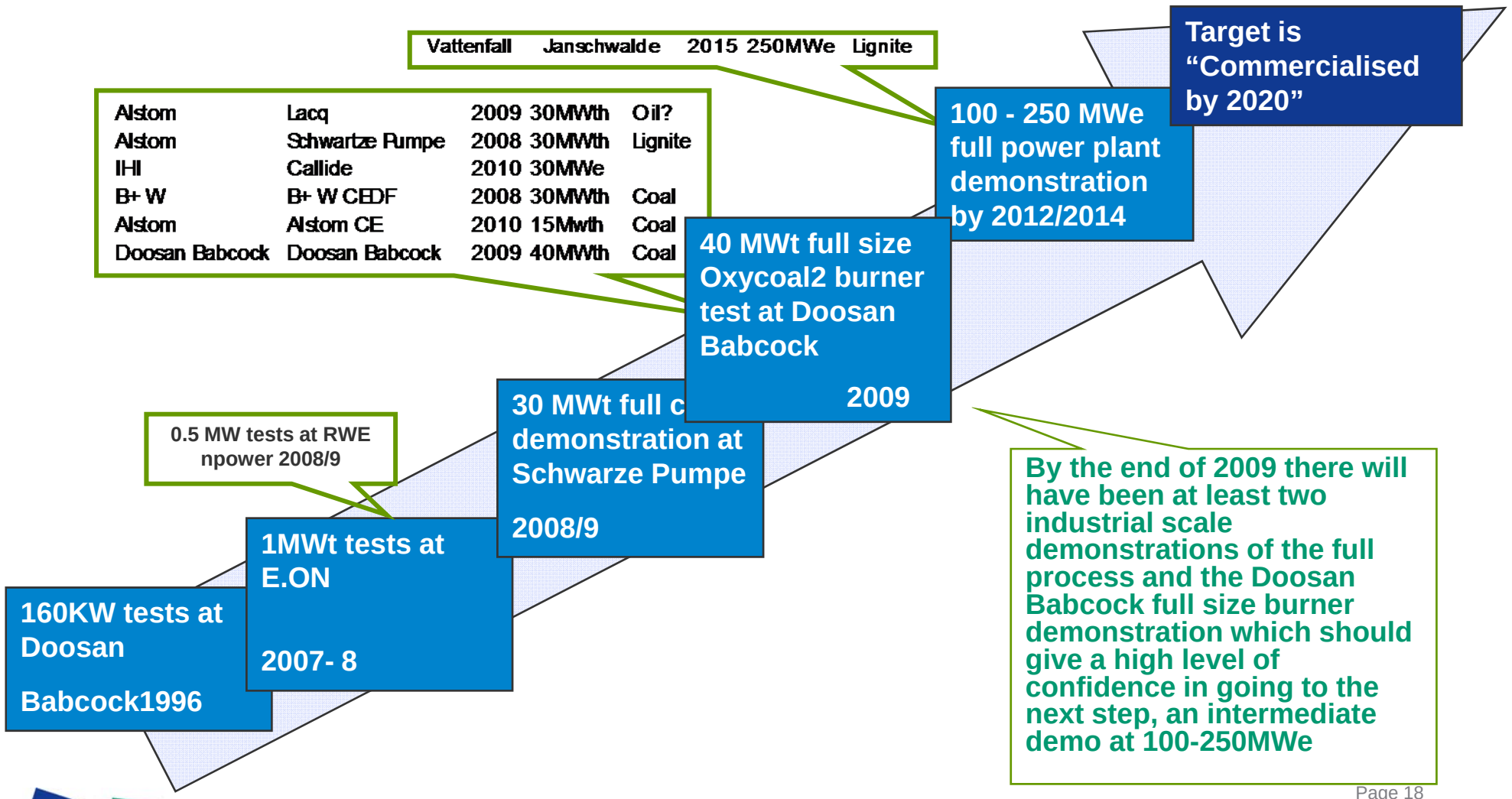
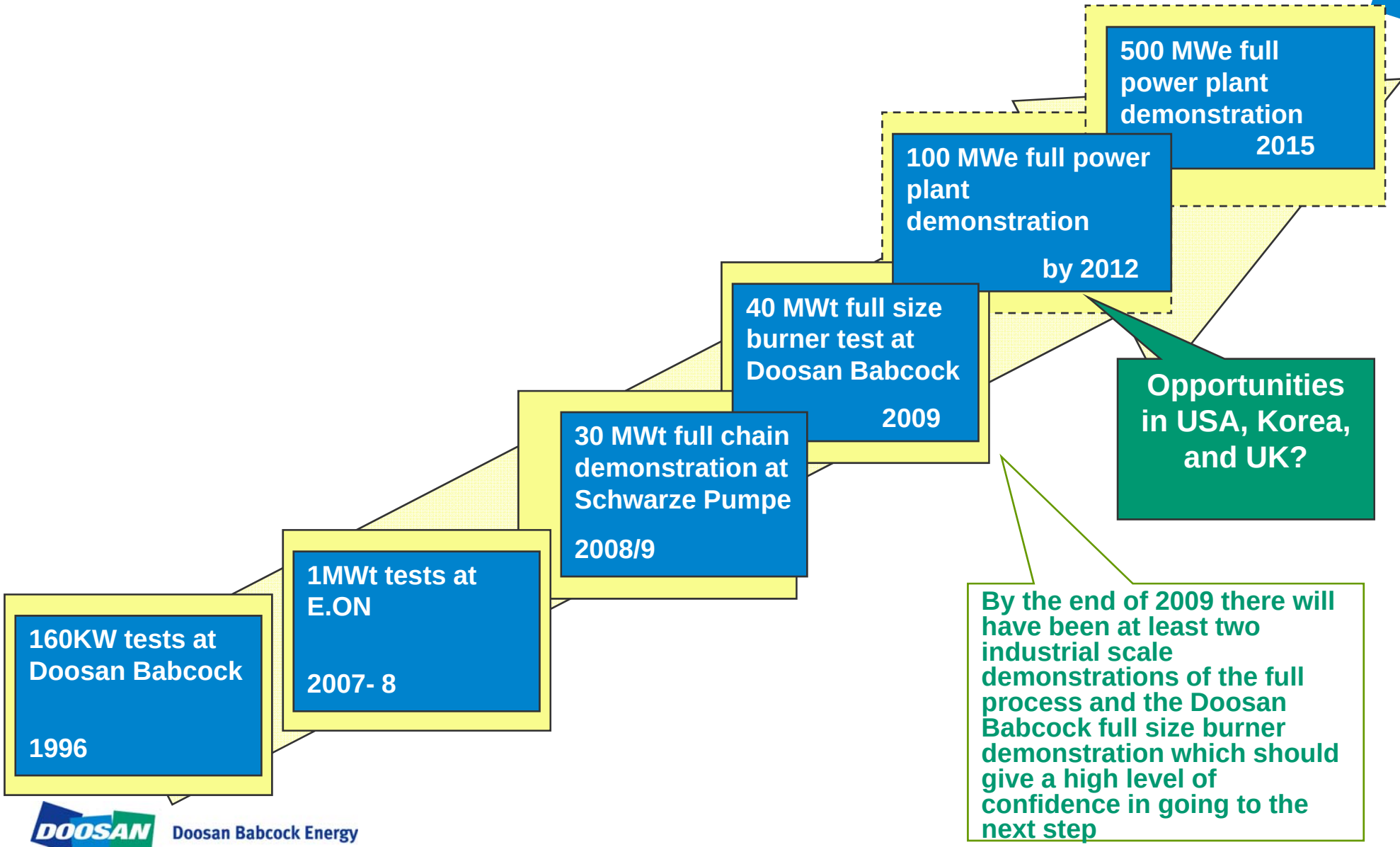
Scale up of Oxyfuel firing for coal power plants



