Roadmaps for Clean Coal Technologies – IGCC, Supercritical and CCS

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Summary of presentation

- Context – coal's significance
- Challenges
- Technologies
- Pathways
- Example international developments
- Conclusions

Importance of coal now and into the future

- **Coal provides currently around 40% of electricity worldwide and an even higher proportion in key developing countries**
- **Future energy diversity, security and pricing are major issues everywhere**
- **Growing electricity usage and plant retirements mean coal will continue to be needed alongside other options to avoid power shortages**

Power generation from coal – challenges

Reducing CO_2 emissions:

- **Higher carbon content than other fossil fuels leads to inherently greater specific CO_2 emissions (kg/kWh)**
- **Raise general level of efficiency of new/refurbished coal-fired plants towards that of best examples (to minimise all emissions)**
- **Put into place the technologies for CO_2 capture and storage**

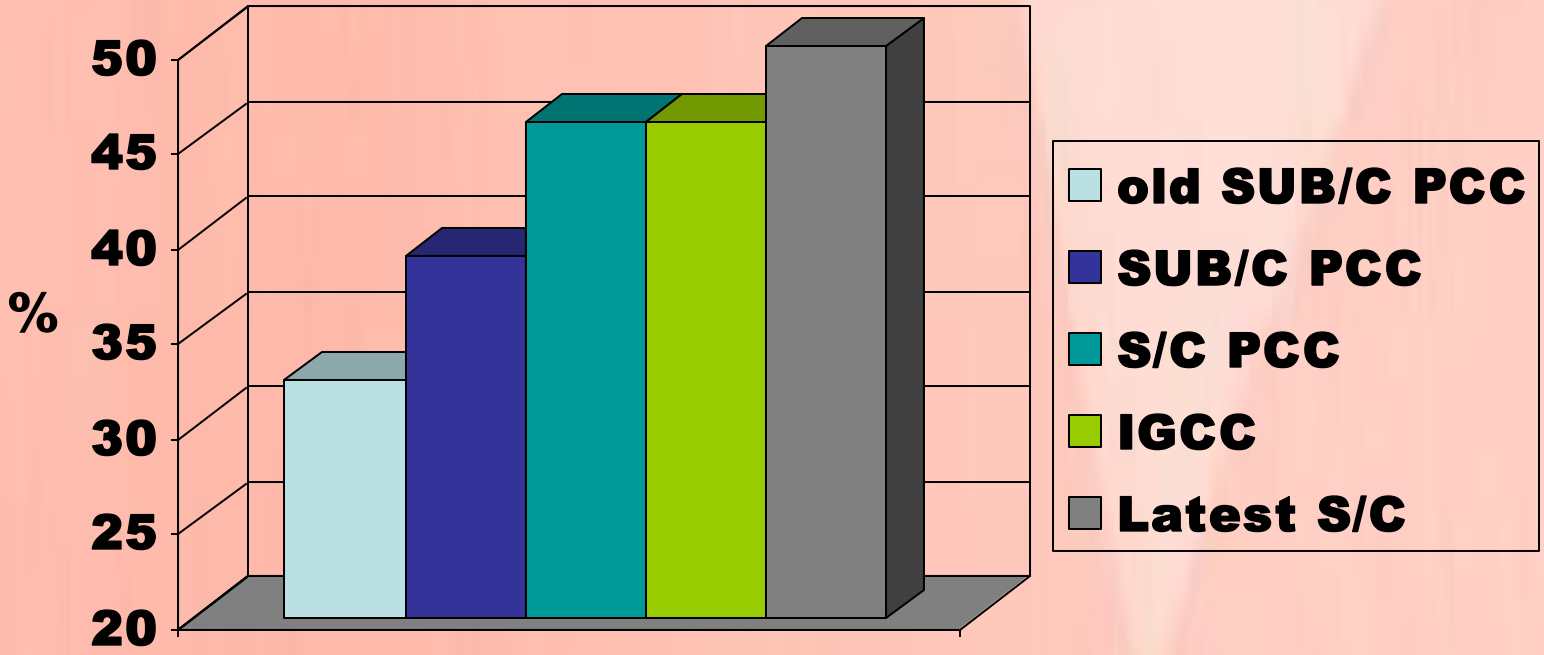
Other major challenges:

- **Tightening conventional emissions regulations**
- **High (and rapidly rising) capital costs compared with natural gas combined cycle plants is causing deferment or even cancellation of some projects**

