FUTURE COAL DEMAND: ROADMAP FOR COAL-FIRED POWER PLANT EFFICIENCY AND INTERACTION WITH CCS

John Topper, Director IEA Clean Coal Centre

15 March 2012, Washington DC

IEA CCC MEMBERS

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Contents

- Coal Aspects from IEA World Energy Outlook;
  - Projections to 2035
  - Impact in climate terms of China and India

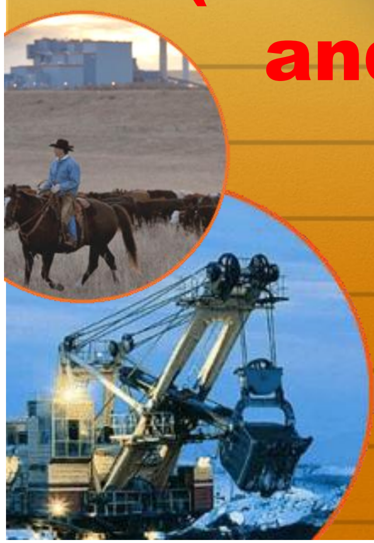
- High Efficiency Low Emissions (HELE) Coal Road Map

- CCS Projects

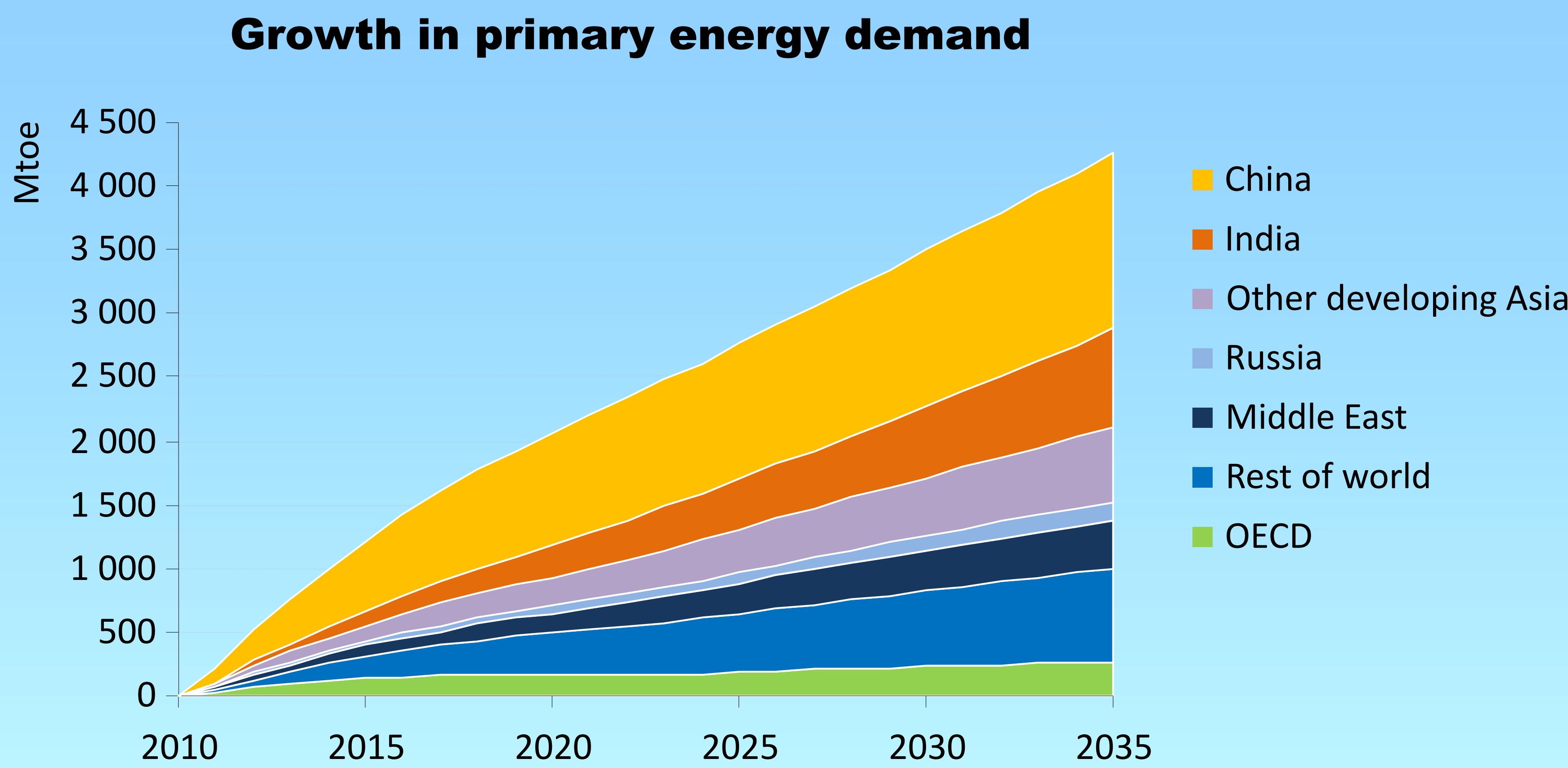
World Energy Outlook

Published by IEA November 2011

(Views expressed are the authors and not necessarily the IEA's)

