# $CO_2$ Capture and Storage
# RD&D Priorities and Investment Needs

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**Using long term scenarios for R&D priority setting**
15-16 February 2007
International Energy Agency, Paris

# Drivers for R&D in CCS

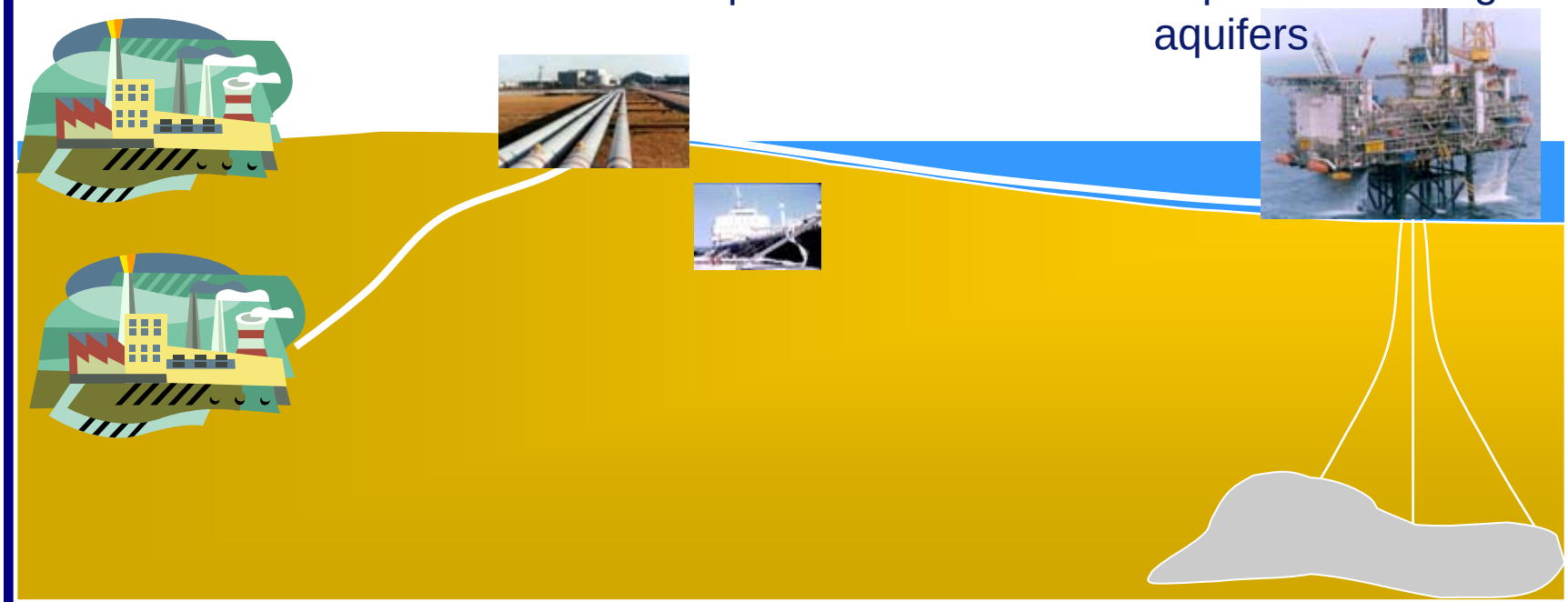
- Capture
  - Cost reduction to reduce cost of electricity with CCS
  - economics of enhanced recovery
  - H2 Generation
- Storage
  - Risk management
  - Trapping Mechanisms/Optimization of injection
  - Monitoring & Verification
  - Long-term interaction $CO_2$ - Formation

# $CO_2$ Capture and Storage - Cost Chain

Power & Industrial processes with $CO_2$ capture and

$CO_2$ export terminal pipeline transportation or shipment

Injection for Geological storage in producing or depleted oil and gas fields aquifers