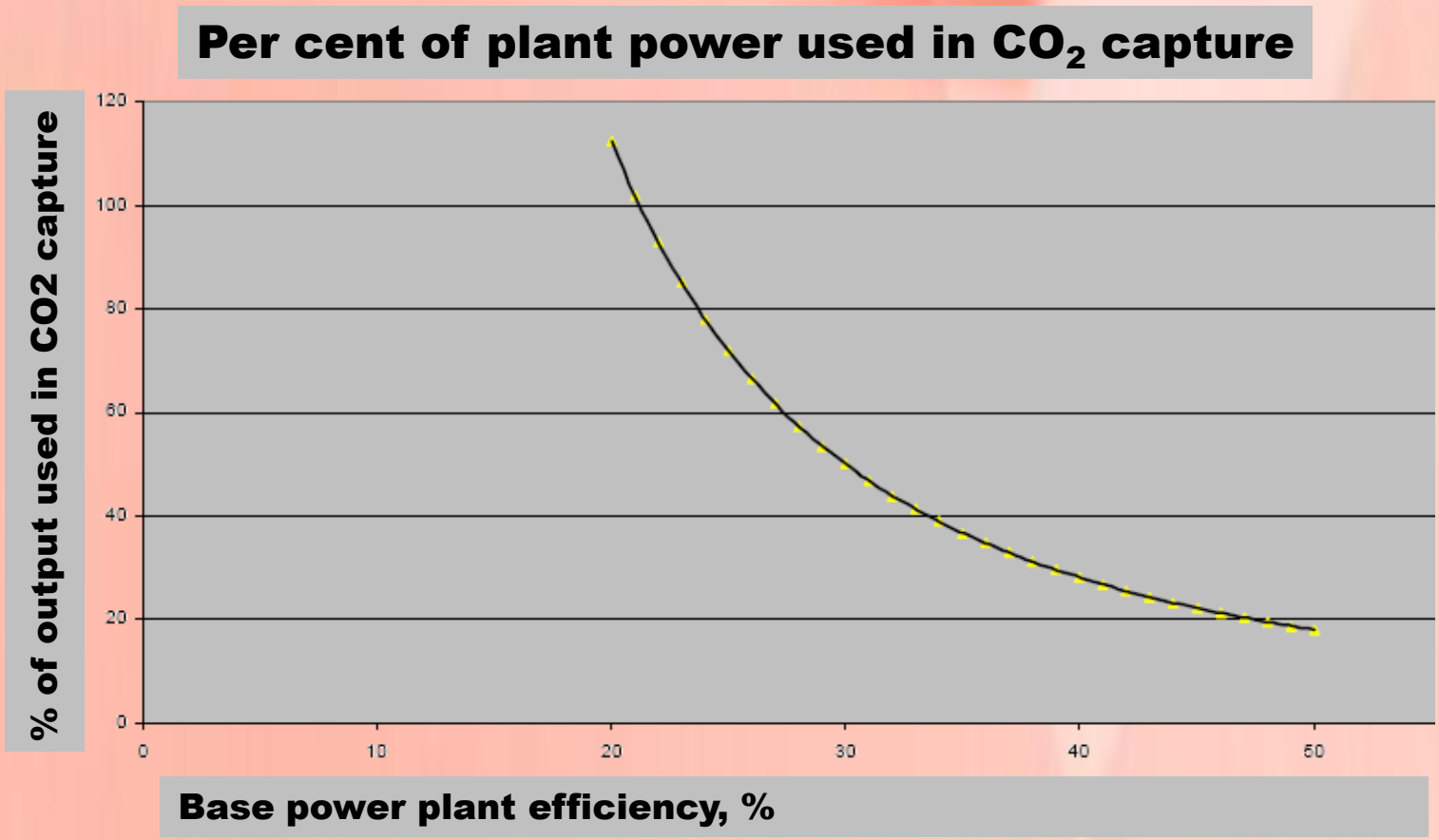
CO_2 emissions and control

- Many ways to reduce CO_2 emissions from fossil power generation – improve efficiency, change fuel, apply carbon capture and storage (CCS)
- CCS from coal-fired plant has been shown in IEA evaluations to be a cost-effective means
- CCS could (and needs to) play an increasing role, incentivised by stable CO_2 price

Indicative efficiencies of coal-fired power technologies (% net, LHV basis)



Efficiency and cost implications of most CO_2 capture options



Source: RWE npower

Coal technologies now and for the future

Conventional clean coal technologies

- Pulverised coal combustion (PCC) – the predominant technology
- Circulating fluidised bed combustion (CFBC) – also important
- Integrated gasification combined cycles (IGCC) – potential for greater use