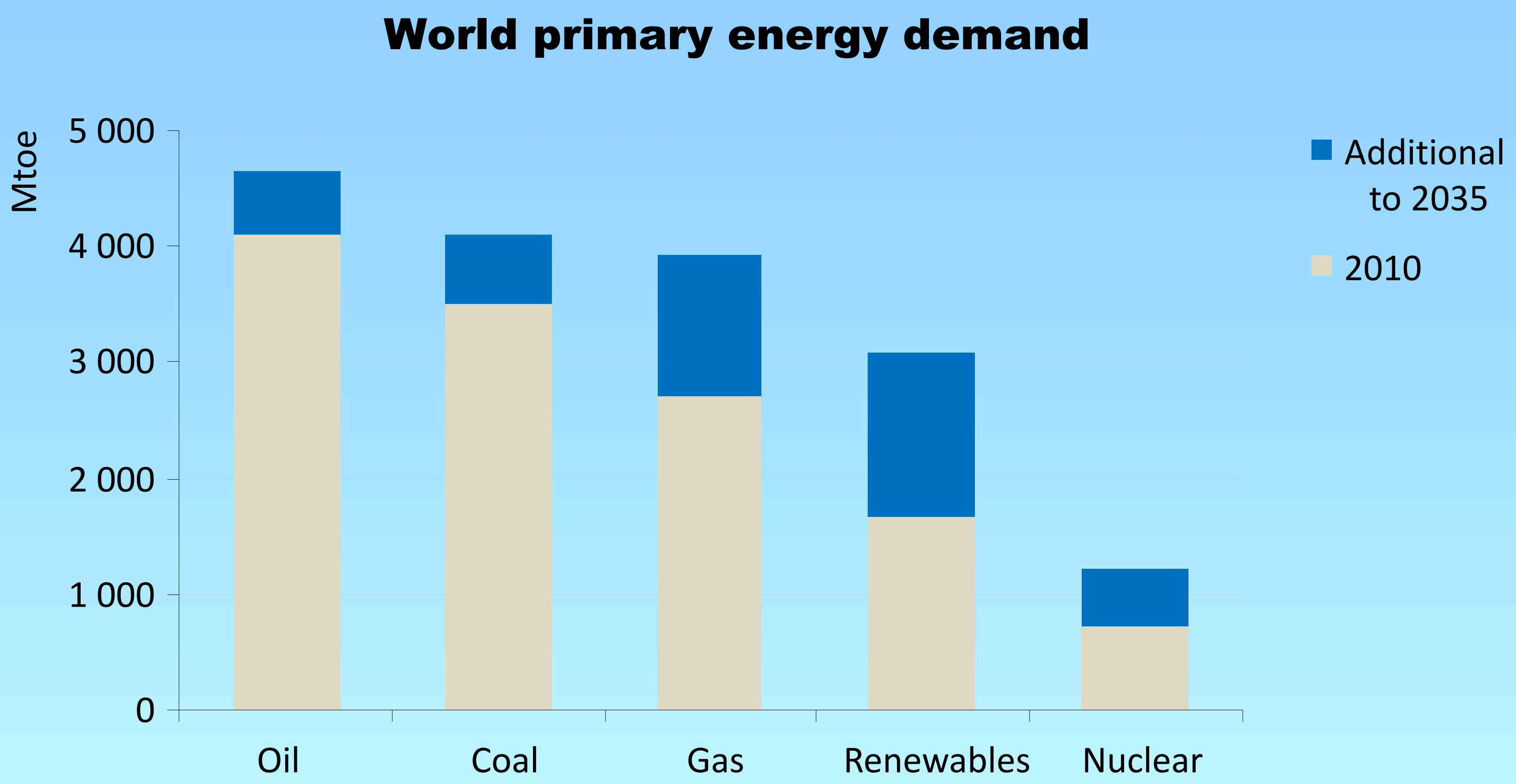


IEA WEO 2011: Emerging economies continue to drive global energy demand



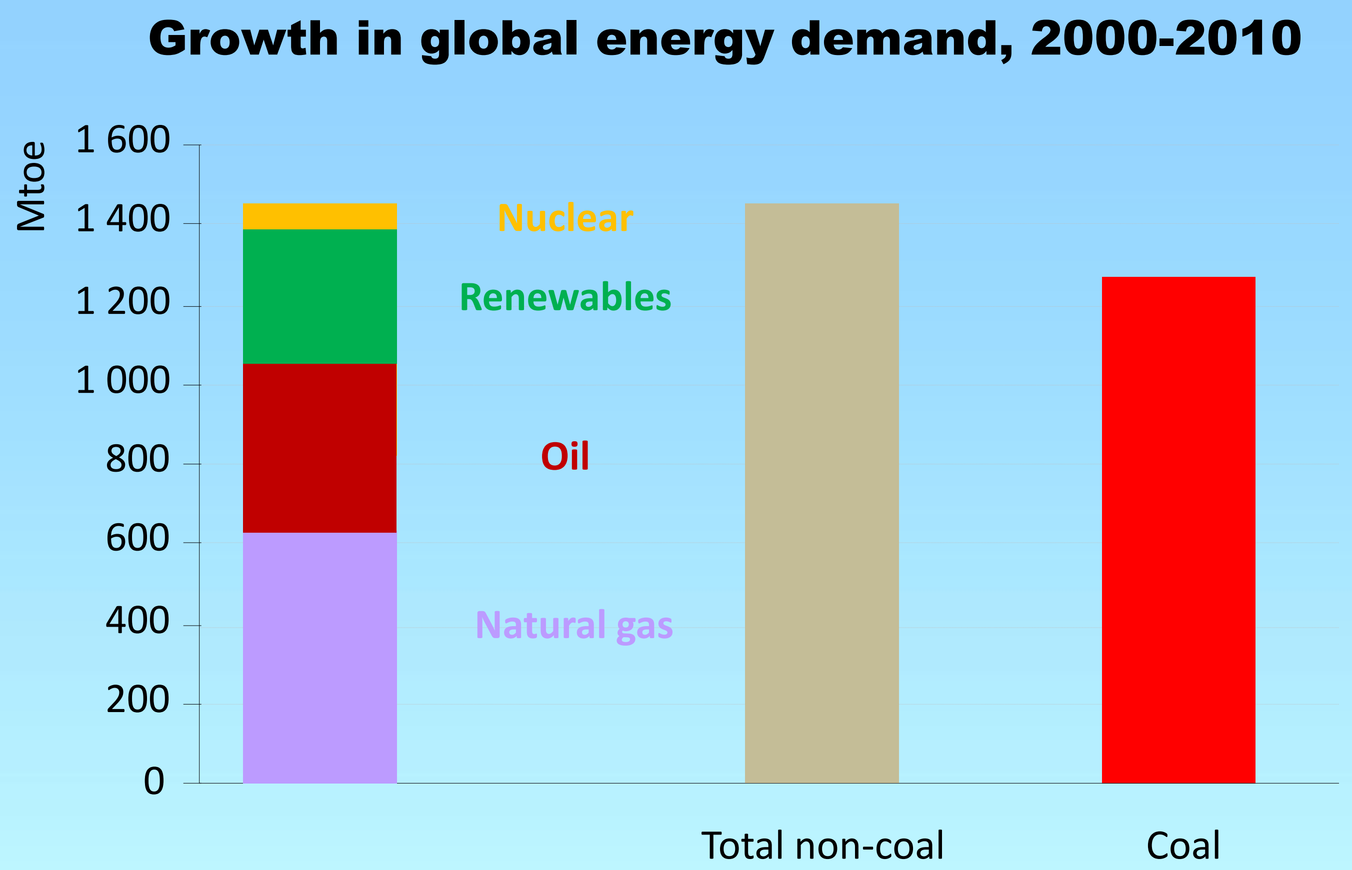
Global energy demand increases by one-third from 2010 to 2035, with China & India accounting for 50% of the growth

IEA WEO 2011: Natural gas & renewables become increasingly important



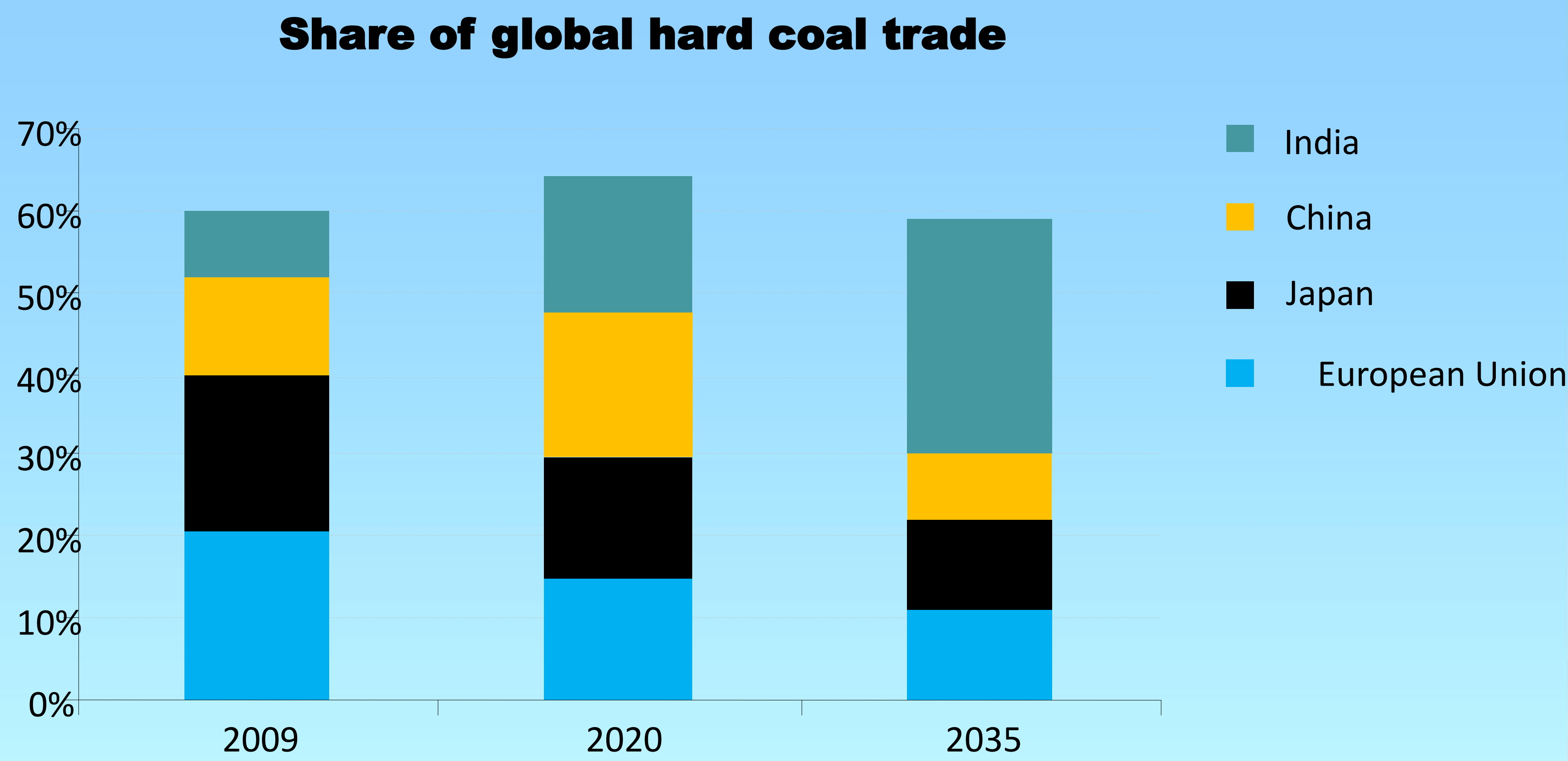
Renewables & natural gas collectively meet almost two-thirds of incremental energy demand in 2010-2035