Scale up of Oxyfuel Firing for coal power plants - Doosan Babcock road map



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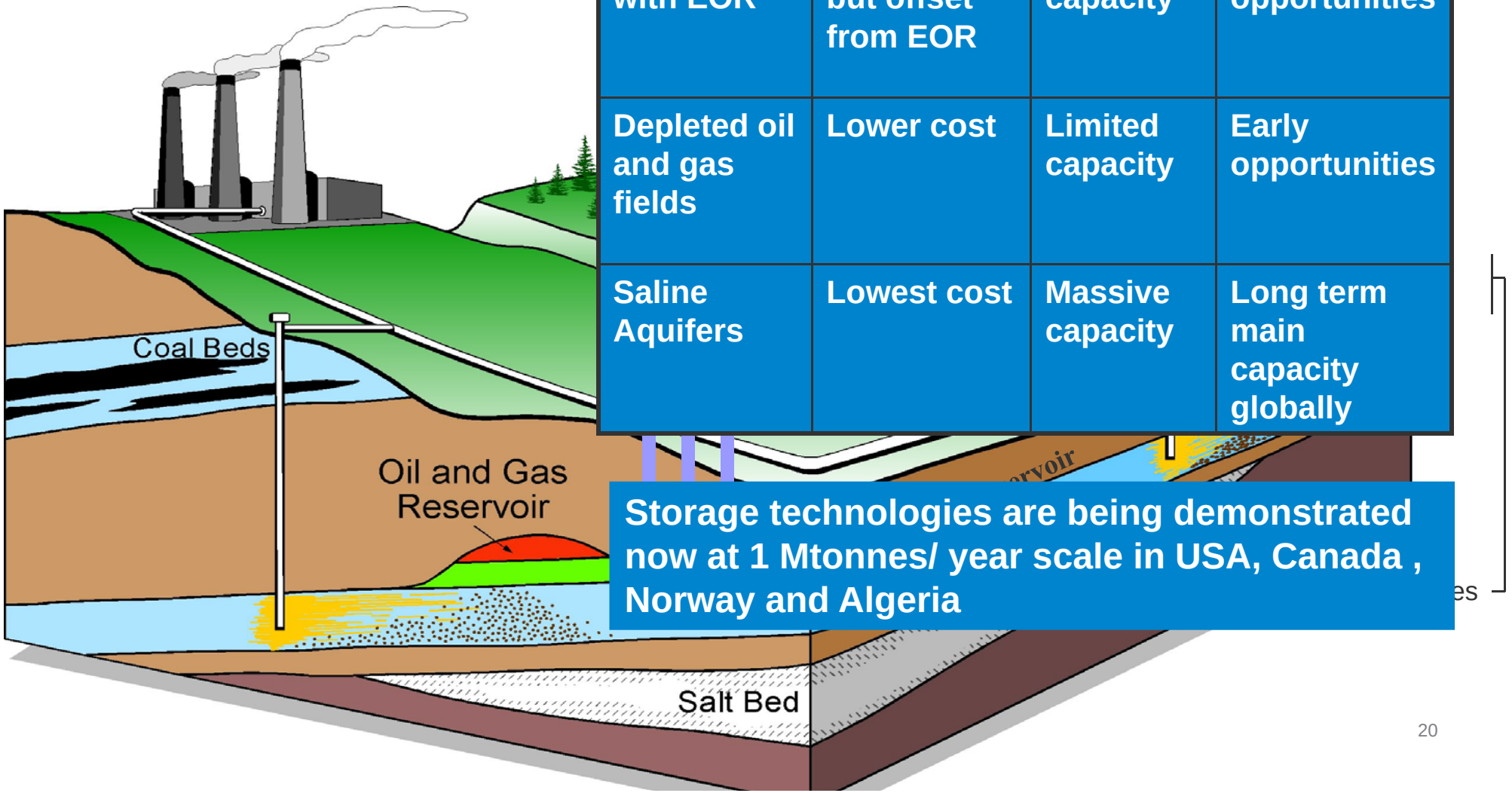
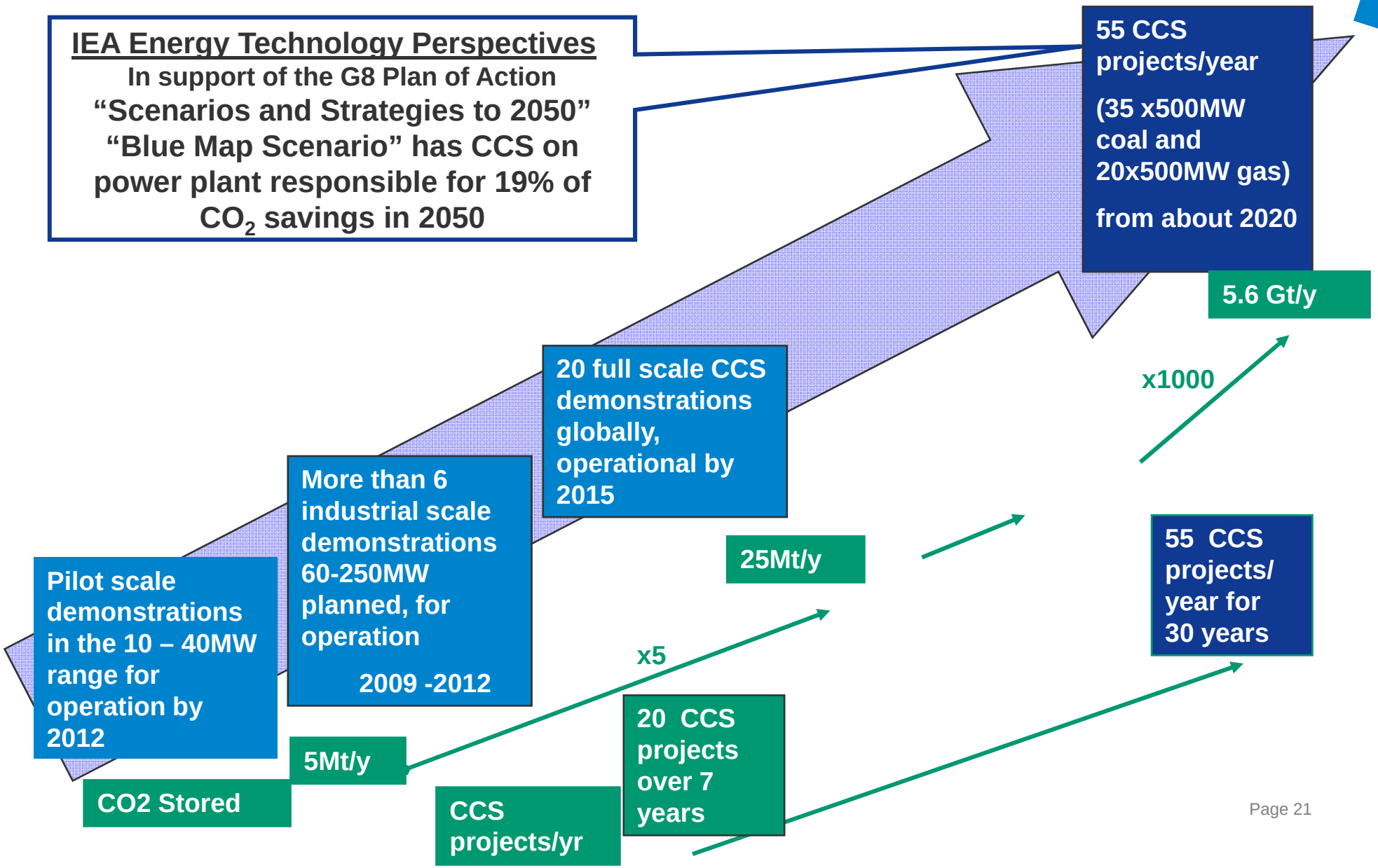
CO_2 storage options