Future CO_2 capture technologies

- Systems based on combustion
- Systems based on gasification

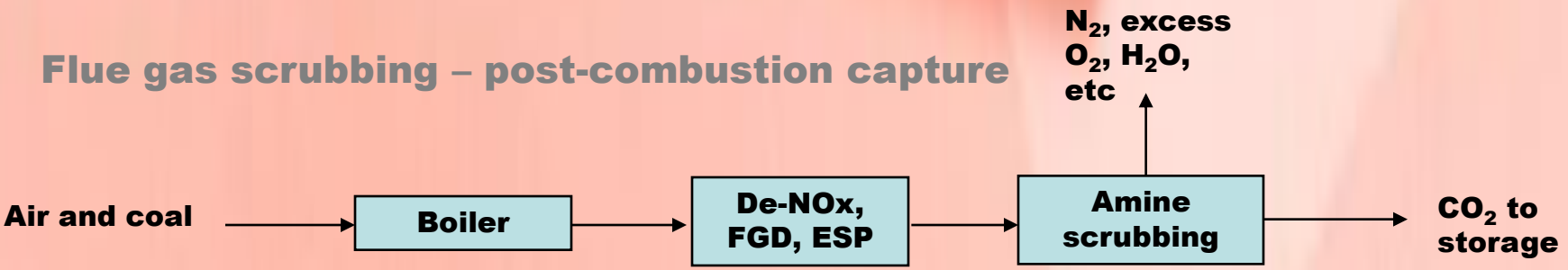
} first wave of CCS plants

- Other systems – e.g fuel cell cycles, hydrogasification, CO_2 turbines

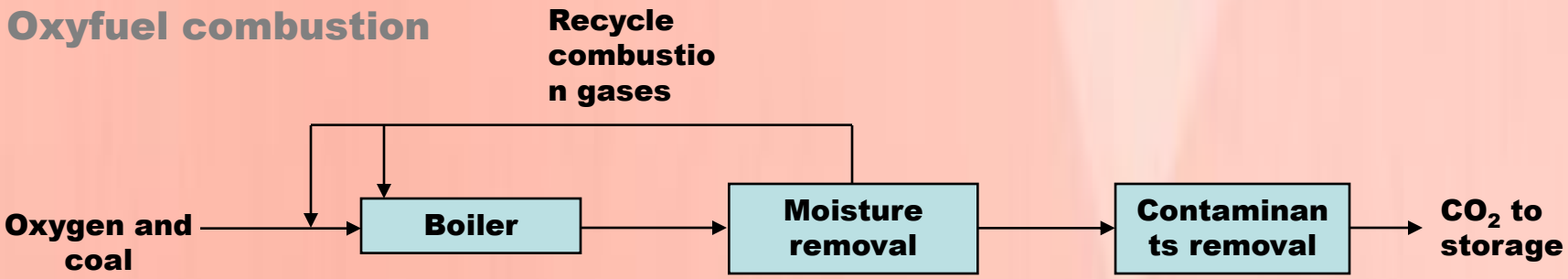
- CCS must be based on PCC and IGCC because: 1) large deployment of PCC – potential CO_2 lock-in; 2) IGCC potential higher efficiency with CCS

CO_2 capture systems for PCC

Flue gas scrubbing – post-combustion capture



Oxyfuel combustion



CO_2 capture - combustion plant

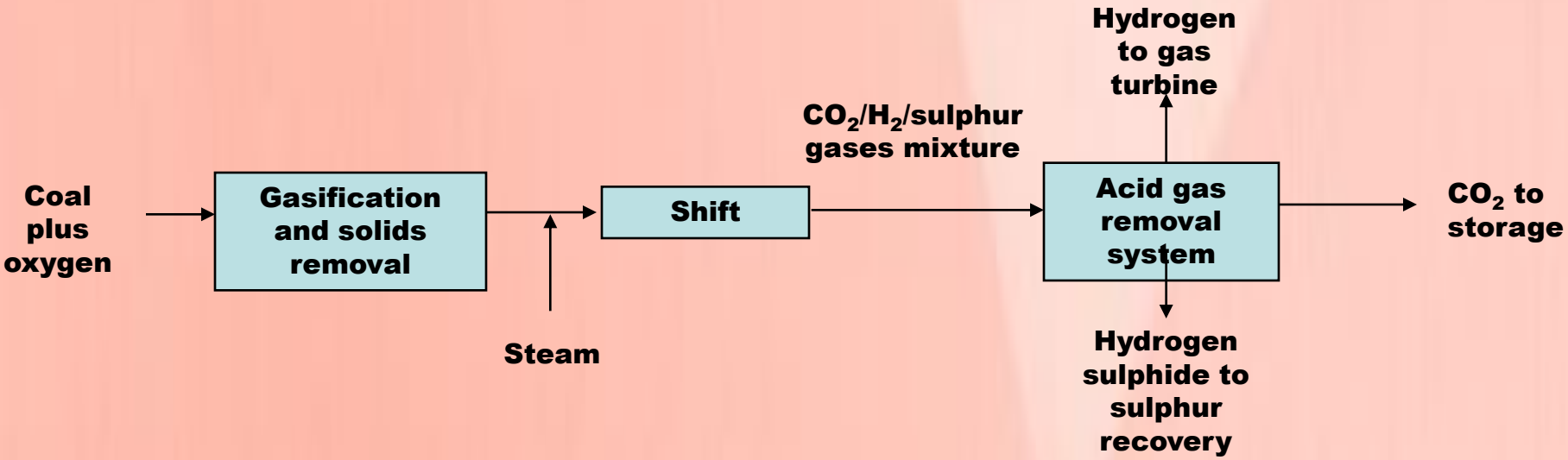
Post-combustion scrubbing:

- Several pilot plants, including sidestream tests, experience on flue gas flows up to 50 MWe (USA, Denmark, Canada, Malaysia)
- Coal flue gas introduces issues such as corrosion, solvent degradation
- Efficiency penalty high but decreasing, ~9-14% pt
- Other work: alternative absorbents; membrane contactors; physical separation

Oxyfuel firing:

- Tested at ~1MW pilot scale, Canada, USA, Japan
- 30 MWe retrofit in Australia
- Efficiency penalty appears similar to chemical scrubbing
- New oxygen production technology would reduce penalty but hard to integrate
- Potential issues: corrosion, deposition, operability

CO_2 pre-combustion capture for IGCC



CO_2 capture: IGCC plants

- Physical solvent scrubbing of CO_2 is established, e.g. in NH_3 production
- Lower energy penalty than for PCC - prospect ultimately of only ~ 4-6% pts
- Experience of E-class GTs on 95% H_2 and GT manufacturers now prepared to guarantee F-class turbines for hydrogen firing
- Other methods of separation – chemical scrubbing, adsorption, membranes
- Other schemes without shift – CO_2 turbines, O_2 combustion of syngas with CO_2/H_2O turbines, even post combustion capture from GT exhaust