IEA WEO 2011: Coal won the energy race in the first decade of the 21st century



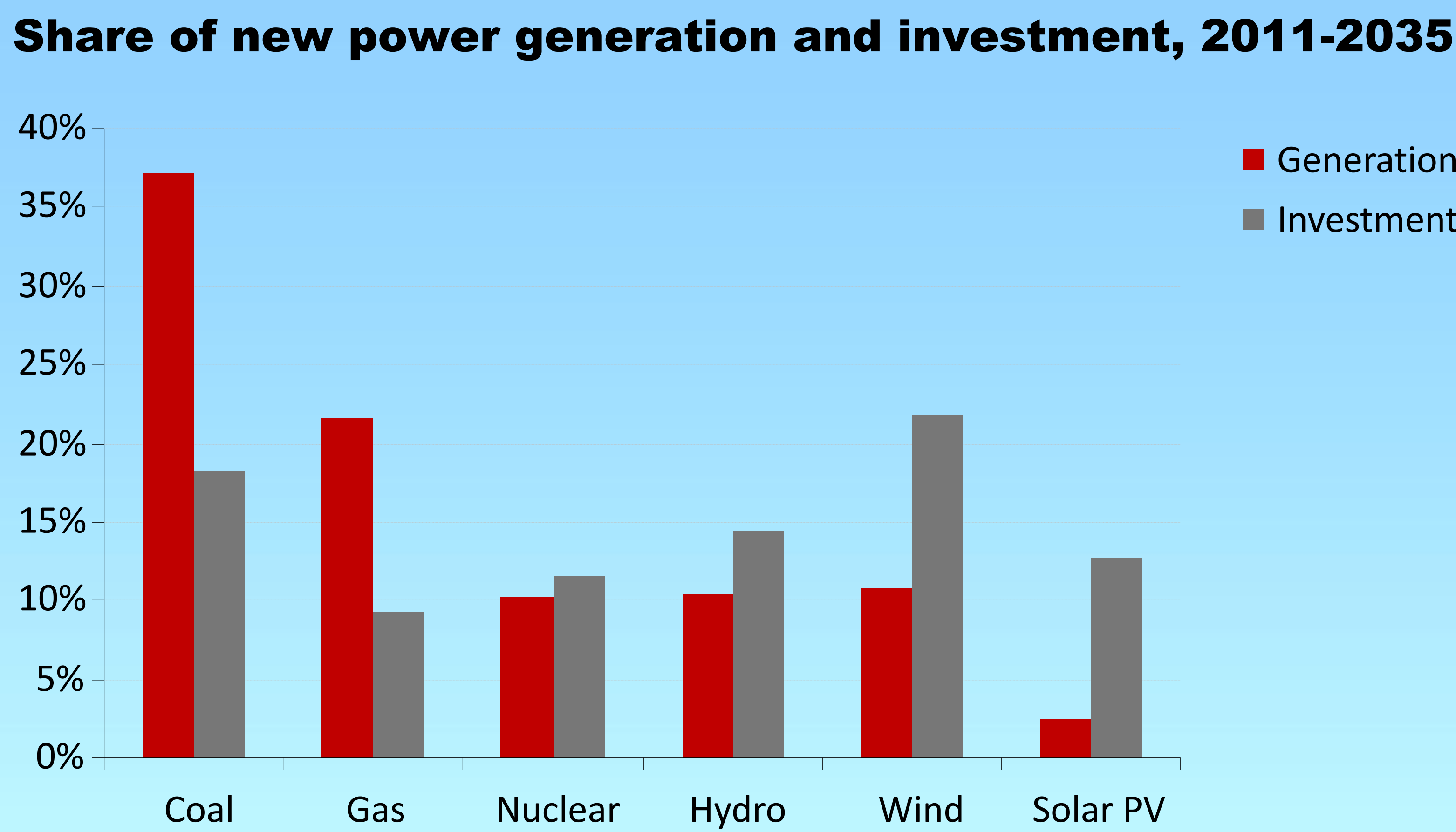
Coal accounted for almost half the increase in energy use over the past decade, with the bulk of growth coming from the power sector in emerging economies

IEA WEO 2011: Asia, the arena of future coal trade



International coal markets & prices become increasingly sensitive to developments in Asia; India surpasses China as the biggest coal importer soon after 2020

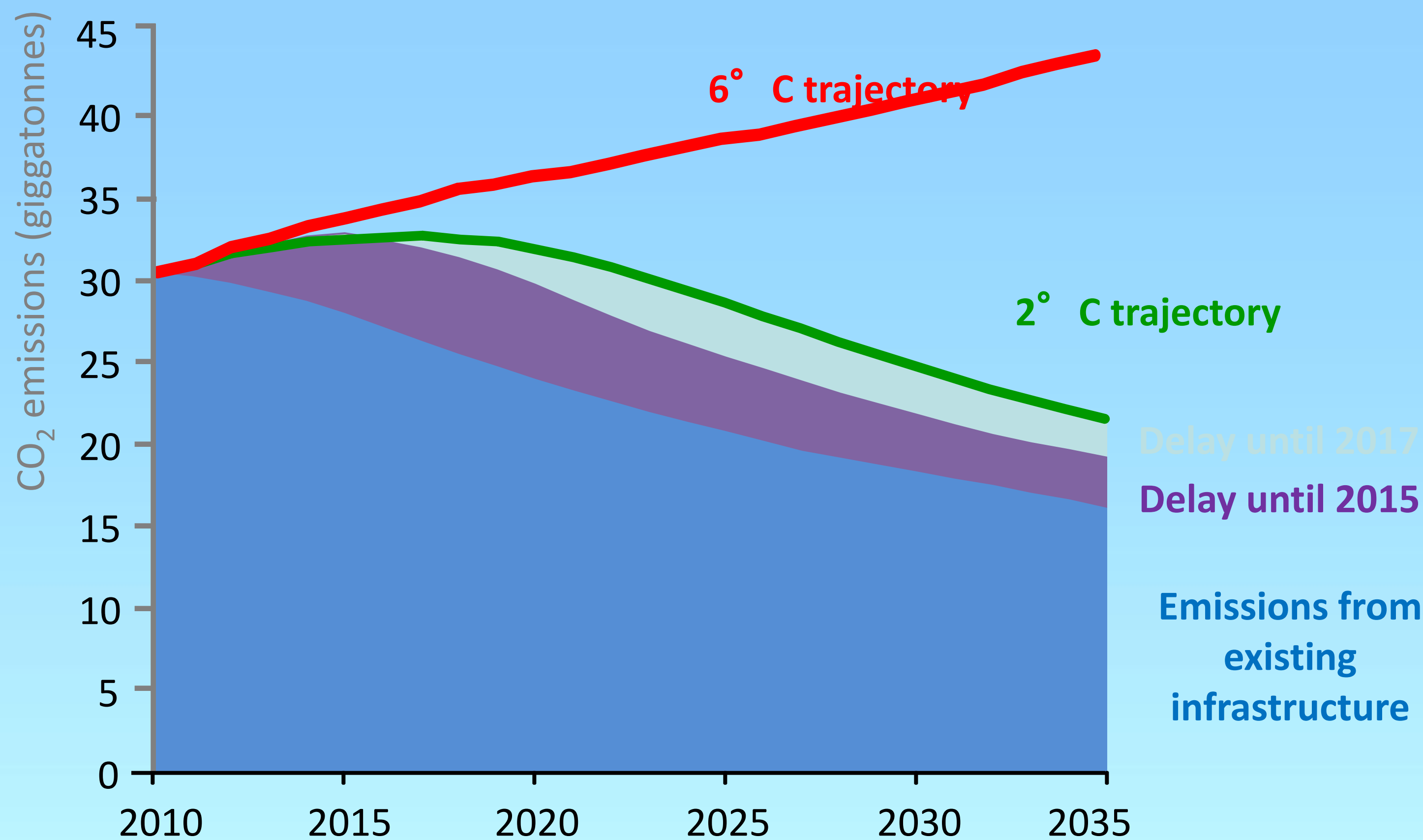
IEA WEO 2011: Power investment focuses on low-carbon technologies



Renewables are capital-intensive, representing 60% of investment for 30% of additional generation, but bring environmental benefits with minimal fuel costs

The door to 2° C is closing, but will we be "locked-in" ?

WORLD ENERGY OUTLOOK 2011



Without further action, <u>by 2017</u> all CO_2 emissions permitted in the 450 Scenario will be "locked-in" by existing power plants, factories, buildings, etc

IEA Coal Road Map

(Work in Progress)

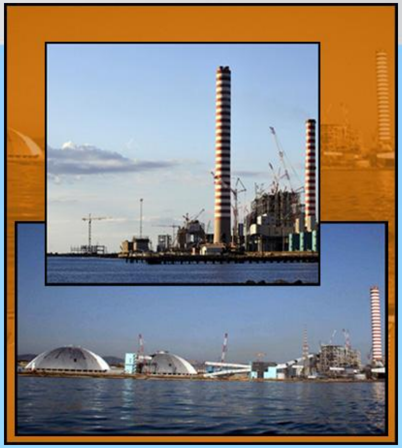
To Be Published by IEA

c. Summer 2012

Rationale

- **Coal fired power plant build in China and India making the IEAs 450ppm scenario (2C temp rise by 2050) almost unattainable**
- **And whilst efficient there are no plans to incorporate CCS in the near or medium term – especially true in India**
- **SE Asia following an even less climate friendly path: many smaller units constructed for sub-critical operating conditions**
- **So best practice in terms of efficiency becomes relatively more important.**
- **Clean air is also a driving force for improved design in many highly polluted urban locations**
- **Hence need for High Efficiency, Low Emissions (HELE) Road map for coal fired power plant**

Torrevaldaliga Nord



USC, boilers supplied by Babcock Hitachi , using bituminous coal

3 units at 660MWe = 1980MWe station

Very low conventional emissions (NOx <100 mg/m^3, sulphur oxides <100 mg/m^3, particulates 15 mg/m^3, at 6% O_2, dry); full waste utilisation

Highest steam conditions: 604°C/612°C at turbine: 25 MPa

Operating net efficiency >44.7% LHV

Wet scrubber based limestone/gypsum FGD

NOx abatement SCR

Particulates removal Bag filters

New sea port for coal delivery

Solids handling all enclosed

Niederaussem K, Germany

USC, tower boiler, tangential wall firing, lignite of 50-60% moisture, inland

- Most efficient lignite-fired plant
- Operating net efficiency 43.2% LHV/37% HHV
- High steam conditions 27.5 MPa/580°C/600°C at turbine; initial difficulties solved using 27% Cr materials in critical areas
- Unique heat recovery arrangements with heat extraction to low temperatures – complex feedwater circuit
- Low backpressure: 200 m cooling tower, 14.7°C condenser inlet
- Lignite drying demonstration plant being installed to process 25% of fuel feed to enable even higher efficiency