	Cost	Capacity	When
Oil – fields with EOR	Higher cost but offset from EOR	Limited capacity	Earliest opportunities
Depleted oil and gas fields	Lower cost	Limited capacity	Early opportunities
Saline Aquifers	Lowest cost	Massive capacity	Long term main capacity globally



Storage technologies are being demonstrated now at 1 Mtonnes/ year scale in USA, Canada , Norway and Algeria

Scale- up of CCS capacity needed to commercialise CCS by 2020



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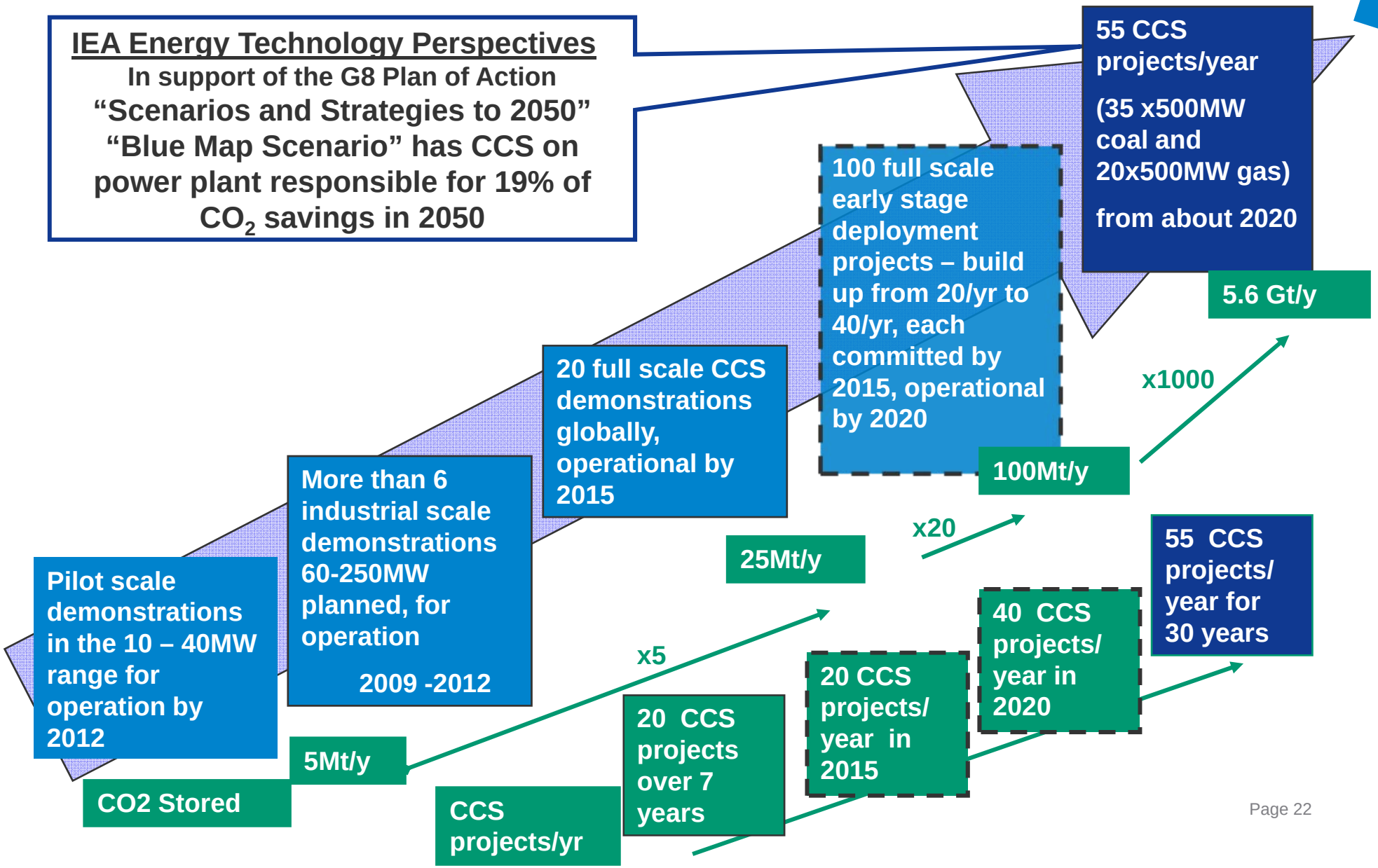