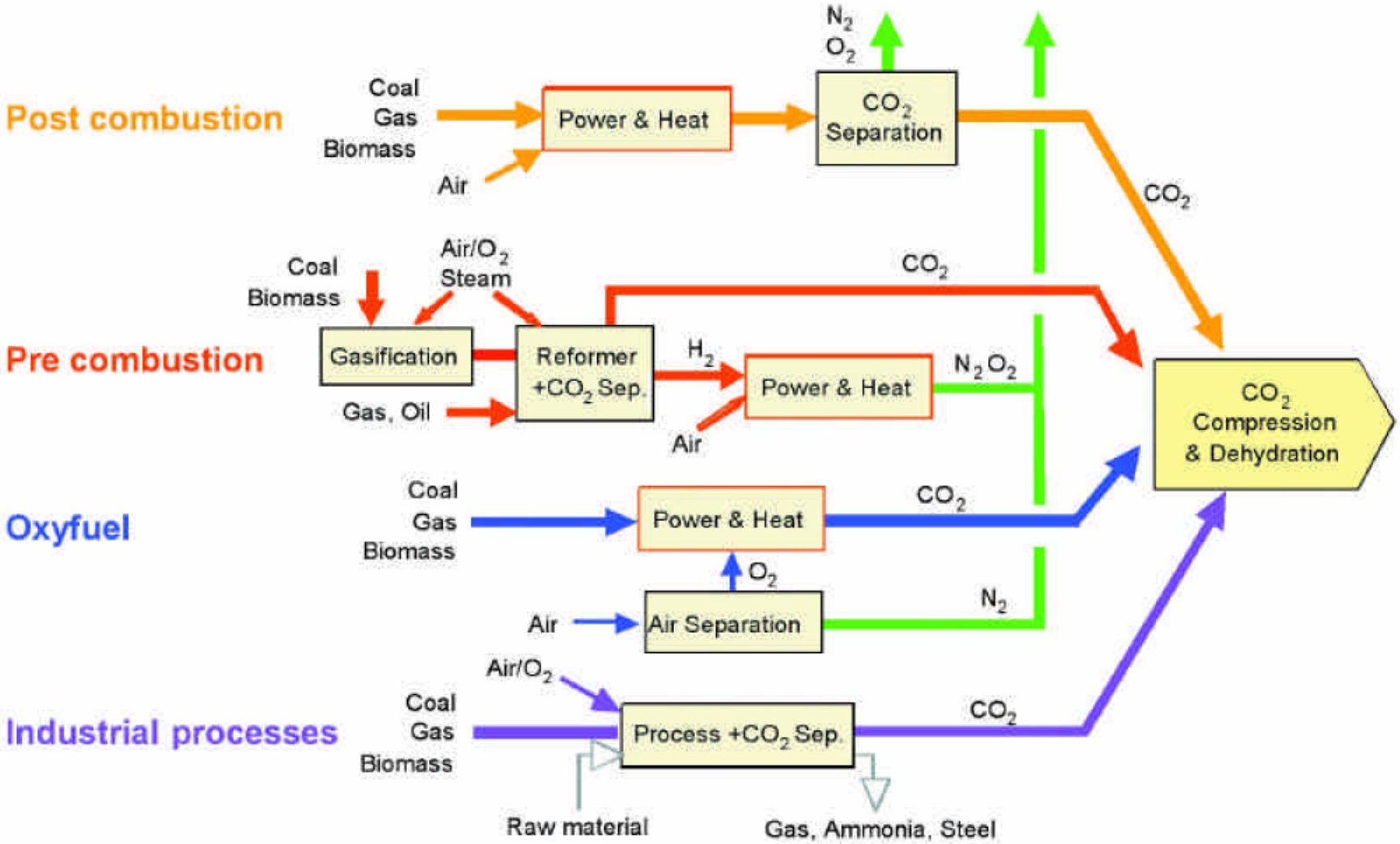
| | | | | |
|---|---|---|---|---|
| **Cost:** | $30 – $80 /t | $1 - $10 /t* | $2 - $10/t | **= $33 – $100/t** |

* Cost principally distance dependant

**Monitoring costs: $0.1-1/t**

IEA GHG

# Overview of CO2 capture processes and systems




IPCC – 2005 / CCP

# Estimated characteristics of power plants with CCS

| Fuel & Technology | Ref. Year | Invest. Cost ($/kW) | Effic. (%) | Effic. Loss (%) | Addit. Fuel (%) | Capture Effic. (%) | Capture Cost ($/t) | Electricity Cost (US¢/kWh) | Electricity cost no ccs (US¢/kWh) |
|---|---|---|---|---|---|---|---|---|---|
| Coal steam cycle, CA | 2010 | 1850 | 31 | 12 | 39 | 85 | 33 | 6.8 | 3.8 |
| Coal steam cycle, CA | 2020 | 1720 | 36 | 8 | 22 | 85 | 29 | 6.1 | 3.8 |
| Coal steam cycle, CA | 2030 | 1675 | 42 | 8 | 19 | 95 | 25 | 5.7 | 3.8 |
| IGCC, selexol, PA | 2010 | 2100 | 38 | 8 | 21 | 85 | 39 | 6.7 | 3.8 |
| IGCC, selexol, PA | 2020 | 1635 | 40 | 6 | 15 | 85 | 26 | 5.7 | 3.8 |
| NGCC CA | 2010 | 800 | 47 | 9 | 19 | 85 | 54 | 5.7 | 3.8 |
| NGCC oxyfuel | 2020 | 800 | 51 | 8 | 16 | 85 | 49 | 5.4 | 3.8 |
| Black liquor, IGCC | 2020 | 1620 | 25 | 3 | 12 | 85 | 15 | 3.4 | 2.4 |
| Biomass IGCC | 2025 | 3000 | 33 | 7 | 21 | 85 | 32 | 10.1 | 7.5 |
| IGCC SOFC | 2035 | 2100 | 56 | 4 | 7 | > 85 | 37 | 6.0 | 3.8 |
| NGCC SOFC | 2030 | 1200 | 66 | 4 | 6 | > 85 | 54 | 5.4 | 3.8 |