Example international developments

European FP7

- **Strong focus on carbon capture and storage**
- **However, re-introduction of clean coal technology in recognition of the drive for greater efficiency whilst CCS is developed and deployed**
- **Technology platform to advise on strategy and direction of these two elements**

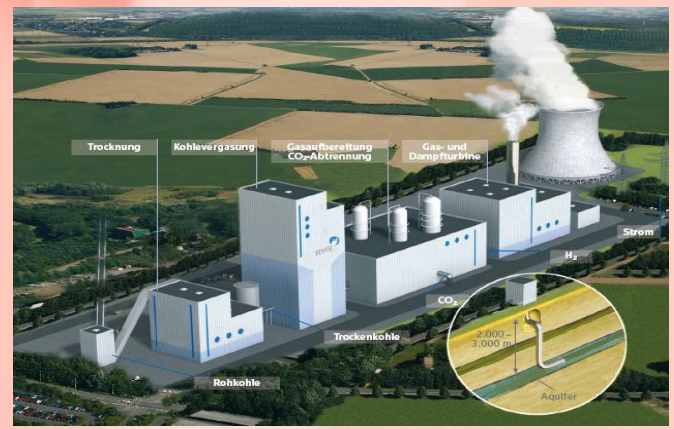
Some major European CCS projects

- **EU aspiration to have 10-12 CCS demonstration projects by 2015**
- **Vattenfall to retrofit Nordjylland 3 double reheat USC unit in Denmark with full-flow post-combustion CCS. Storage of CO_2 in Vedsted aquifer, planned commercial operation 2013-15**

- **UK post-combustion CCS demonstration at 300 MWe**
- **Vattenfall 30 MWth oxyfuel pilot plant, Schwarze Pumpe power plant, Germany, commissioning this year**

Some major European CCS projects (2)

- **Utilities plan for IGCC with CCS (RWE, E.ON, Progressive Energy)**



- **High efficiency USC PCC:**
  - **AD700 programme**
  - **Wilhelmshaven 50%, net (LHV) 500 MWe PCC, start-up 2014**

US clean coal developments (1)

- **Clean Coal Power Initiative (CCPI) - federal cost ~US$2 billion over 10 years - is successor to CCT Program for secure, clean electricity supply**
- **CCPI implements National Energy Policy (NEP) recommendations to increase investment in CCTs. Addresses Clear Skies Initiative (CSI), which calls for large reductions in emissions of SO_2, NOx and mercury**
- **USDOE $95 million Power Plant Improvement Initiative (PPII) set up in 2000 for commercial-scale demonstration of near-term technologies**

US clean coal developments (2)

- **Coal Power Program Roadmap of Coal Utilization Research Council (CURC), EPRI and USDOE (~US$11bn) identified technology destinations, R&D needs and technical, environmental and economic targets, near-, medium- and long-term, latter using Vision 21 targets (now part of CCPI)**
- **Carbon Sequestration Leadership Forum (CSLF) formed in 2003 gathers and exchanges information internationally on CCS and promotes joint projects**
- **FutureGen, previously intended as a single IGCC plant with hydrogen production and CCS, now to be a USDOE funding vehicle for CCS on new coal plants around the country**
- **USC PCC and IGCC projects planned, some of latter with US DOE part-funding, but many planned commercial projects currently deferred because of high capital costs**

Environmental performance targets in US Coal Power Program Roadmap

	Criterion	Reference plant	2010	2020 Vision 21
Air emissions	SO_2 removal, %	98%	99%	>99%
	NOx, lb/10^6Btu (kg/kJ)	0.15 (0.072)	0.05 (0.024)	<0.01 (<0.005)
	Particulate matter, lb/10^6Btu (kg/kJ)	0.01 (0.005)	0.005 (0.002)	0.002 (0.001)
	Mercury removal, %		90	95
By-product utilisation	%	30	5	near 100

The roadmap also has a target for 90% CO2 capture and storage at an additional electricity cost of less than 10% using Vision 21 destinations and R&D needs. It includes a field demonstration of capture and storage by 2010.