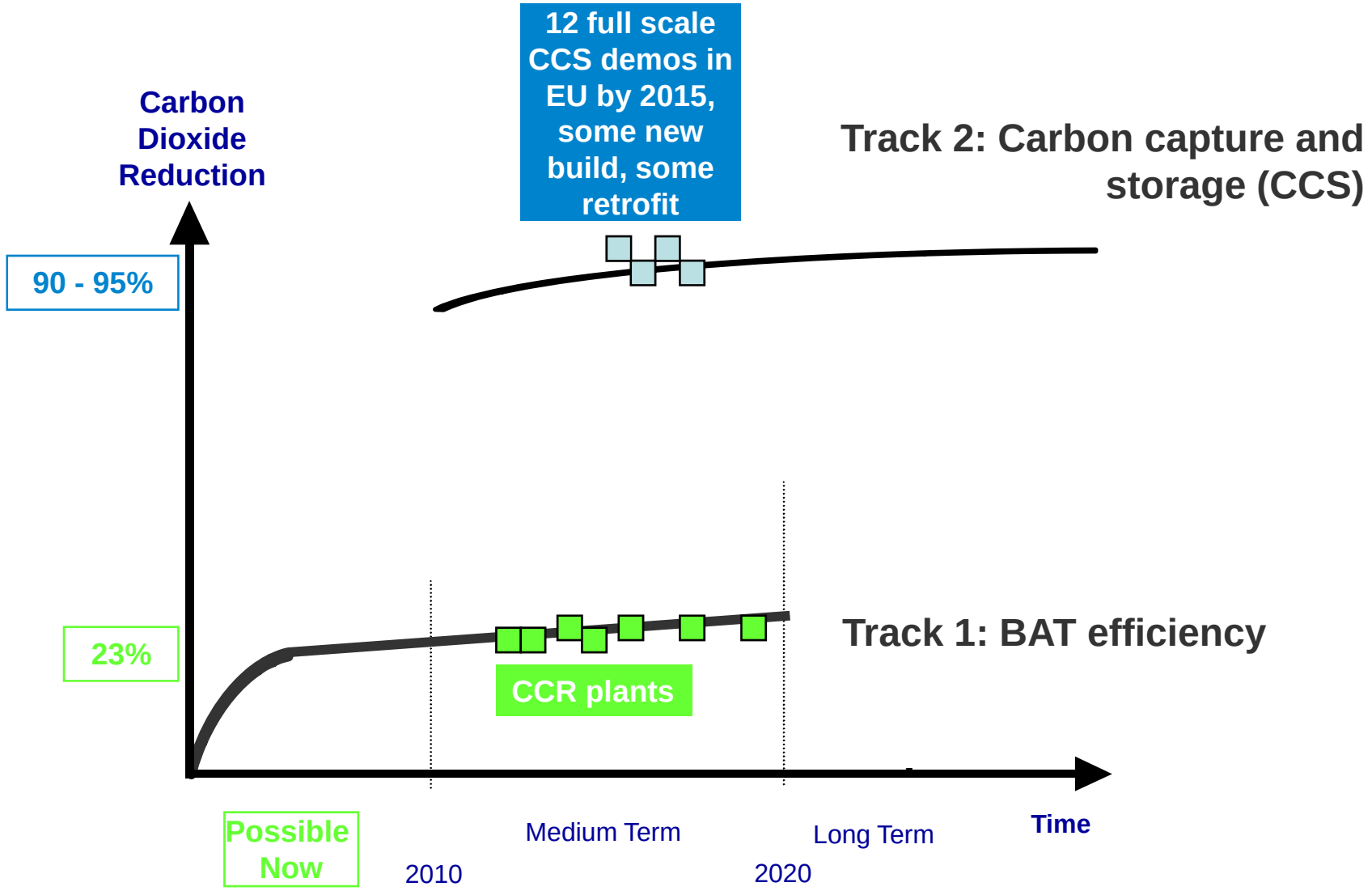
Clean coal and gas power plant - CCS or CCR (Carbon Capture Ready) ?

- **Our objective:**

IEA scenario presented to G8 requires 35 coal (800MW) and 20 gas (500MW) CCS power plants per year

- **Timing and scale of introduction of CCS is restricted by the pace of**
  - **pilot/demonstration projects**
  - **introduction of regulations and**
  - **market conditions/incentives …dependent on the carbon price under the ETS**
- **"Capture ready (CCR)" is therefore very important since new power plants are needed in UK and globally on a scale larger and on a timescale faster than it is feasible to adopt CCS**
- **We conclude that we need *both* CCR and multiple CCS demonstrations**
- **We can set an excellent global example by building power plants capture ready and in parallel accelerating the demonstration of CCS**

CAT Strategy twin – track approach –
Cleaner coal *now* and near - zero emissions power commercialised by 2020