# Post-Combustion Status

| Overall Status | Concept | EXP | ENP | Deployment |
|---|---|---|---|---|
| Process Integration | | | | |
| Boiler & Power Process | | | | |
| DeSOx | | | | |
| DeNOx | | | | |
| CO2 Capture | | | | |
| New Solvents | | | | |
| CO2 Processing | | | | |

ZEP – WG1 - 2006

# Pre-Combustion Status

| Overall Status | Concept | EXP | ENP | Deployment |
|---|---|---|---|---|
| Process Integration | | | | |
| ASU | | | | |
| Coal Gasification | | | | |
| Nat Gas Reforming | | | | |
| Syngas Processing | | | | |
| CO2 Capture | | | | |
| CO2 Processing | | | | |
| High Efficiency H2 Gas Turbine | | | | |

# Oxy-Fuel Status

| Overall Status | Concept | EXP | ENP | Deployment |
|---|---|---|---|---|
| Process Integration | | | | |
| ASU | | | | |
| Combustion process and Boiler | | | | |
| Water/steam cycle - Particle removal | | | | |
| DeSOx | | | | |
| Flue Gas condensation | | | | |
| CO2 Processing | | | | |

ZEP – WG1 - 2006

# CO2 Capture Technologies

| | Post-Combustion | | Oxy-Fuel | | Pre-Combustion | |
|---|---|---|---|---|---|---|
| **Separation** | **CO2/N2** | | **O2/N2** | | **CO2/H2** | |
| **Capture technology** | Current | Emerging | Current | Emerging | Current | Emerging |
| **Solvents (Absorption)** | Chemical Solvents | Improved Solvents | N/A | Biomimetic solvents | Physical & Chemical Solvents | Improved chemical solvents |
| **Membranes** | Polymeric | Ceramic | Polymeric | Ion transport membranes | Polymeric | Ceramic, Palladium |
| **Solid sorbents** | Zeolites | Carbonates | Zeolites | O2 chemical looping | Zeolites | Carbonates |
| **Cryogenic** | Liquefaction | Hybrid processes | Distillation | Improved distillation | Liquefaction | Hybrid processes |