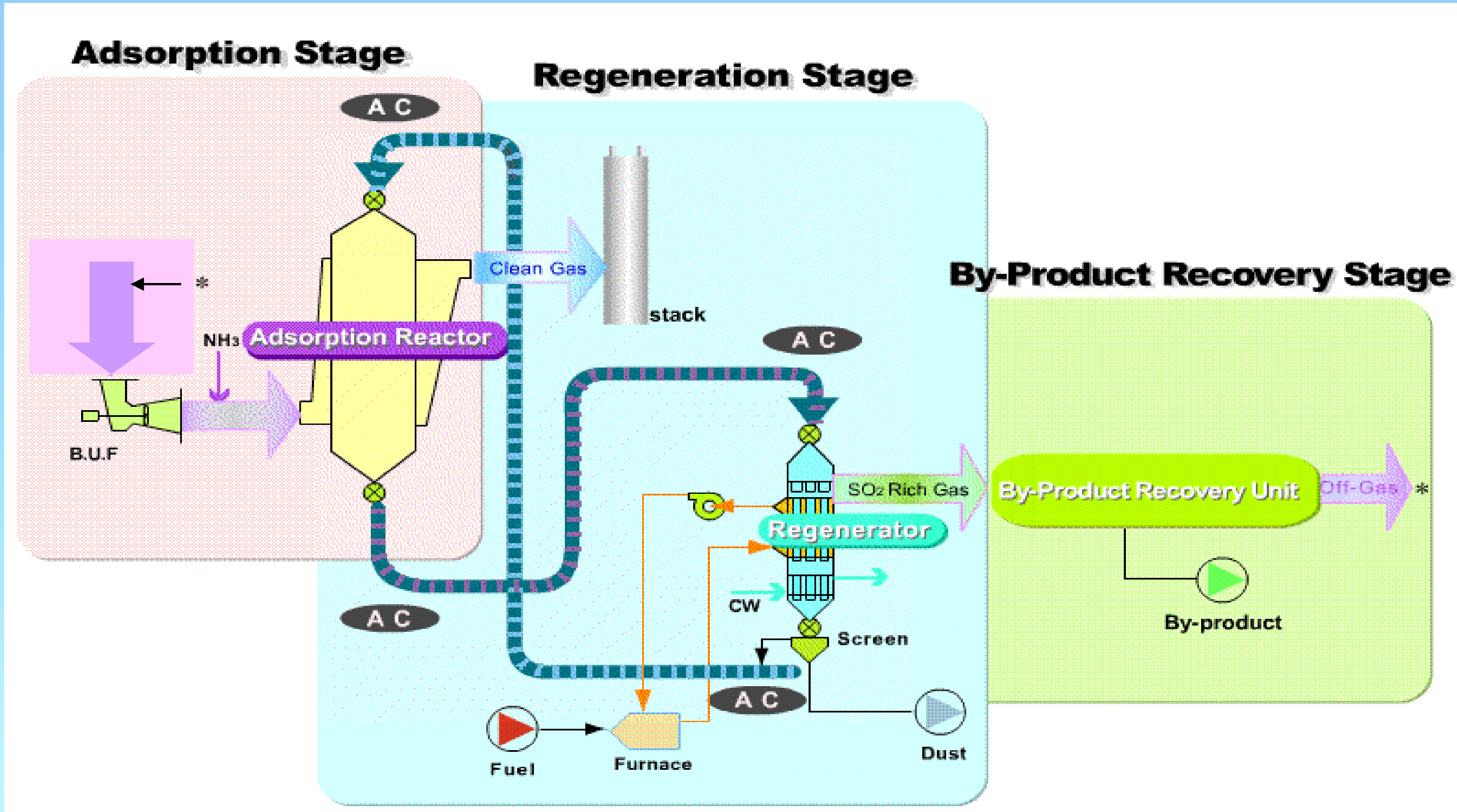
NOx abatement	Combustion measures
Particulates removal	ESP
Desulphurisation	Wet FGD

Isogo New Units 1 & 2, Japan – highlights

USC, tower boiler, opposed wall firing, international bituminous coal and Japanese coals, warm sea water

- Near zero conventional emissions (NOx 20 mg/m^3, sulphur oxides 6 mg/m^3, particulates 1 mg/m^3, at 6% O_2, dry); full waste utilisation
- Highest steam conditions: 25.0 MPa/600°C/610°C at turbine: ASME CC 2328 steels in S/H; P122 for main steam pipework
- Operating net efficiency >42% LHV/40.6% HHV
- Efficiency tempered slightly by 21°C CW, fewer FW heating stages
- Dry regenerable activated coke FGD (ReACT)
- NOx abatement: Combustion measures and SCR
- Particulates removal: ESP
- Isogo New Unit 2 uses ReACT specifically for multi-pollutant control, including mercury

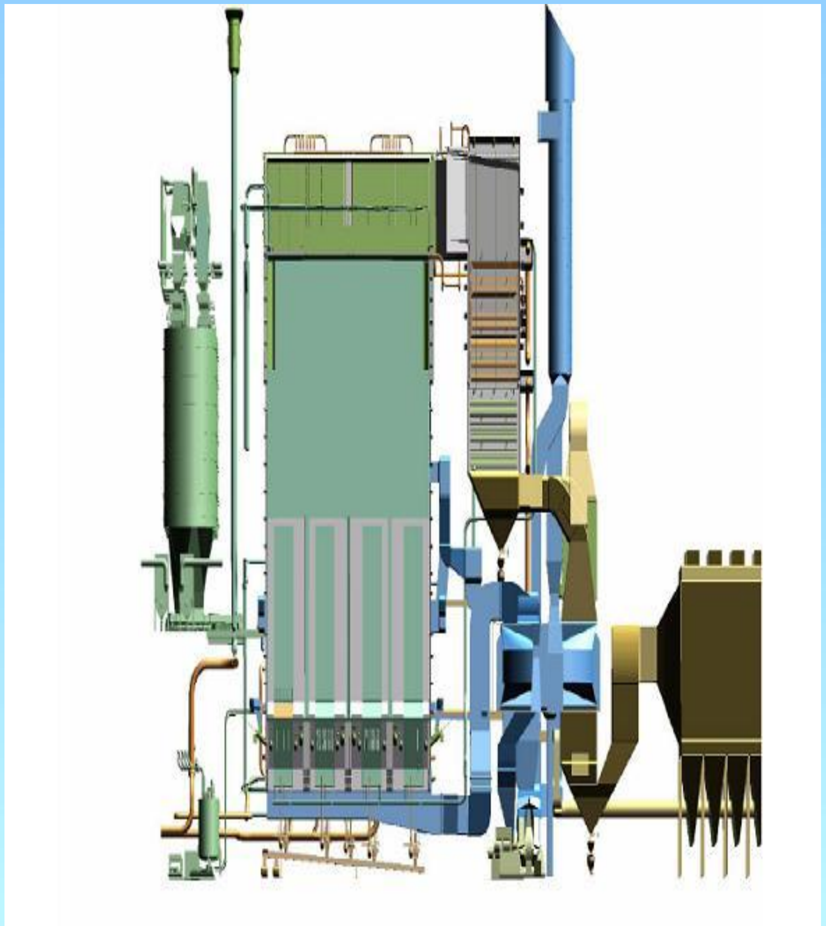
ReACT process flow, *courtesy JPower*



Huaneng Yuhuan 4x 1000MWe USC coal fired power plant

Lagisza Supercritical CFBC

- The world's first CFBC unit with supercritical steam conditions
- Largest CFBC; 460 MWe
- First electricity in February 2009
- Emissions of SOx, NOx and particulates lower than required by latest EU LCPD limits.
- Located to NE of Katowice, Poland



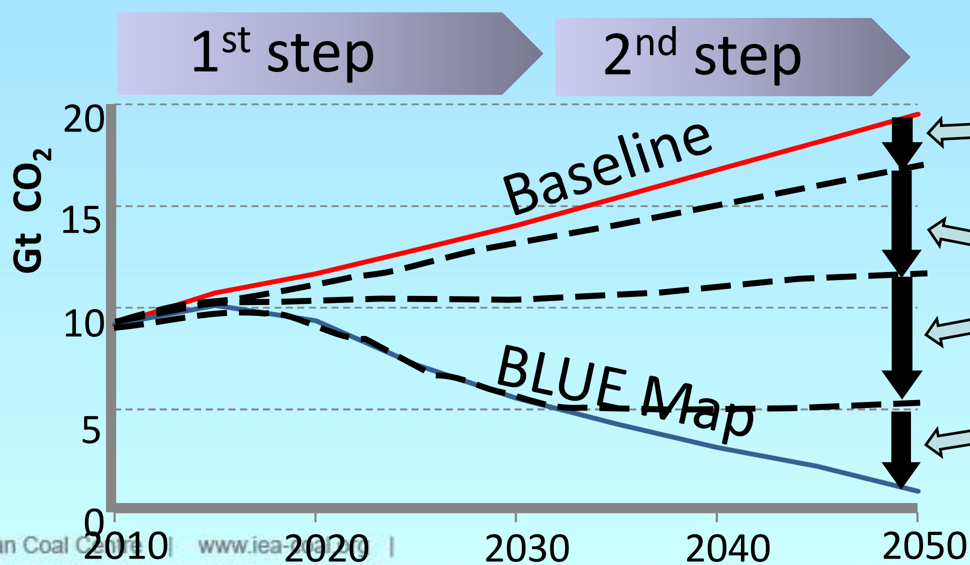
High Efficiency, Low Emissions Coal Technology Roadmap

Content

- Milestones for the development of coal technologies for power generation to 2050;
- Technical, financial, policy and other matters important to generation of electricity from coal;
- Regional implications of this development pathway, particularly for major coal-using countries.