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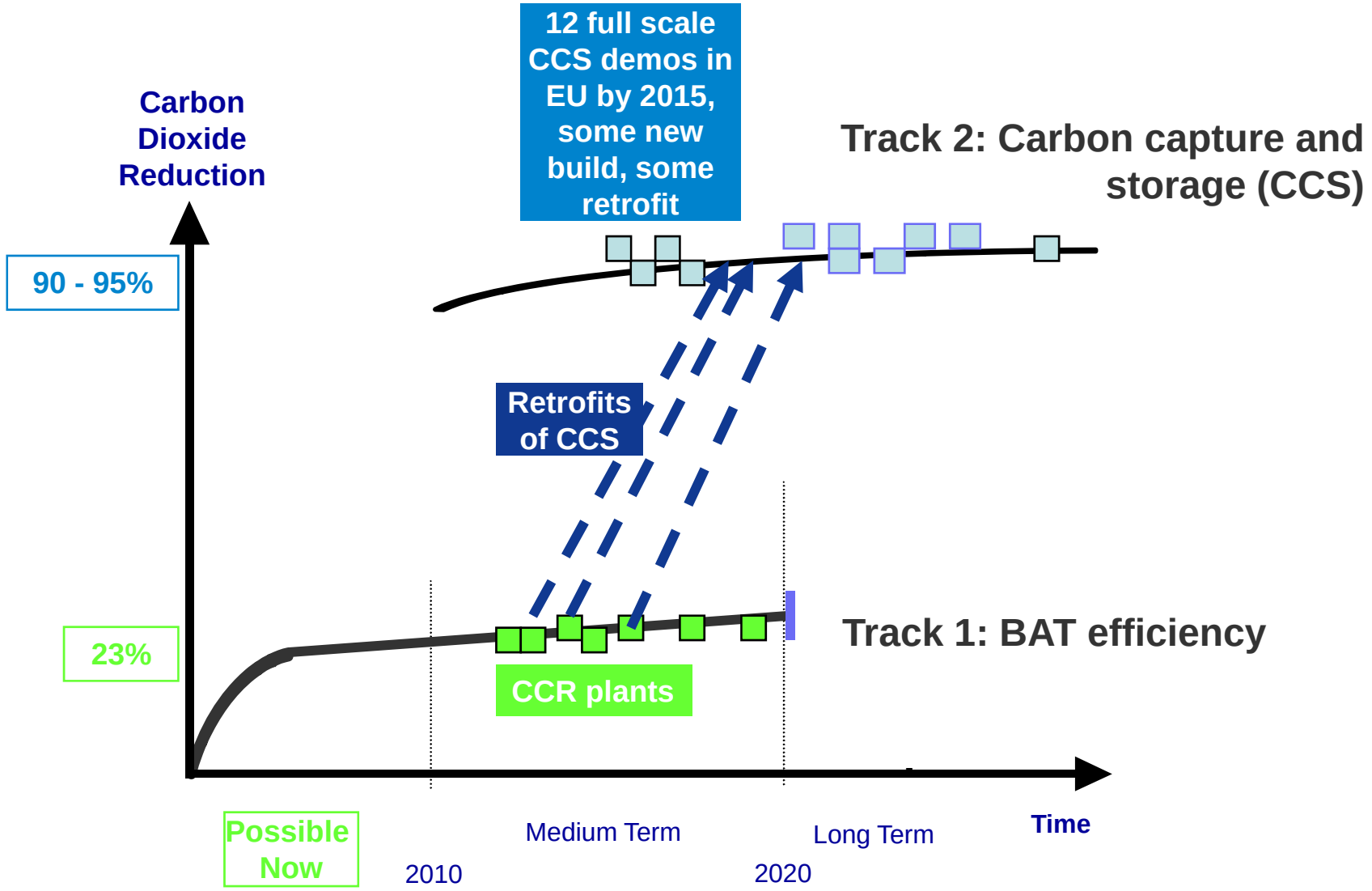