IPCC - 2005

# $CO_2$ Storage Phases

**Pre-Operation Phase**

Certification at start

~ 1-2 year

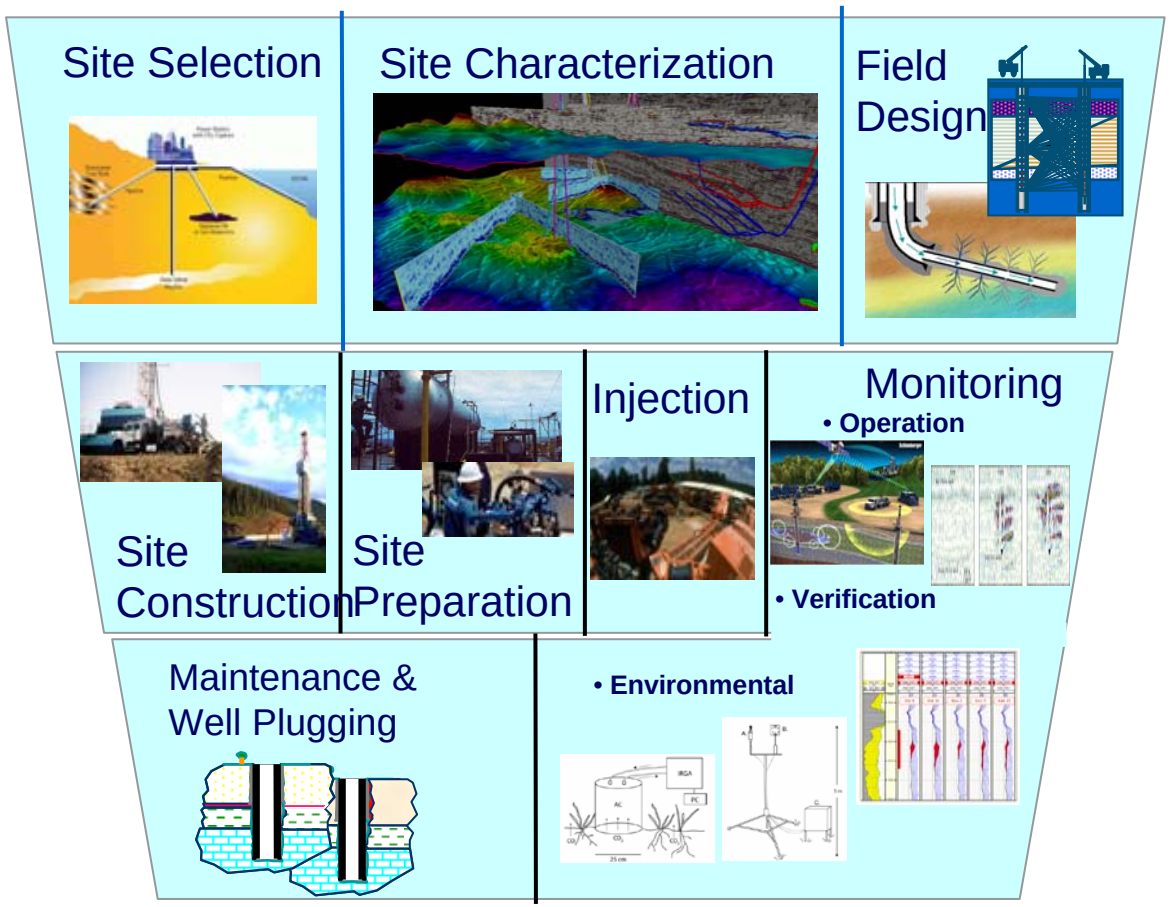
**Operation Phase**

~ 10-50 years

**Post-Injection Phase**

Transfer of Liabilities

~ 100-1000 years




Schlumberger - 2006

# Major R&D programs

- IEA GHG R&D Programme
- EU FP5, FP6, and FP7 projects
- Japan: Rite > 60 MEuros pa
- Australia: CO2CRC
- USA:
  - DOE funding/Regional partnerships>€50 M € pa
  - Major University-led projects: GCEP, Stanford, MIT…
- Canada: NRCan, ARC, CANMET
- Germany: Cooretec
- Other International Projects: CCP …
- China joint projects: EU, Canada, USA
- Private Sector

# CCS Technology Roadmaps

- European Union ZEP 2006
- US: NETL 2006, CURC/EPRI
- Canada: CANMET Center 2006, CCTRM
- Australia: CO2CRC – 2004
- CSLF – 2004
- Japan – Clean Coal 2002
- Germany, UK …

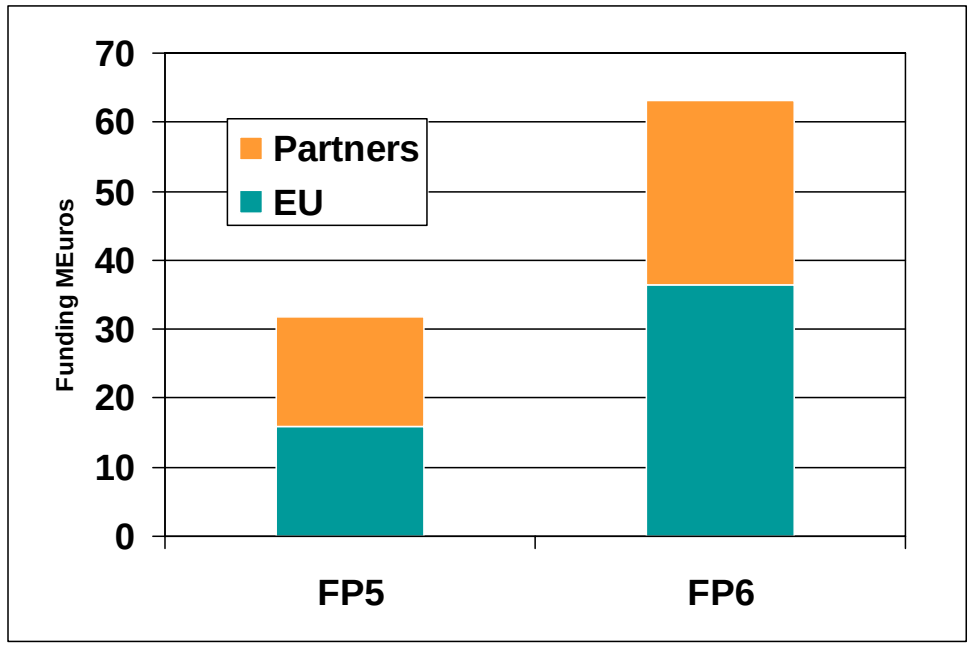
# Components of FP7

- Continued focus on Carbon Capture and Storage
- 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

# EU R&D Funding for CCS Technologies

Objectives:

- Capture
  - •Less than 20% increase in energy cost by 2007
  - •Less than 10% by 2012
- •Storage
  - •Storage capacity within 30% by 2012
- •MMV
  - •95 % accounting




•European Technology Platform on Zero Emission Fuel Power Plants launched on December 2005