Vision: courtesy of Isamu Ito, IEA

1st step (to 2030):	2nd step (beyond 2030):
1) Deployment of USC/A-USC, **2) Closure of old plants,** **3) Coal to gas/renewables**	**4) Deployment CCS with lower energy penalty**
USC and A-USC for new installation and retrofit will be largely deployed. Policies enacted to lead to closure of old existing plants. Replacement of coal plants by, eg gas and renewables to be promoted.	*Following successful demonstration of large scale integrated plant and reduction of its energy penalty, CCS will be equipped for deployment in both newly installed and existing plants.*



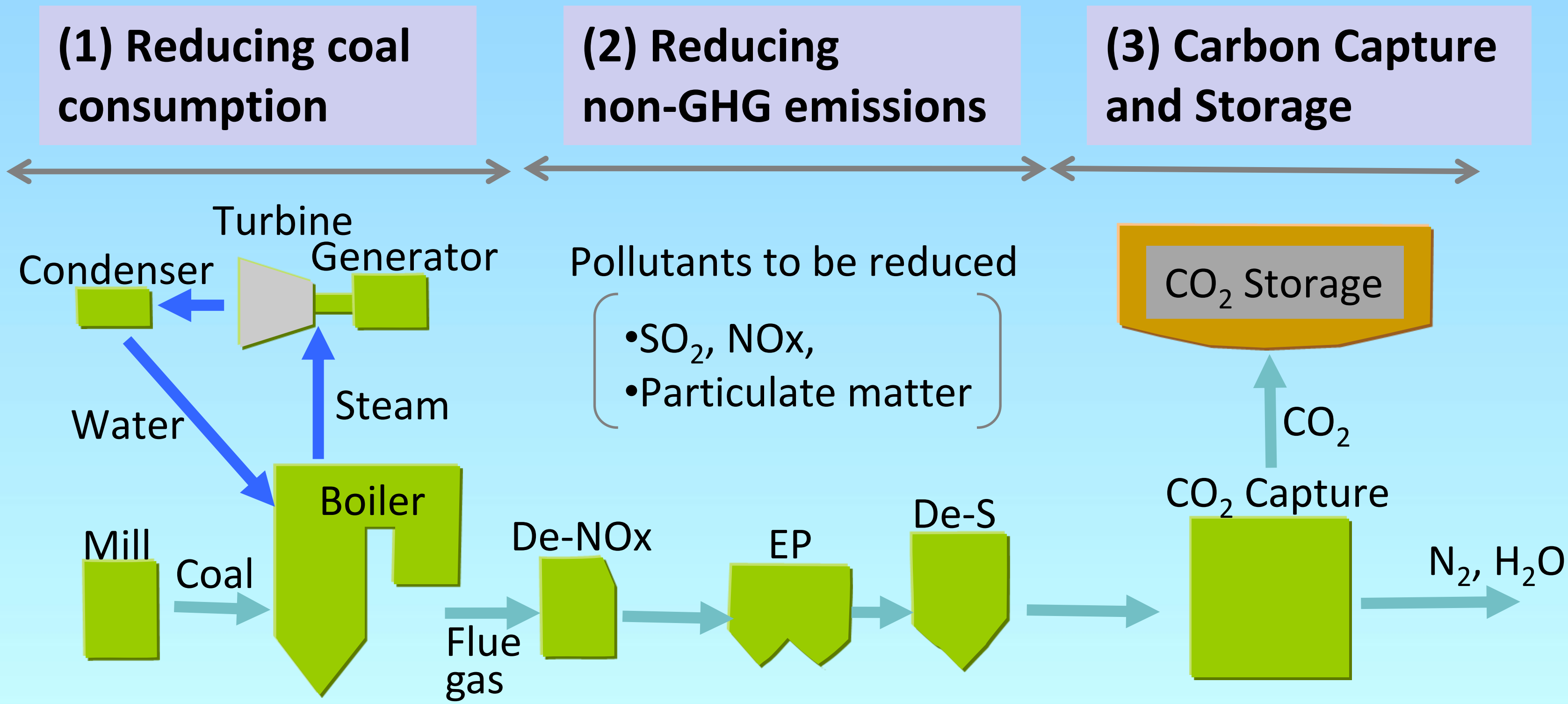
Action items for CO_2 reduction

1) Deploy USC/ A-USC and retrofit to raise efficiency
2) Close older existing coal
3) Replace coal plants by gas, renewables, …
4) CCS with low energy penalty

Technologies

Focus on technologies to reduce both GHG and non-GHG (NOx, SO_2, PM) emissions.

Technologies for cleaner coal generation



EP: Electrostatic Precipitator

Schedule Activity

- Draft Report by March; final by July or August

- Kick off Workshop in Paris in June 2011
- Workshops and/or discussions in Russia, China, India
- Final workshop likely in Paris

- IEA CCC Chaired initial workshop
- Participated in all visits
- Produced tailored reports on combustion technology development and on prospects for emissions reductions

Date ranges for technical developments (draft)

Technology	2012-2020	2021-2025	2026-2030	2031-2050
PCC – bituminous coals	Commercial supercritical and USC plants; oxyfuel demos; R&D on A-USC	Commercial USC plants; commercial scale A-USC demo with CCS; supporting R&D; oxyfuel A-USC pilot/demo	A-USC commercial plants; oxyfuel A-USC demo	A-USC with full CCS commercially available, including oxyfuel
PCC – lignite	Commercial supercritical and USC plants; lignite drying: 100% dry feed boiler demo and first commercial orders; oxyfuel demo; R&D on A-USC	Commercial USC plants with 100% fuel drying; A-USC lignite plant demos with lignite drying; oxyfuel A-USC pilot/demo	Commercial A-USC plants with 100% fuel drying; oxyfuel A-USC demo	Lignite A-USC incorp drying fully commercially available with full CCS, including oxyfuel
CFBC	Sales of commercial supercritical then USC CFBC boilers	Commercial USC CFBC	A-USC CFBC commercial demo; A-USC oxyfuel demo; first A-USC commercial orders	A-USC CFBC with full CCS commercially available, including oxyfuel
IGCC	Commercial plants with 1400°C-1500°C turbines; R&D on availability, low grade coals; pilot dry gas cleaning, non-cryogenic oxygen; dev of GTs	Commercial plants with 1600°C turbines for high hydrogen fuel for CCS capability; dry syngas cleaning; some non-cryogenic oxygen; supporting R&D	Commercial plants with 1700°C turbines for high hydrogen fuel for CCS capability; some non-cryogenic oxygen; supporting R&D	Commercial plants with 1700°C+ turbines for high hydrogen fuel with full CCS; non-cryogenic oxygen option

Future Developments in conventional technology

Advanced-USC technology

A-USC technology

- Work is being undertaken in EU, Japan, USA, India and China to develop these high temperature (700˚C += 1300F+) systems to increase the efficiency of generation to around 50%, LHV basis, and so reduce CO_2 emissions
- In China a consortium has been recently formed. There is a vision which ends with 1000MWe demonstration of 700C material in a PC boiler in 2021
- in India, an ambitious date has been set for operation of an 800MW demonstration plant. Work is in its initial stages
- All envisage using advanced alloys based on nickel (superalloys) to cope with the high temperature, high pressure steam. Nickel-iron superalloys are also under consideration

A-USC Technology in USA (1)

- US DoE/NETL, EPRI and Energy Industries of Ohio involved
- The USA programme is currently aimed more immediately at higher temperatures than the EU and Japanese programmes up to 1400F
- The USA also has an aim to develop oxy-fired A-USC technology
- Active interest in international collaboration – already in contact with Indian programme

A-USC technology in the USA(2)

- Focus currently on developing superalloys, fabrication and welding
- Boiler: superalloy tests in coal combustion products showed good corrosion resistance. Successfully welded in 75 mm thicknesses
- Component test facility planned for operation from 2014. A-USC oxy-coal combustion systems being designed.
- Turbine: superalloys had acceptable properties for rotor, blade, and bolting components; there is on-going effort on welding of turbine casings and other cast components
- A 600 MWe demonstration is planned for operation from 2021