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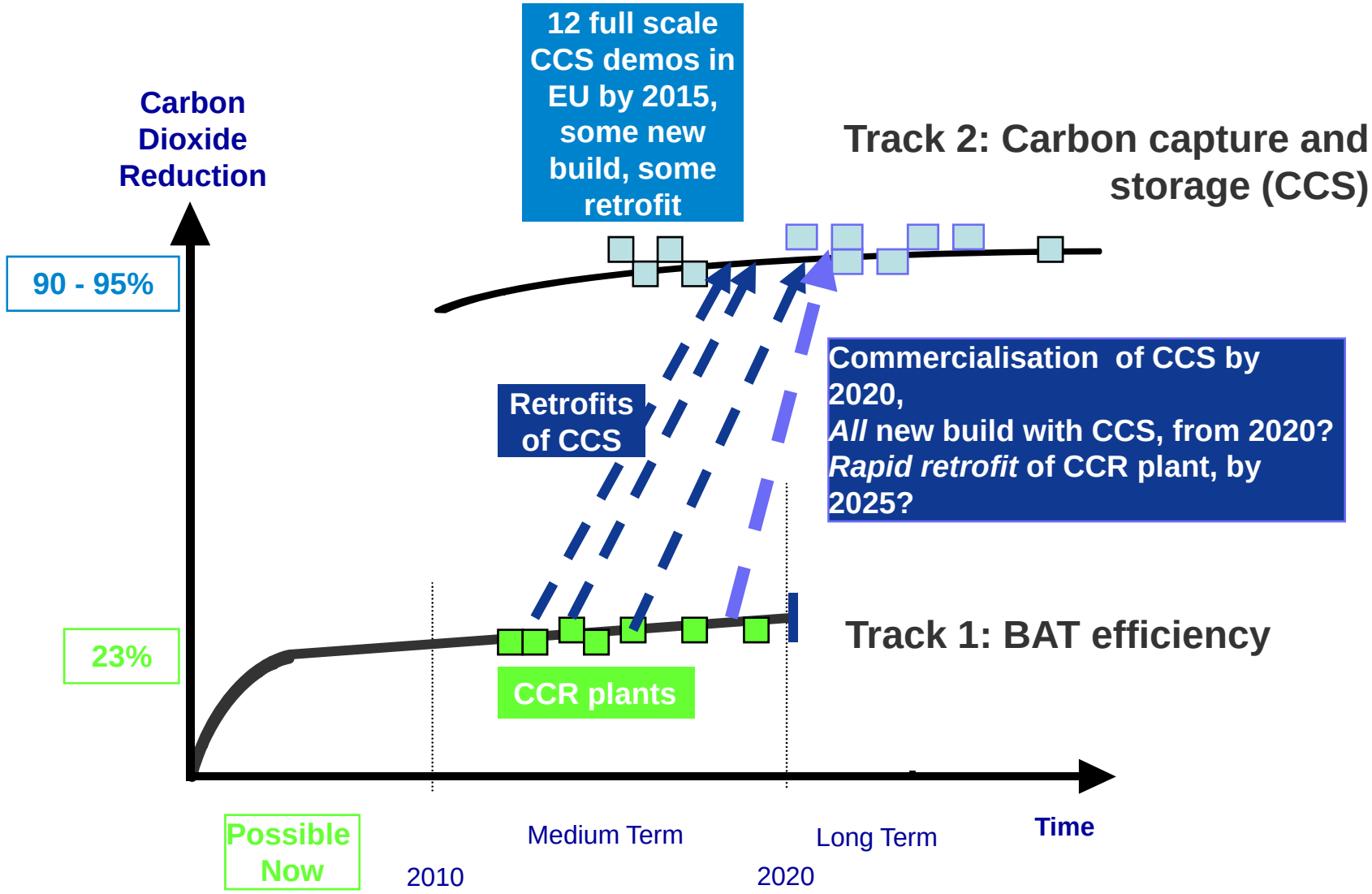
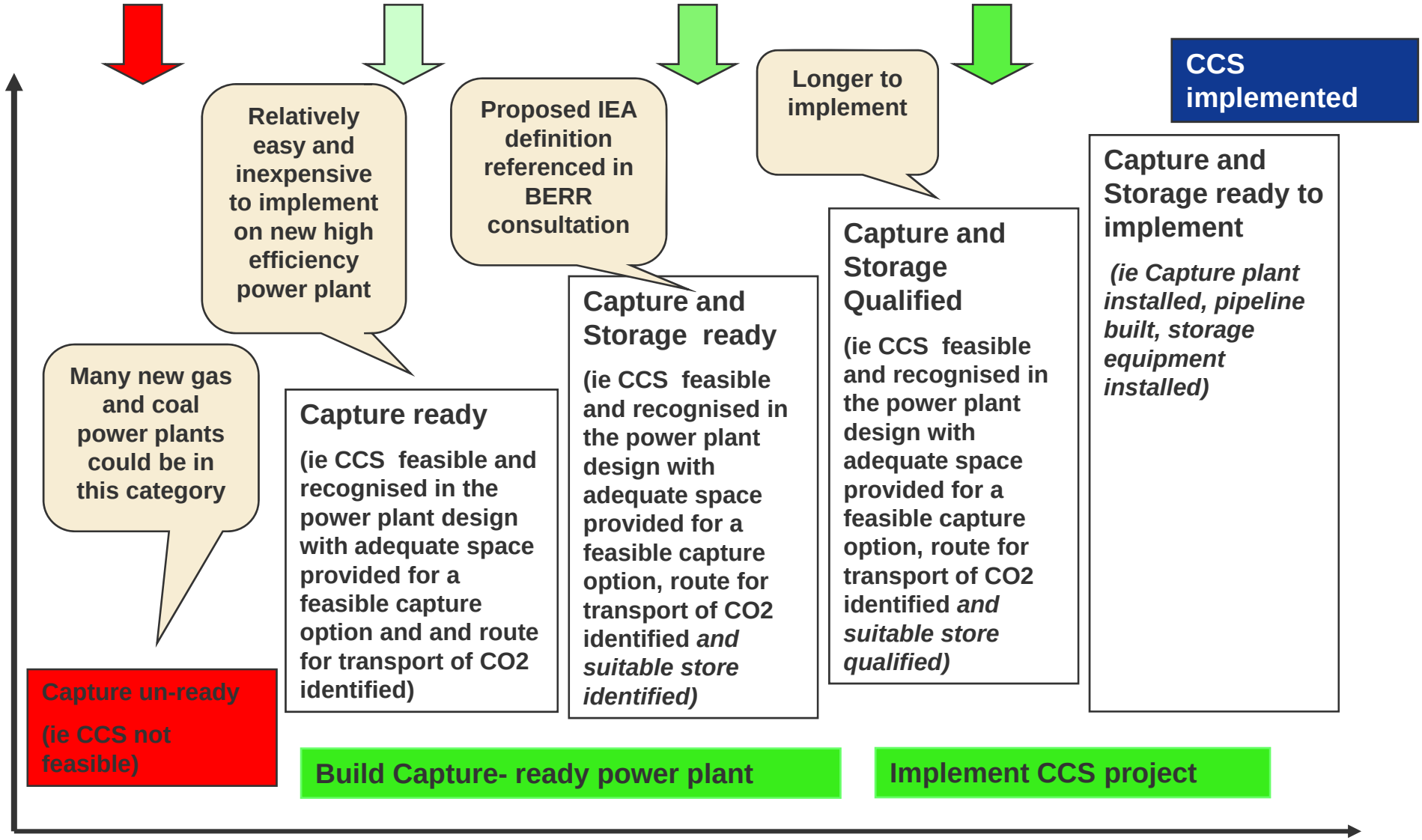


What is CCR? Stages of Capture- Readiness



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What's happening in the CATs R+D in UK industry?

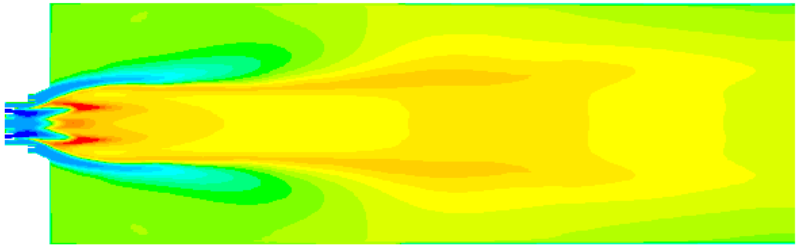
UK companies are participating in EU, UK govt and international R+D projects on High Efficiency Boiler/Steam Turbine , biomass cofiring and CO_2 Capture, Transport and Storage

What's happening in the CATs field in UK industry?