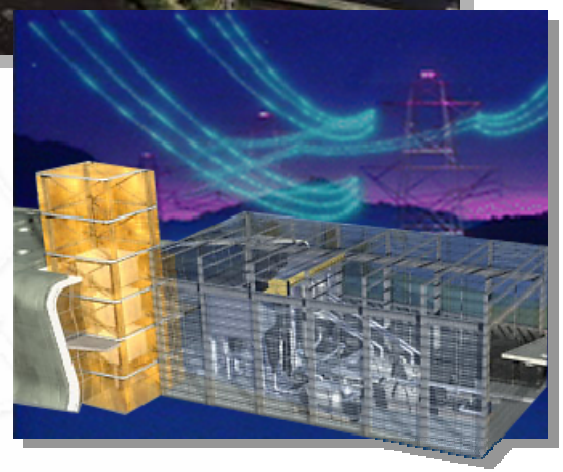
•Outreach programs (COACH …)

# European Based R&D Programme

- CCS Projects
  - Enhanced Capture of $CO_2$ in Large Power Plant (ENCAP) Project – FP6 funded project
  - $CO_2$ from Capture and Storage (CASTOR) – FP6 funded project dealing with post-combustion capture
  - ISCC (In-situ $CO_2$ Capture Technology for Solid Fuel Gasification) – FP6 funded project
  - Vattenfall taking the initiative – 30 MW pilot plant study
- Polygeneration of Hydrogen and Electricity
  - HYPOGEN Project
- Material Development Programme
  - Component Test Facility for a 700$^{o}$C Power Plant (COMTES700) – RFCS funded project – continuation of AD700 programme

# USA Roadmap Development Principle

- *Short-term:* keep existing fleet in service; prepare for transition to n zero-emission future
  - $SO_2$, $NO_x$, Hg
  - Plant optimization and control
  - Reduced carbon intensity
- *Long-term:* add near-zero emissio energy plants
  - IGCCs to market
  - Advanced materials
  - Ultra-high efficiency hybrid systems
  - $CO_2$ capture and storage



# USA Roadmap Development

- Global Climate Change Initiative
  - set a target of 18% GHG emission intensity reduction by 2012 (baseline year 2001)
- Future Gen – “Integrated Sequestration and Hydrogen Research Initiative”
  - US$ 1 Billion – 10 year programme
  - Target to demonstration a 275MW polygeneration plant by 2015
- Turbine of the Future Programme
  - Development of Gas Turbine firing with $H_2$ rich fuel