E On's 50% efficient plant

… 50 plus by using new nickel alloy superheater tubing at 700C

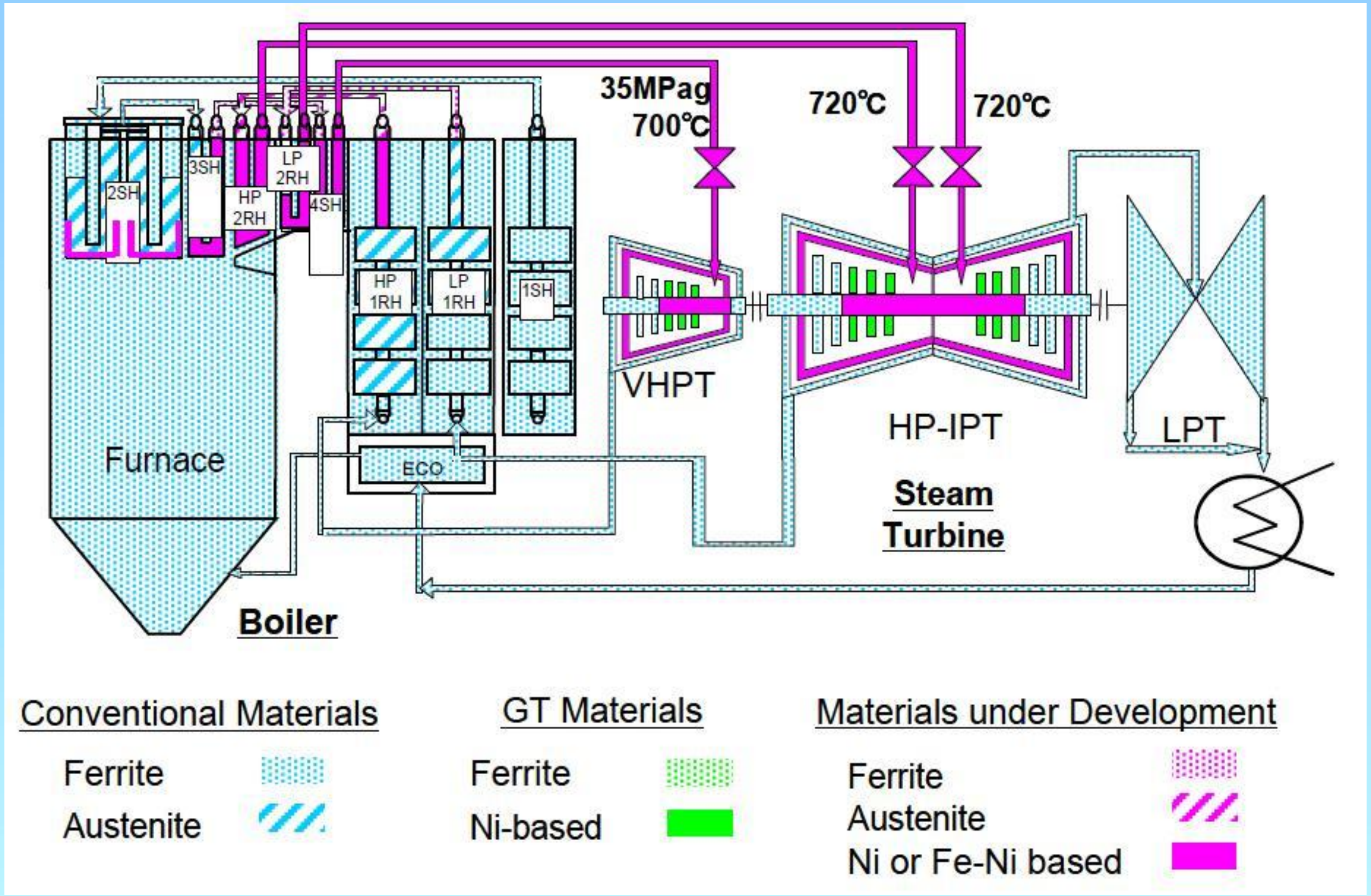
Location	**Wilhelmshaven**
Efficiency	50 %
Capacity	500 MW_e

Postponed/Cancelled in 2010
Looked very expensive; technical problems with welding and post weld heat treatment BUT research and development continues

A-USC technology in Japan

- METI Cool Earth calling for the main A-USC programme – started in 2008
- Started with materials development and evaluation for boiler components.
- Turbine: rotors and casings have been forged and cast and are undergoing testing. Valve materials are also being tested
- Boiler components and small turbine test scheduled for operation 2015-2016
- Commercialisation at 48% (LHV basis) efficiency is expected around 2020

A-USC technology in Japan

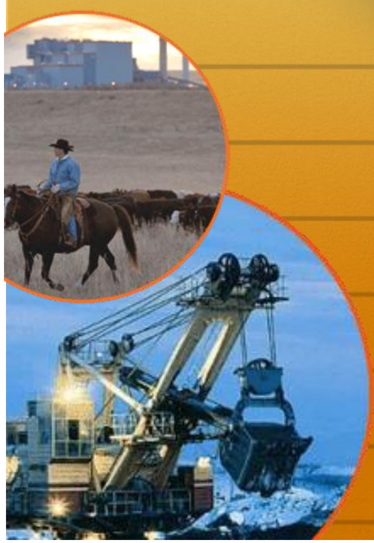


Materials in Japanese double-reheat A-USC design *(Fukuda M, 9th Liege Conference: Materials for Advanced Power Engineering, 2010***)**

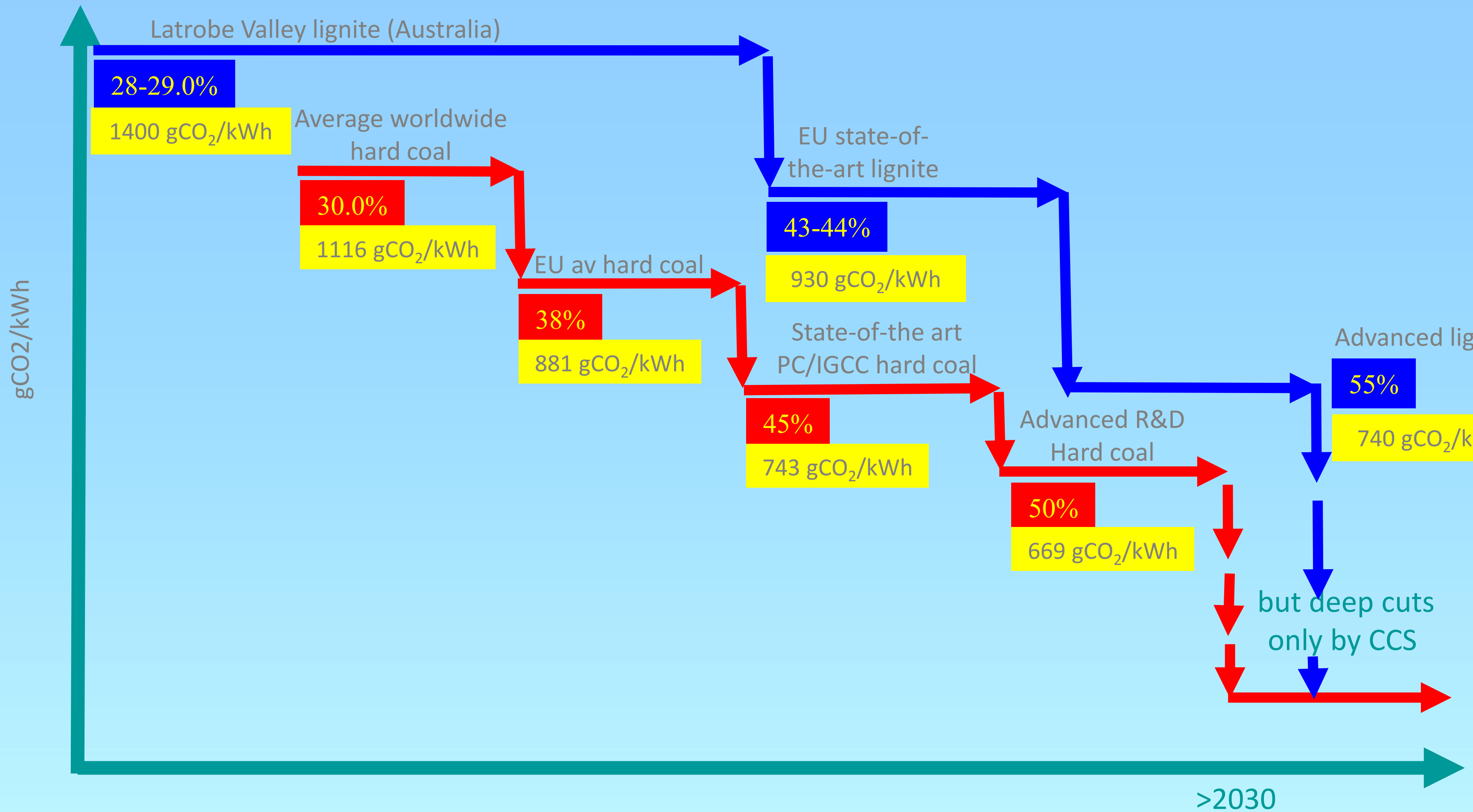
Carbon Capture & Storage

- GCCSI summary

- What is China doing?