- EU Research projects on Efficiency (COST 536 Materials for Advanced Plant, COMTES 700), Capture (ENCAP, CASTOR, CESAR, ASSOCOGS, ECOSCRUB) and Storage
- DTI Projects (largely complete)
  - Retrofit of Gasifier to CCGT,DTI Project 407- Retrofits of Boiler/Turbines with CO_2 capture, DTI - 366 'Future CO2 Capture Technology Options for the Canadian Market', High pressure coal gasification, DTI Project 410 - Materials and fabrication for 700degC power plant,
- BERR/TSB projects underway:
  - Post-combustion capture (CASSCAP), Oxyfuel combustion (Oxycoal1,Oxycoal2), High efficiency hydrogen gas turbines, Integrated Gasification Steam Cycle (IGSC), CO_2 Aquifer Storage (CASSEM), Improved Modelling of Material Properties for Higher Efficiency Power Plant (TSB - IMMP3), DTI/BERR: Modelling Fireside Corrosion of Heat Exchanger Materials in Advanced Energy Systems
- Devolved Administrations/RDAs
  - Yorkshire Forward CO_2 network study
  - Scottish CCS Study
- International R+D
  - Vattenfall Oxyfuel demonstration
  - E.ON Collaborative Pilot R&D activities(University of Texas, ITC Canada) and Bilateral Development of pilot plants (up to 5MW scale) with Alstom, Siemens
  - Involvement in Futuregen 275MWe Project Development
  - RWE npower is an industrial sponsor of the pilot amine scrubbing research facility of University of Texas at Austin (and is building its own 1MW pilot at Aberthaw)

Oxycoal2 - Demonstration of Oxycoal combustion system for coal fired power plants

- Convert Doosan Babcock's full-scale burner test facility to oxyfuel firing
  - Oxygen supply
  - Flue gas recycle system (fans, ducts, cooler, heater, etc.)
  - Instrumentation
- Design and build full-scale utility Oxycoal burner (40MW)
  - Derived from air-firing experience, CFD modelling and Oxyfuel R+D
- Demonstrate a full-scale utility Oxycoal burner
  - Flame stability, combustion efficiency, emissions, flame shape, and heat transfer characteristics as function of %CO_2 recycle and excess oxygen
  - Start-up, shut down, transition from air to oxyfuel, load change



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Oxycoal 2

The substantial contributions of:

BERR | Department for Business Enterprise & Regulatory Reform

- **the Prime Sponsor**

Scottish and Southern Energy
energy made better

- **Sponsors**

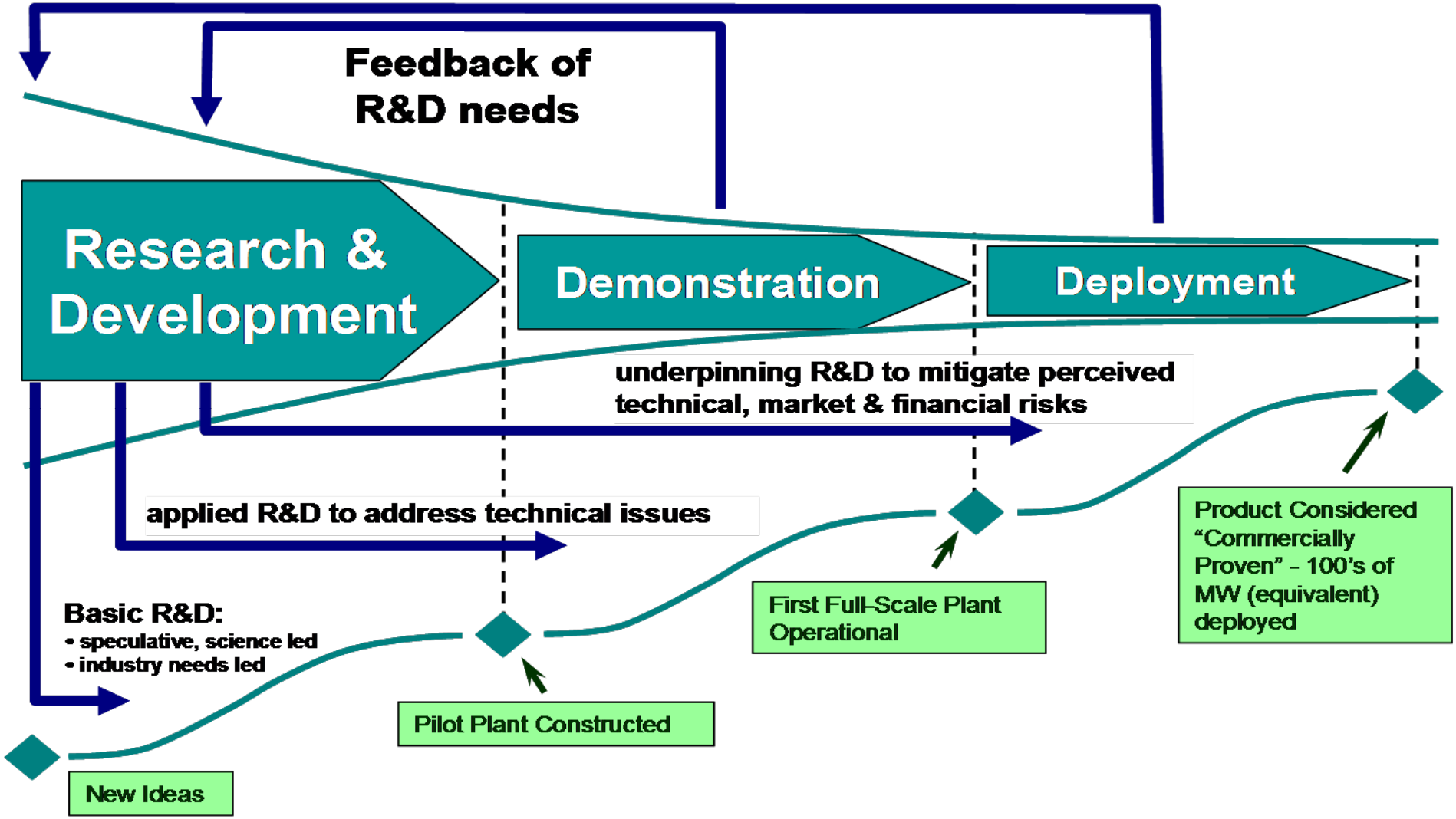
AIR PRODUCTS
DONG energy
Drax Power Limited
EDF ENERGY
e·on | UK
ScottishPower
energy wholesale