Japan (1) - C3 (Clean Coal Cycle) Initiative

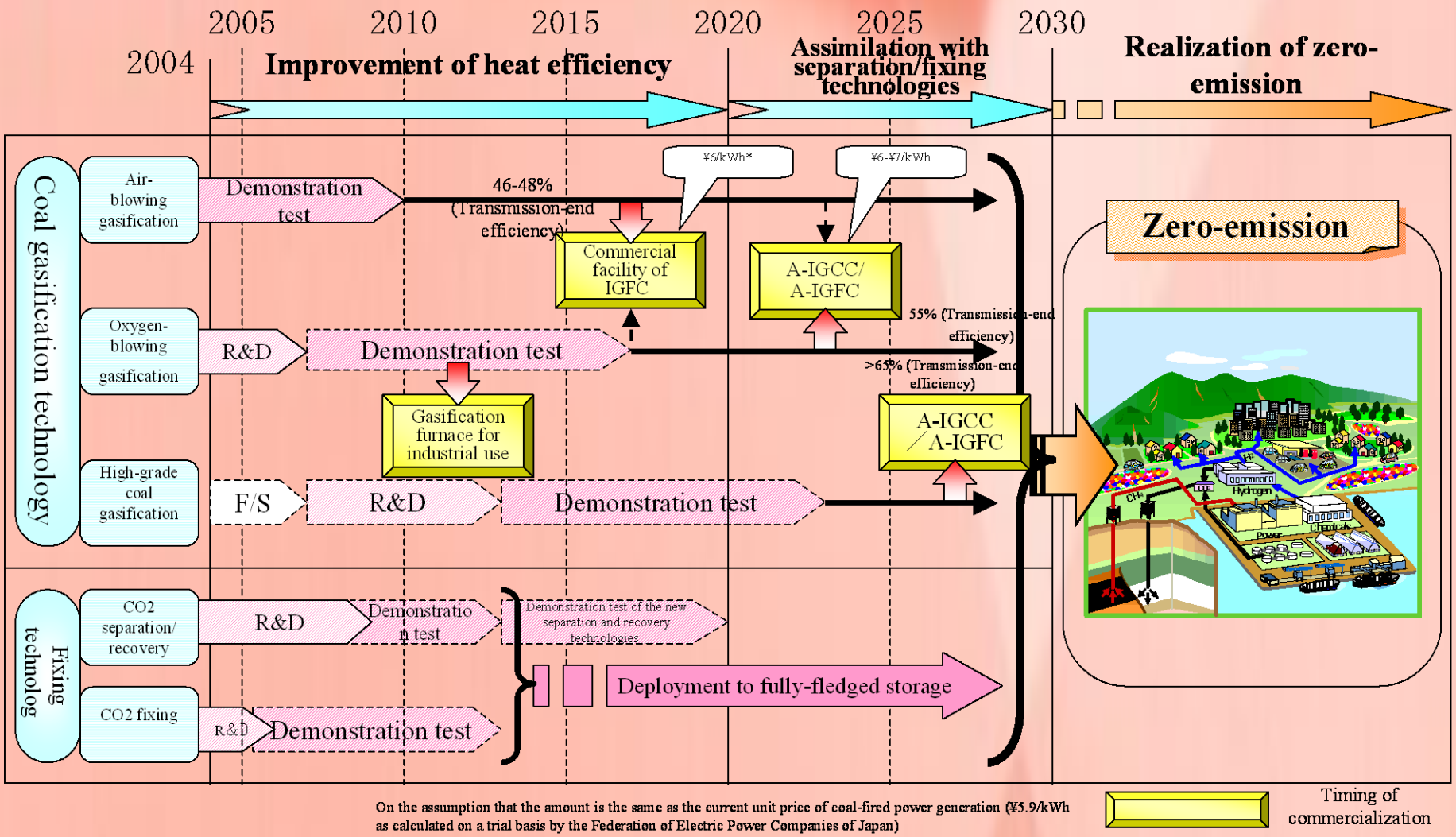
Targets to 2030:

- **reduce environmental impact of coal utilisation**
- **diversify energy sources**
- **secure stable supply of coal**

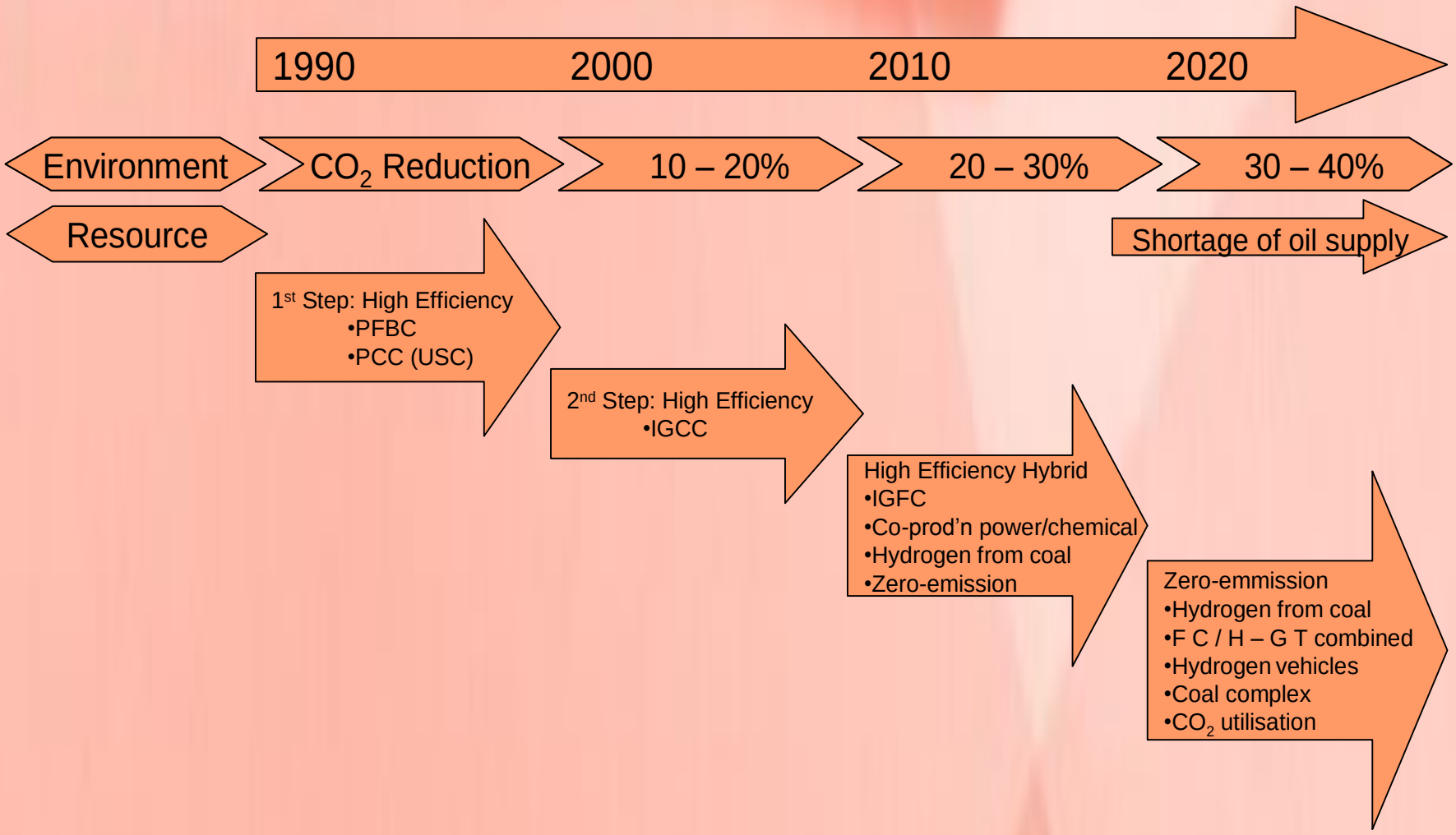
Five basic directions:

- **Promotion of high-efficiency to reduce emissions and costs, establishment of programmes under Kyoto Mechanisms.**
- **Development and deployment of technologies for reduction and utilisation of byproducts including SO_2, NOx, ash and CO_2**
- **New coal uses to improve competitiveness of coal**
- **Expansion of coal supply and removal of supply bottlenecks**
- **Improvement of procurement to preserve cost advantage as coal demand in Asia increases**

Japan (2) C3 roadmap for realising zero-emission coal utilisation



Japan (3) - Coal utilisation technology development strategy for the 21st century (Centre for Coal Utilization Japan, 2003)



Australia – COAL21

- Major initiative, involving key stakeholders across industry, government and researchers to develop a National Clean Coal Strategy and facilitate demonstration and commercialisation of CCTs
- Funded entirely by voluntary levy on bituminous coal producers
- CO_2 emissions reduction from coal use in power generation seen as key issue to address to maintain energy security through retention of coal
- Range of CO_2 abatement options studied, from mining and coal preparation to utilisation (efficiency improvements and CCTs) and CO_2 capture and storage

Australia (2)

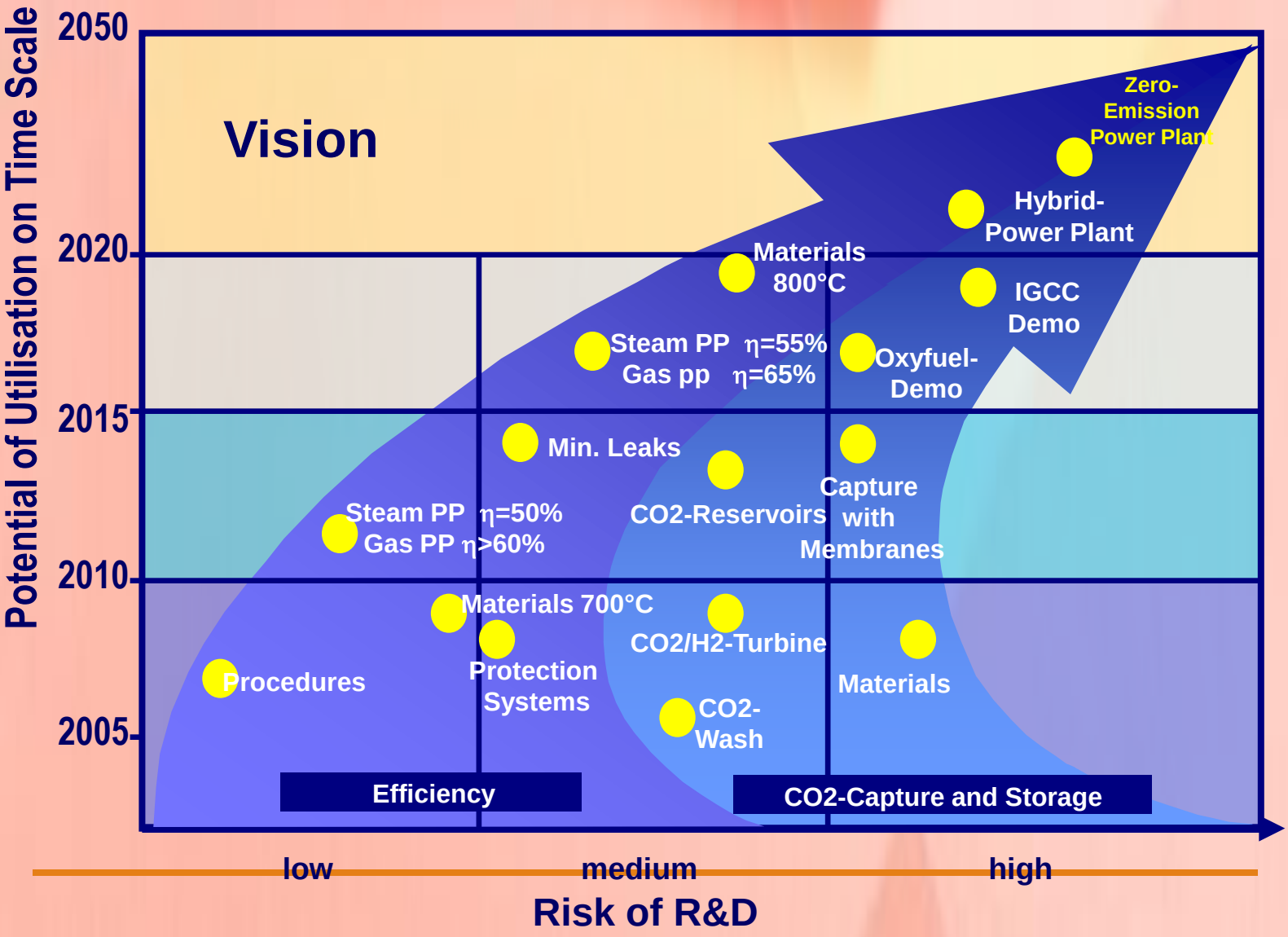
- **Funding of ~ A$ 1 billion from COAL21 over 10 years for black coal projects including A$ 300 million for 80 MWe ZeroGen (Stanwell) IGCC with CCS, ~A$ 70 million for CS Energy's Callide A oxyfuel CCS project, and A$ 20 million for a post combustion CCS project (ammonia based) in NSW**