CO_2 emission reduction by key technologies

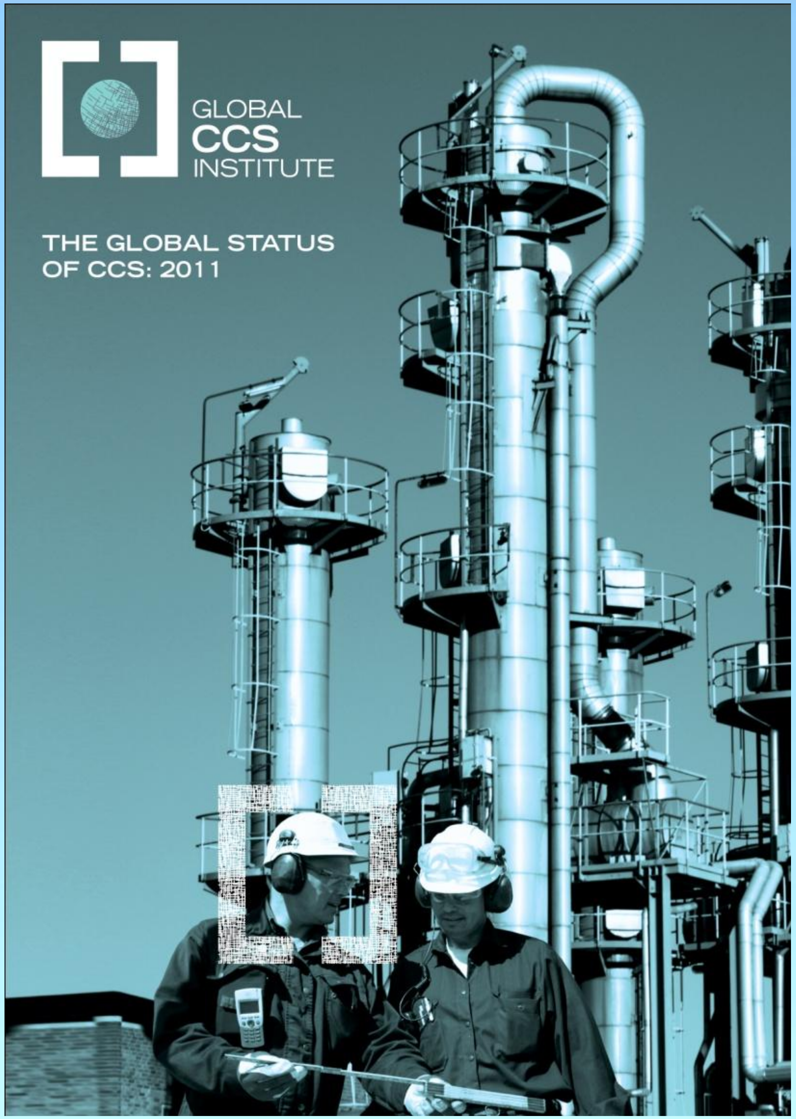


Data for hard coal-fired power plants from VGB 2007; data for lignite plants from C Henderson, IEA Clean Coal Centre; efficiencies are LHV,net

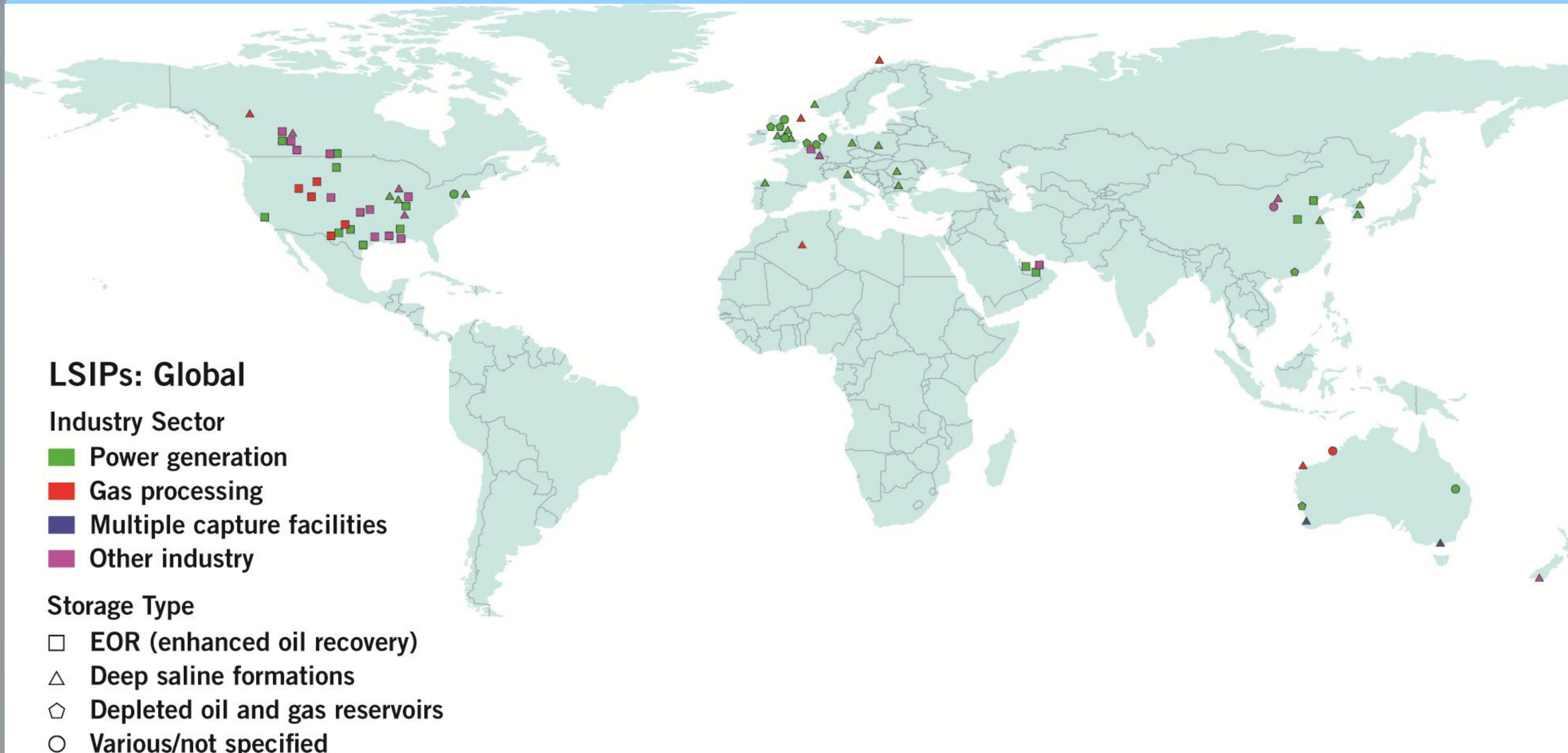
Energy Efficiency makes big change but deep cuts of CO_2 emission can be done only by Carbon Capture and Storage (CCS)

Released 4 October 2011

The *Global Status of CCS: 2011* report.



Global Spread of Projects (source: GCCSI October 2011)