*Fuel Cells*


*Carbon Sequestration*

*Gasification with Cleanup Separation*

*$H_2$ Production*

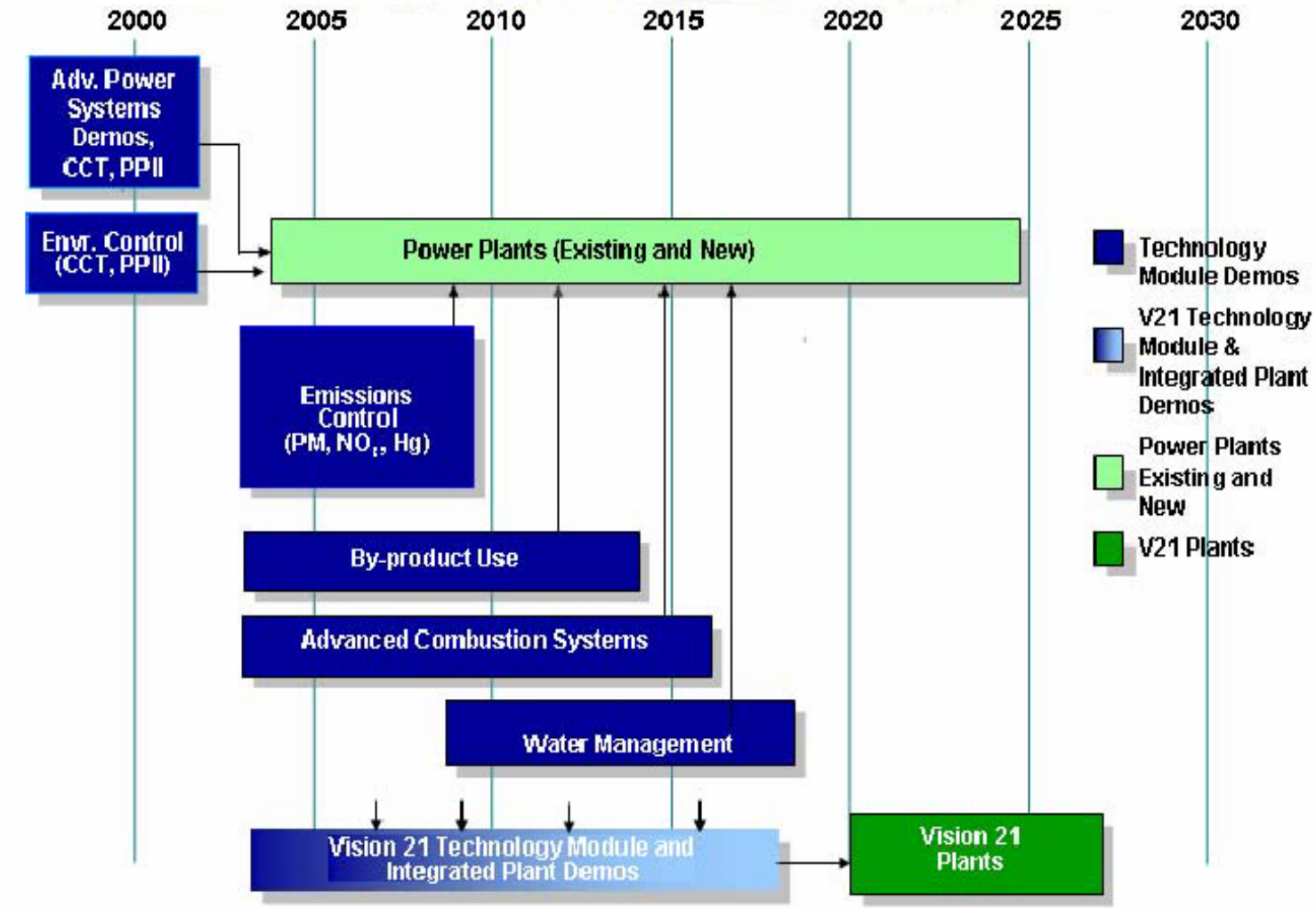
*Optimized Turbines*

*System Integration*

# USA Roadmap Development

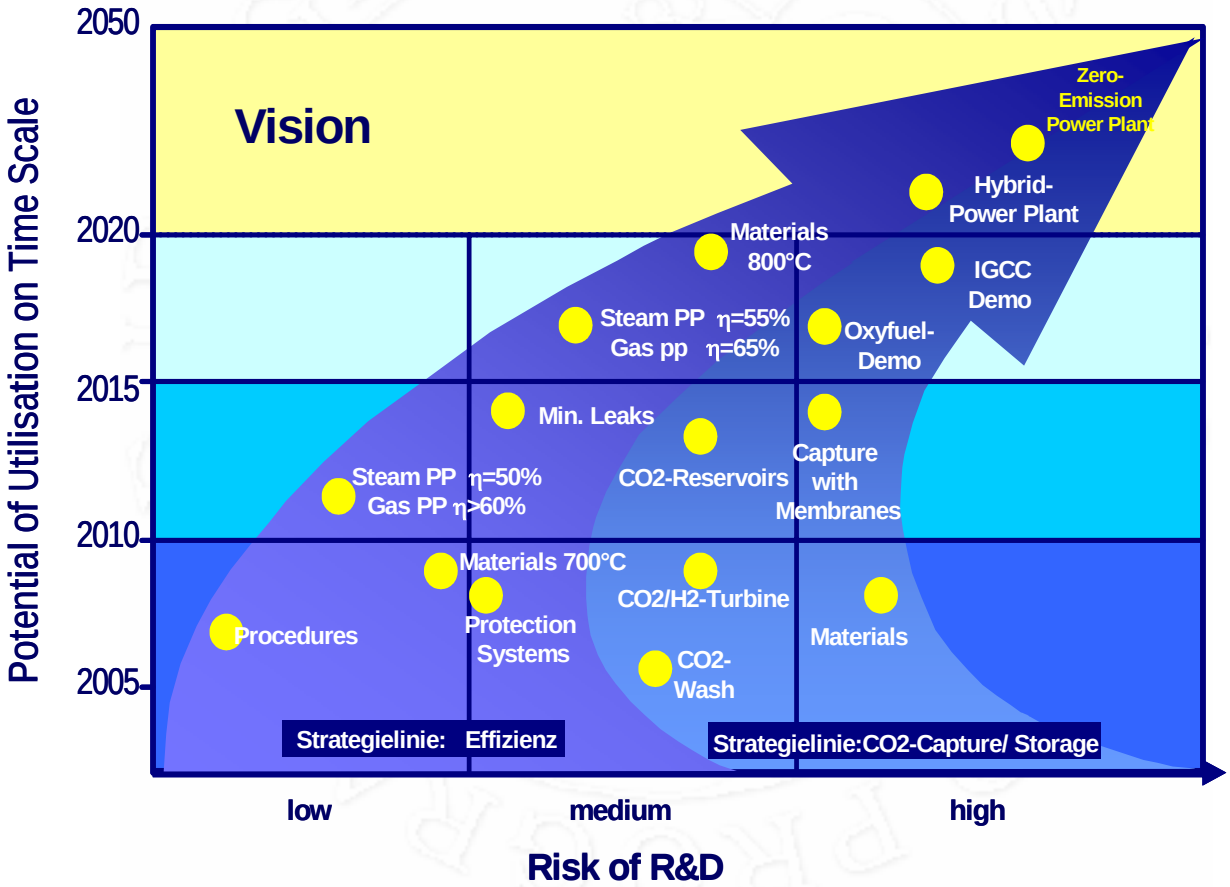
- Clean Coal Technology –
  - "Clean Coal Power Initiative" (2001 – 2011)
    - US $ 2 Billion over 10 years
  - "Power Plant Improvement Initiative" (2001)
    - Focus on efficiency improvement and emission reduction
- VISION 21 Programme – "21st Century Power Plant"
- Material Development Programme
  - Development of boiler material to achieve operating steam temperature greater than 750°C