- **Government's Low Emissions Technologies Development Fund (LETDF) (A$ 500 million) is part-funding Callide A project and others including Monash Energy Project for brown coal to liquids with power and CCS, the Hazlewood brown coal drying and post combustion CCS project and HRL's IDGCC brown coal gasification project in Victoria**
- **Funding from Queensland State Government for ZeroGen and A$ 100 million from NSW for coal projects recently announced**

Germany

- Hard coal and lignite significant - over 50% of power generation
- Lignite is competitive for power generation without subsidy
- COORETEC - Government review of R&D needs of CCS plants by working groups from utilities, R&D institutions and academia.
- On efficiency, materials to permit steam conditions for efficiencies of new stations >50%; combined cycle power cycles for 55% efficiency

COORETEC roadmap



Germany - example projects

- E-max initiative – VGB plus European utilities. Goal to have AD700 technology commercially available after 2010. Focusing on oxidation and high temperature corrosion properties of superheater materials including austenitic steels and nickel-based alloys
- Wilhelmshaven advanced 500 MWe USC PCC with 35MPa/700°C/720°C turbine to be constructed by E-ON. Efficiency goal of 50% on a LHV basis. Planned start-up 2014
- E-max tests at Scholven power plant. Tests also at Esbjerg power plant in Denmark
- Lignite drying demonstration (RWE's WTA process) on Niederaussem K (25% of fuel flow to 1000 MWe USC PCC
- RWE planned 450 MWe IGCC with CCS, 2014 – lignite preferred

Canada

Government policy of energy diversity, security and sustainability

- **Long-term role for coal, stringent environmental requirements**
- **Coal accounts for ~20% electrical generation, from 25 generating stations**
- **Plant retirements 18 GWe of coal capacity next 25 years plus 40 GWe expected increase in demand**
- **Recognition of need for strategy for development and implementation of CCTs**
- **Industry involvement is considerable although there have been setbacks recently with cancellation of projects such as the CCPC oxyfuel project**

Canada

The Canadian Clean Coal Technology Roadmap and CO_2 Capture and Storage Roadmaps aim to:

- **identify pathways, integration needs and developments needed to capture CO_2 from large emitters (various technologies)**
- **to identify CO_2 storage opportunities and synergistic opportunities to use for EOR, CBM production and H_2 production**

Canadian Clean Power Coalition (CCPC)

Public-private R, D&D initiative to demonstrate that coal-fired power generation can address all environmental issues

Assessed feasibility and costs of retrofitting plant with CCS and of new CCS plants:

- **3 Canadian fuels: bituminous coal, sub-bituminous coal and lignite.**
- **Targets for near-zero emissions identified)**

Options considered for CCS were amine scrubbing, oxy-coal combustion and IGCC with pre-combustion capture:

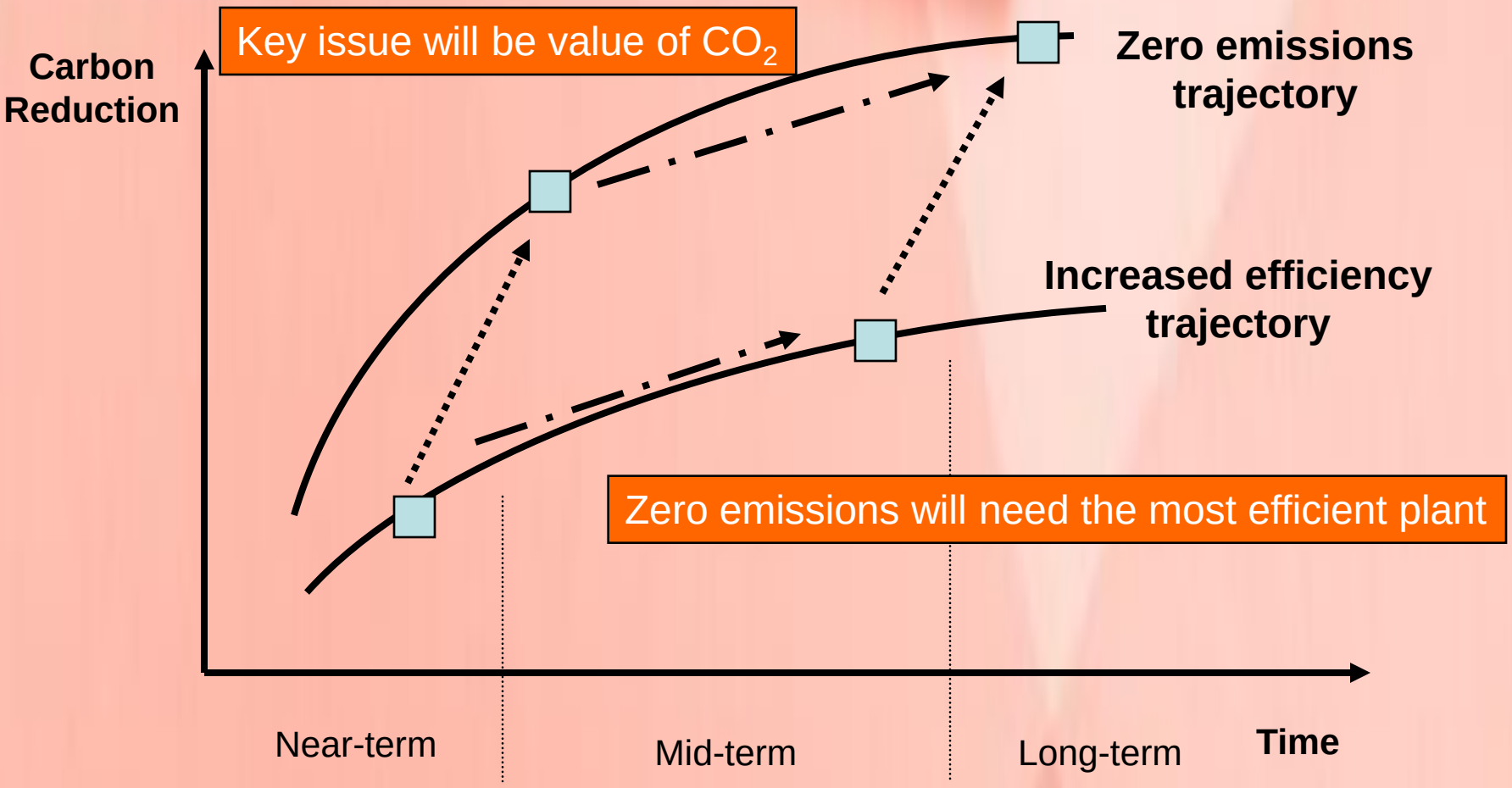
- **For new plants, oxycoal and IGCC identified as best options**
- **Retrofits for CCS found not to be attractive**

Canada has many other activities on technologies for CCS, including Weyburn EOR project using CO_2 from Great Plains syngas plant in USA

UK CCS projects

- **PCC post-combustion CCS competition later this year for 300 MWe full flow demonstration project, ~90% capture from c.2014**
- **FEED studies done on capture ready USC at power plant sites**
- **Oxycoal2 demonstration project – full-scale (40MWth) oxyfuel coal burner, Doosan Babcock**
- **Plans for IGCCs with CCS at Killingholme (coal or coal + petcoke IGCC with CCS), Hatfield (800 MWe), Teesside and Drym, S. Wales**

UK DTI
CAT options are complementary



China and India

China

- Large existing capacity of sub-critical PCC
- Policy to deploy supercritical PCC - currently around 30 units of 600 MWe and 800 MWe operating, approved or under construction
- At least three IGCC or polygeneration projects planned or under construction

India

- BHEL operated 6 MWe fluidised bed gasifier IGCC during the late 1990s. Now seeking partners for 100 MWe demonstration plant
- Lignite-fuelled IGCC also planned
- Installation of supercritical PCC has begun. A 3x660 MWe plant at Sipat is due for completion by 2009 (steam conditions 24.7 MPa/540°C/565°C). Major new supercritical power projects programme with 800 MW units is beginning.

Conclusions

- Secure electricity supply requires continuing use of coal
- Sharp rises in capital costs have resulted in power project deferments and cancellations from cost rises and permitting difficulties
- Interim reductions in CO_2 will come from efficiency improvements in PCC and IGCC plus biomass co-firing
- Development paths exist for much higher efficiency of PCC and IGCC, but CCS will also need to be applied to both as soon as possible for deep cuts in emissions
- CCS initiatives and planned projects in many OECD areas: Europe, USA, Canada, Australia
- Deployment of CCS in developing countries will be hindered by the over-riding priority of extending provision of electricity supplies to all. However, interest in CCTs is high.
- Ensuring CO_2 capture readiness of future plants is very important