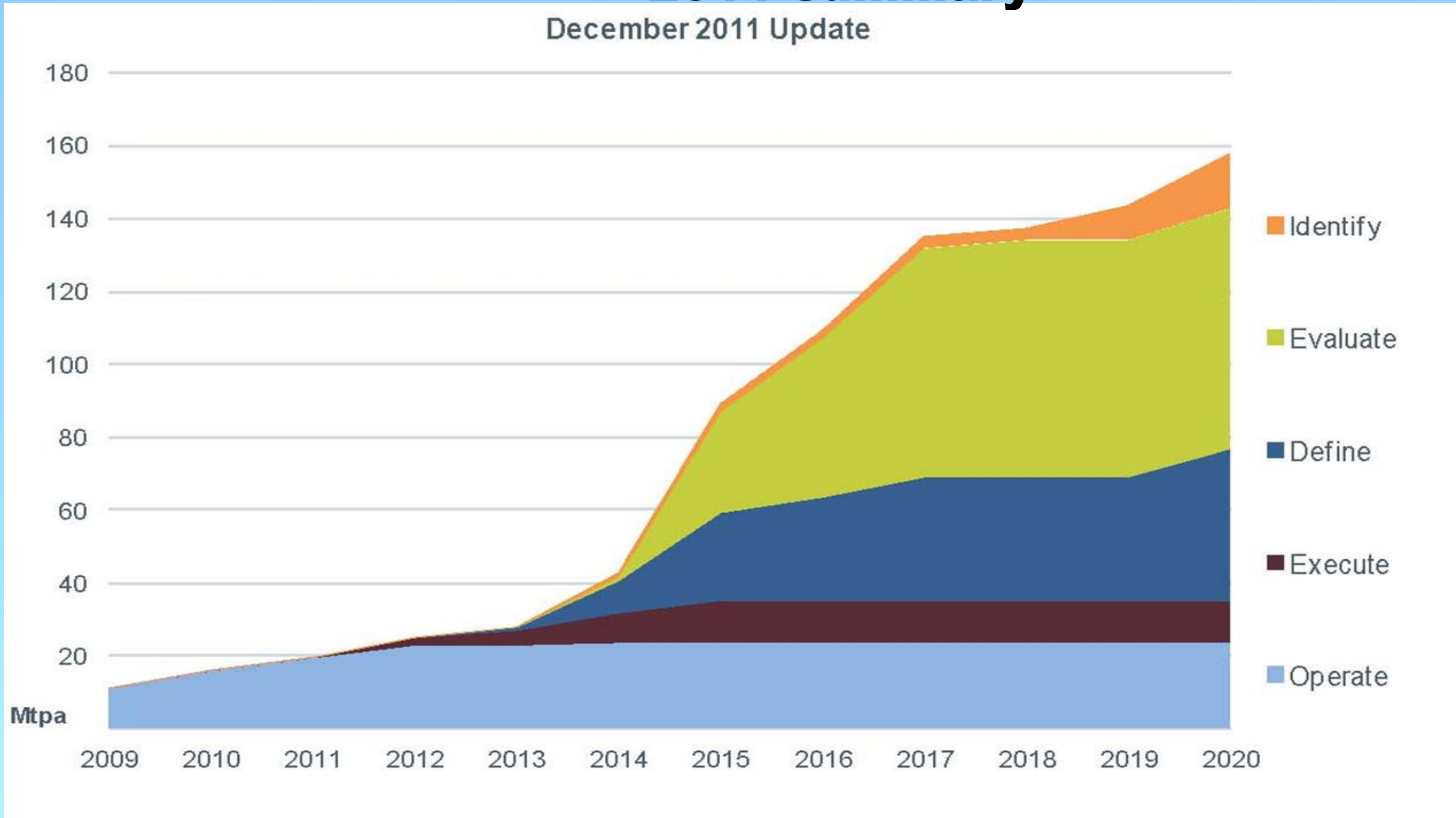


Europe Losing Edge in Carbon Capture Technology

17 Jan 2012
New York Times

The European Union's long-term energy plans hinge on proposals to capture carbon dioxide emissions and store them in deep underground rock formations, to abate global warming while still burning fossil fuels. Yet weak support for the untested technology is putting the Union in the rear ranks of its development. Two major carbon capture and storage, or C.C.S., projects in Germany and Britain were cancelled last quarter, and many of the remaining projects will probably share that fate this year, sandbagged by a mix of regulatory objections, a lack of funds, public opposition to the possible geological risks, and broader uncertainty about strategies to slow climate change.

GCCSI – Large Scale Integrated Projects – 2011 summary



The Global CCS Institute has identified 74 LSIPs around the world, including 15 that are currently operating or in construction, totalling a confirmed capture capacity of 35.4 million tonnes per annum (Mtpa) of carbon dioxide (CO2). A further 59 LSIPs are in the planning stages of development, with an additional, potential capture capacity of more than 122 Mtpa.

GCCSI – Global Status of Large CCS Projects December 2011 Update

Cancelled Projects			
Europe Area	Longannet Project	*2 Mtpa*	*Considered cancelled – project was shelved following announcement by the UK Department of Energy and Climate Change that it would not fund the construction of the CO_2 capture facilities.*
	Vattenfall Jänschwalde	*1.7 Mtpa*	*Considered cancelled – plans were stopped, citing the lack of government support and the absence of a clear legal framework.*
Newly-Identified Projects			
China	Datang Daqing Oxy-fuel Combustion CCS Demo Project	*> 1 Mtpa*	*New build super-critical coal-fired power plant generating electricity and heat, with oxy-fuel combustion CO_2 capture. Operation is expected to start in 2015.*
United States	NRG Energy Parish CCS Project	*1.5 Mtpa*	*Retrofit of post-combustion CO_2 capture technology at a coal-fired power plant in Texas. The CO_2 will be used for enhanced oil recovery starting from 2015.*
Project Progress			
United States	Air Products Steam Methane Reformer EOR Project	*1 Mtpa*	*Moved to Execute as it started construction in August 2011 – the new build hydrogen plant is expected to begin operation in 2012.*
Other key changes			
Europe Area	Sleipner CO_2 Injection	*1.1 to 1.2 Mtpa*	*Volume of CO_2 captured and injected will be expanded to 1.1 - 1.2 Mtpa in 2014, with the addition of 0.1 to 0.2 Mtpa of CO_2 from the gas produced from the Gudrun field, currently under development.*
United States	(HECA) Hydrogen Energy California Project	*2.3 Mtpa*	*Purchased by SCS Energy. The hydrogen plant was requalified as a polygeneration plant and will include the manufacturing of urea. Expected operation date was moved back by one year to 2017.*

http://cdn.globalccsinstitute.com/sites/default/files/publications/27936/quarterly-update-december-2011-final-v4.pdf

More Press – 7 June 2011

Looking where we are now in terms of CCS, I am not very hopeful that we will see a substantial amount of CCS before the next 20 years, unless governments and the industry make extraordinary efforts or we have international legally binding agreements which end up with a carbon price to give a proper incentive for CCS," Birol told reporters in Oslo Tuesday

Based on an interview by Fatih Birol, IEA Chief Economist

CCS for China

Does not feature in the economic goals of 12th FYP but is included as a high technological priority within the R&D programme

- CO_2 capture, utilisation and storage technologies, namely through the development of key technologies and measures for capturing, utilising and storing CO_2;
- the design of a technology roadmap for CO_2 capture, utilisation and storage;
- the implementation of capacity building;
- the establishment of an engineering and technical demonstration project.

Mixture of domestic R&D programmes plus larger scale industrial trials and significant international cooperation for capacity building

China's national CCS R&D programme

MOST supports both fundamental research (973) and technology development (863) while the National Science Foundation focuses on fundamental and generic research.

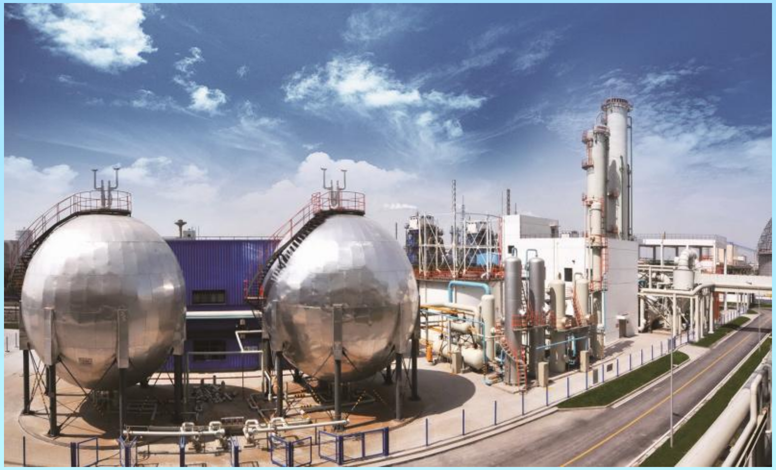
In terms of GHG emission controls and climate change mitigation, R&D includes work on a wide range of CO_2 capture, utilisation and storage technologies. China has stressed that it will pay special attention to the research and development of new and innovative methods and technologies to use captured CO_2 as a resource.

Scope of work

The aim is to establish Chinese based techniques upon which can be secured independent intellectual property rights.

- **The National Basic Research (973) Programme includes a major programme of fundamental research on CO_2 use for EOR applications and long term storage, on syngas production from coal gasification and pyrolysis, and the high efficiency conversion of natural gas and syngas either for chemical products or for carbon free use in gas turbines; while**
- **The National High-Tech Research and Development (863) Programme includes several projects to develop advanced CO_2 capture technologies based on adsorption and absorption processes, and to explore CO_2 storage technology.**
- **There is support for the understanding and development of oxyfuel combustion and chemical looping combustion processes**
- **A preliminary assessment of CO_2 potential storage capacity in China is underway**

China - CO_2 capture and utilisation trials in the coal fired power sector



- In 2008, Huaneng Group established a side stream post-combustion capture unit on the 800MWe Gaobadian PC CHP plant in Beijing, with an annual CO_2 capture capacity of 3000 tonnes.

- In 2010, Huaneng installed a larger unit on the 2x660 MWe Shidongkou No. 2 Power Plant in Shanghai, which can capture 120,000 tonnes of CO_2 each year.

In both cases, captured CO_2 is sold to the food and beverage industries.

China - Greengen IGCC CCS project

- High-efficiency, coal-based IGCC polygeneration system and efficient treatment of pollutants with near-zero emissions of CO_2.
- Phase 1 is to prove the scale-up of the Chinese gasifier
- Phase 2 aims to improve the IGCC polygeneration technology, and to determine how best to take forward the fuel cell power generation technology, and to produce up to 30-60,000 tonnes/year of CO_2 for EOR trials.
- Phase 3 will comprise a 400 MWe demonstration of the overall concept.

China - CCS potential in the coal to chemicals sector

- There is a growth in scale and extent of application in the coal to chemicals sector, with the opportunity to capture CO2 at relatively low cost,

- So, there is potential for some early CCS demonstrations and commercial prototypes, probably for EOR applications.

China - CCS trial underway

- The first major coal gasifier CCS trial in China is underway at the Shenhua Direct Coal to Liquids (CTL) Demonstration Plant, close to Erdos, Inner Mongolia Autonomous Region
- Aim is to remove up to 100,000 tonnes/year of CO_2 from the waste stream and transport it for storage in a nearby aquifer

Concluding Remarks

- Coal extraction and trade are set to continue to expand over the next 2 decades
- Trade will increasingly focus on China India and Asia
- The opportunity to limit average global temperature rise to no more than 2C is disappearing fast
- CCS is taking off more slowly than had been hoped. It is happening with much technical success but hampered by non-technical issues
- Coal users can make a more immediate contribution to reducing CO2 emissions by use of advanced more efficient technologies with commensurate improvements in clean air

THE END – THANKS FOR LISTENING

Brown Coal Roadmap Dinner – Melbourne – July 2011

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