# Vision 21 Programme - Strategy

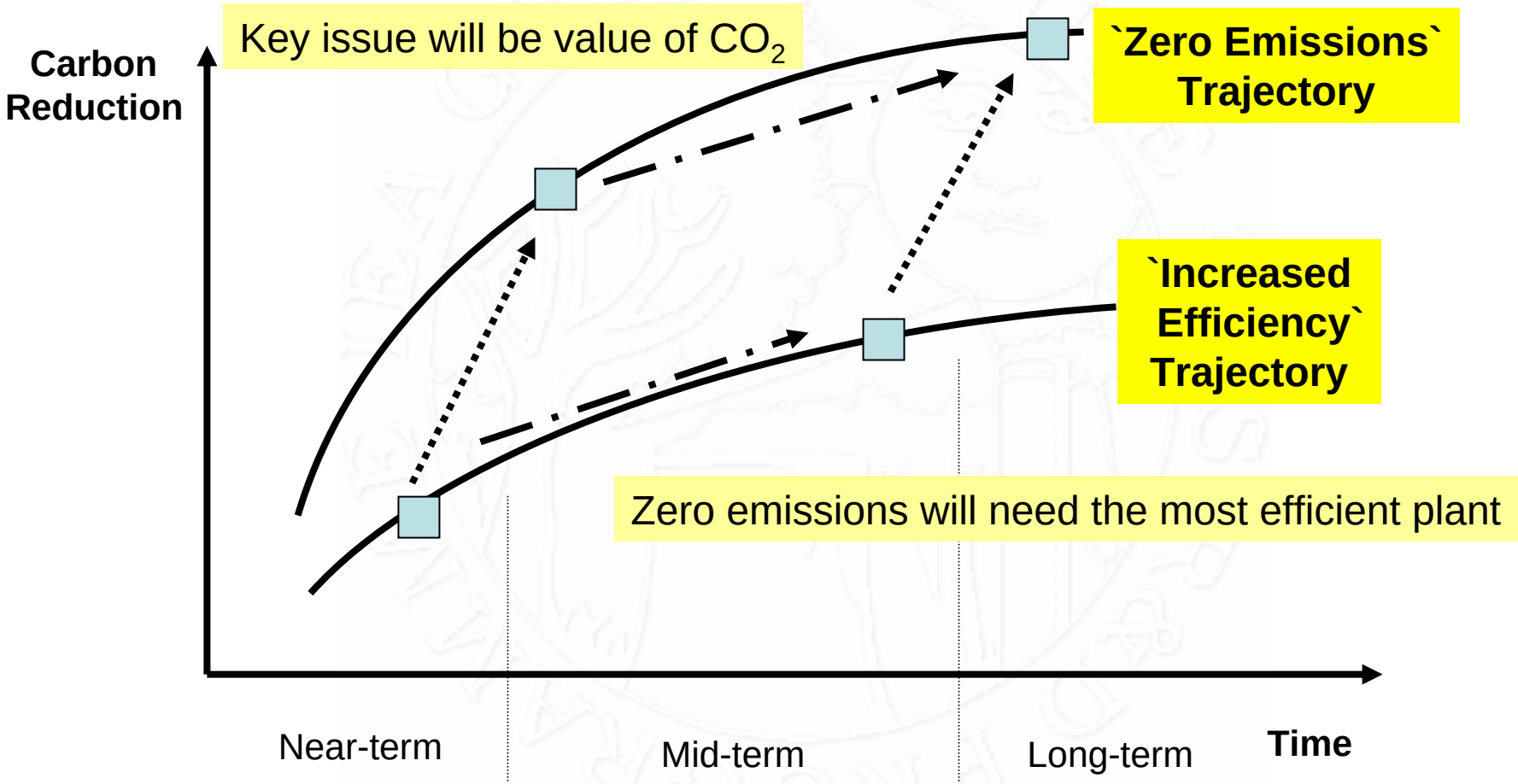


| Table 4.3 Performance Targets for Vision 21 Program | |
|---|---|
| Electrical Efficiency | 60% (LHV) |
| Cost competitiveness | Cost competitive with other energy systems |
| Timing | Major benefits by 2005;<br>subsystems and modules by 2012;<br>commercial plant design by 2015 |
| $NO_X/SO_X$ emissions | <4.3 µg/kJ |
| PM emissions | <2.5 µg/kJ |
| Hg emissions | <430 þg/kJ |
| $CO_2$ emissions | 40 - 50% reduction with efficiency improvement;<br>100% reduction with CCS |
| (Source: IEA, 2003) | |