- **University participants**

Imperial College London
The University of Nottingham

are acknowledged by Doosan Babcock

Energy Innovation Chain: R+D needs



Structure of Presentation

Ambitions:
What we should be aiming for if UK is to be a leader in Carbon abatement technologies for fossil fuels

Priorities for R+D and Demonstration:

Based on discussions at APGTF

Efficiency improvement for Power Plant with CCS

Ambition:

• a high efficiency coal power plant (efficiency 50 % before CCS and >43 % with CCS), designed for CCS, and integrated with a heat utilisation scheme

• *operating in the UK by 2016*

Priorities for R+D and Demonstration:

- **Materials, fabrication, inspection, monitoring and life assessment technologies for progressive increases in steam temperature and pressure to 350 bar and 750°C**
  - **Particular issues relating to high nickel alloys**
- ***Optimisation of cycles recognising***
  - ***Carbon capture***
  - ***Large scale CHP, utilisation of waste heat***
  - ***Double reheat (towards 50% efficiency without nickel alloys)***

Biomass cofiring with CCS

Ambitions:

- **a biomass cofired 600deg coal power plant (efficiency >45 %), designed for CCS, integrated with a heat utilisation scheme, with 20% cofiring of a wide range of biomass fuels**

- **operating in the UK by 2016**

Priorities for R+D and Demonstration:

- **Advanced cofiring or co-gasification (up to 20% or more by heat input), including corrosion, slagging and fouling issues**
- **Efficient preparation and processing of sustainable biomass energy crops (e.g. pelletisation, torrefaction)**
- **Better understanding of availability of sustainable biomass resources for cofiring**
- **Impact of biomass cofiring on precombustion, post combustion and oxyfuel carbon capture processes**

Carbon Dioxide Capture Technologies – Post combustion capture

Ambitions:

- a 600deg coal power plant (efficiency >45 % before CCS and >36 % with CCS), initially capture ready by 2013, then with 400MW Post combustion capture, operating in the UK by 2014
- a 400MW CCGT with CCS operating in the UK by 2015
- *several smaller scale pilots/demonstrations of competing scrubbing technologies eg up to 100MW slip stream*
- capacity of industry built up to match market needs

BERR competition

Priorities for R+D and Demonstration:

- *Process optimisation/ heat integration (including utilisation of waste heat)*
- *New and less energy intensive solvents (e.g. amines, carbonates, ammonia)*
- *Avoidance of solvent degradation*

and for the longer term

- Improved capture technologies

Carbon Dioxide Capture Technologies – Pre- combustion capture

Ambitions: UK demonstration and UK OEM capability

Priorities for R+D and Demonstration:

- Gasification : process integration/optimisation, improved availability, biomass cogasification
- Gas cleaning : improved reliability
- Gas conditioning :
  - CO_2 capture : integration and optimisation of shift conversion and CO_2 capture processes
  - conditioning of H_2 fuel gas stream for GT
- Gas turbine : Premix burners for hydrogen requiring
- Air separation unit : Process optimisation, improved absorbents for contaminant removal, high efficiency packing for distilling fluids close to supercritical conditions

Carbon Dioxide Capture Technologies - Oxyfuel combustion

Ambitions:

- ***a 100 -200 MWe Demonstration of an Oxyfuel power plant on hard coals by 2012***

- **a 500 MW Demonstration CCS project by 2017**

Priorities for R+D and Demonstration:

- **Process optimisation, including start-up/shut-down/flexibility**
- **Combustion chemistry and kinetics, Heat transfer prediction**
- **Materials for oxyfuel environment, corrosion issues, ash properties**
- **FGD performance, *Flue gas cleaning to meet CO_2 specifications***
- **ASUs (including membranes)**
- ***40MW demo of new burners, more coal types***
- ***a 100 -200 MWe Demonstration of Oxyfuel power plant on hard coals***

Carbon Dioxide Transport

Ambitions:

• early stages of a transport network linked to one or more storage sites and several capture sites by 2015/7

Priorities for R+D and Demonstration:

- Crack formation and growth, major high pressure leaks
- Corrosion behaviour of pipelines as a function of material, temperature, etc and content of CO2 stream
- Alternative materials, joining technologies, sealing technologies

Carbon Dioxide Storage

Ambitions:

• multiple storage demonstrations in UK by 2015, including EOR, depleted gas and oil fields and saline aquifers

Priorities for R+D and Demonstration:

- **Site appraisal: methods to assess aquifer injectivity, aquifer seal performance**
- **Saline aquifers: improve estimation of storage ability e.g. atlas of seal and injectivity properties**
- **Site stability: subsurface remote sensing of geomechanical stability during re-pressurisation**
- **CO_2 mobility:**
  - **improved validated software for reservoir and region**
  - **develop measuring, hi-resolution monitoring, modelling and verification techniques**
- **Site performance: reduce impact of sub-surface uncertainty on performance prediction and risk**
- **CO_2 physical properties: experimental data at different groundwater salinities**
- **Geochemical impact:**
  - **major reactions of minor contaminants in CO_2 stream**
  - **validated database of equilibrium and kinetic data for modelling**
- **ECBM /UCG - capacity of coal as function of depth and permeability**

Comments

- Support by DTI, BERR, TSB , and the Research Councils has laid a good foundation and we have now the opportunity to build on this
- Need to be open to capabilities and opportunities available overseas and leverage these
- Need to join up environmental, energy and enterprise and research objectives – consistent with global roll out of the technologies
- Need targeted research as headlined above but also require underpinning R+D in cross cutting areas such as coal science, modelling, environmental impact etc
- R+D in Universities also has an important role in creating the skilled people which industry needs for the future and specialist laboratory facilities – EPSRC Doctorate Training initiatives welcome
- EPSRC/EON Strategic Partnership - Call for University proposals, very timely (deadline 6 Nov) and appropriately targeted
  - APGTF volunteering to organise subject groups of parties interested in the seven topics to work with Research Councils, TSB, ETF, and ETI
- ETI (autumn), TSB (next year) and BERR ETF(?) expected to call for proposals in this topic area – all will encourage involvement of the Research community in what will be industry- led projects

Doosan Babcock are committed to development and global implementation of cleaner power plants - clean coal, clean gas, nuclear and renewables as rapidly as the market allows

Thank you for your attention

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