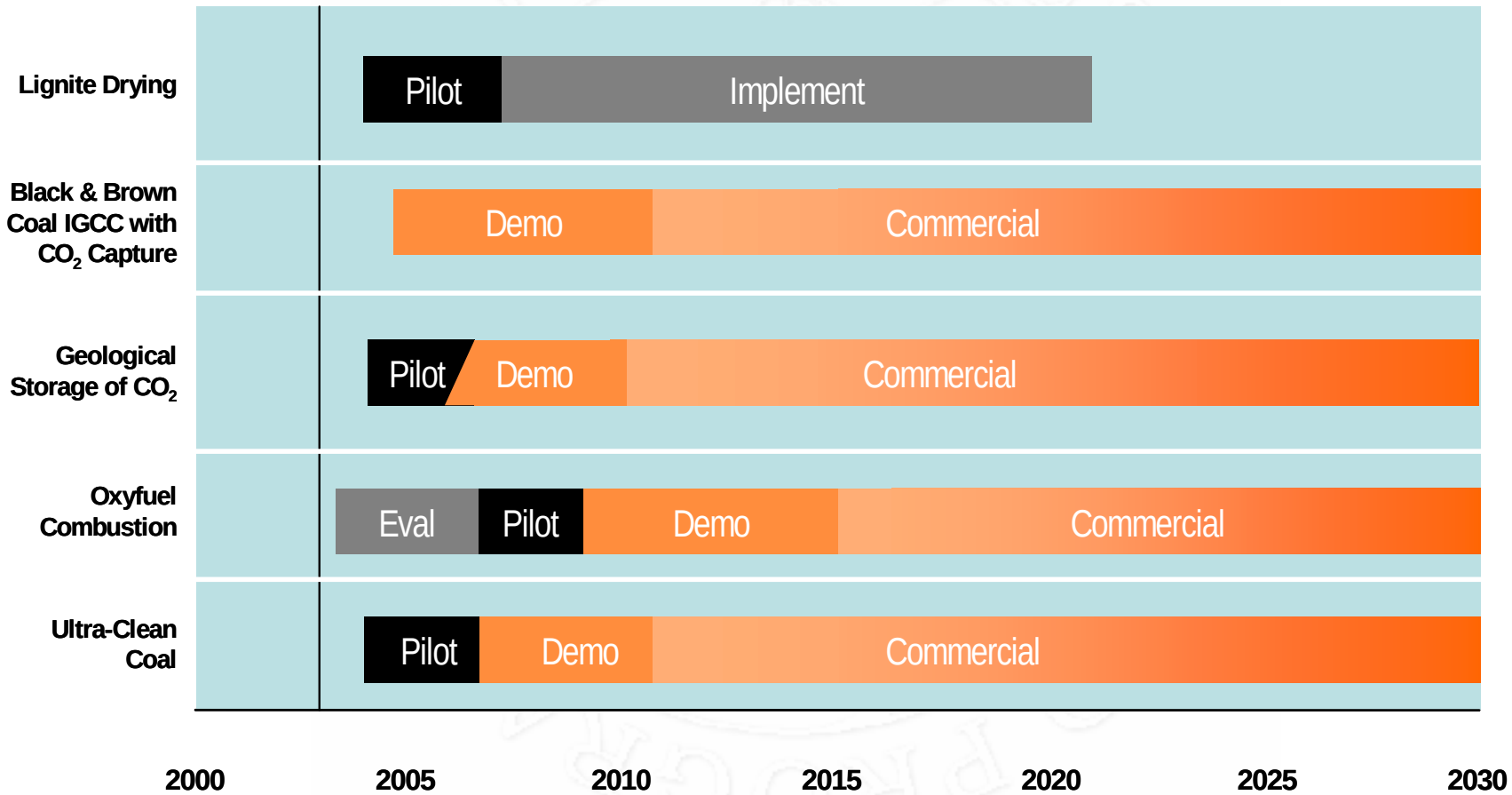
# German: COORETEC Programme



# UK: CAT Options are complementary



# Australia – Coal21 Action Plan



# Australian R&D Programme

- Oxy-Combustion Development
  - Japanese-Australian cooperation
  - Pilot Scale study for PC Boiler Retrofit (25 MWe) – Callide A Project
- IGCC Demonstration Plant Programme
  - Demonstration of IGCC with carbon capture programme
  - Pilot plant study (16 MW and 65 MW)
  - 200 MW will be commissioned at Stanwell Power Station by 2010 - depending on the outcome of the feasibility study
- IDGCC for brown coal
  - Target to commission 800 MWe IDGCC by 2010
  - 100 MW IDGCC demonstration project is currently at site selection and costing stage. Decision to proceed will be made by mid-2006
- Ultra Clean Coal Development Programme
  - International cooperation with the Japanese (Hyper Coal Project)
  - A relationship was developed with the Chinese power utilities

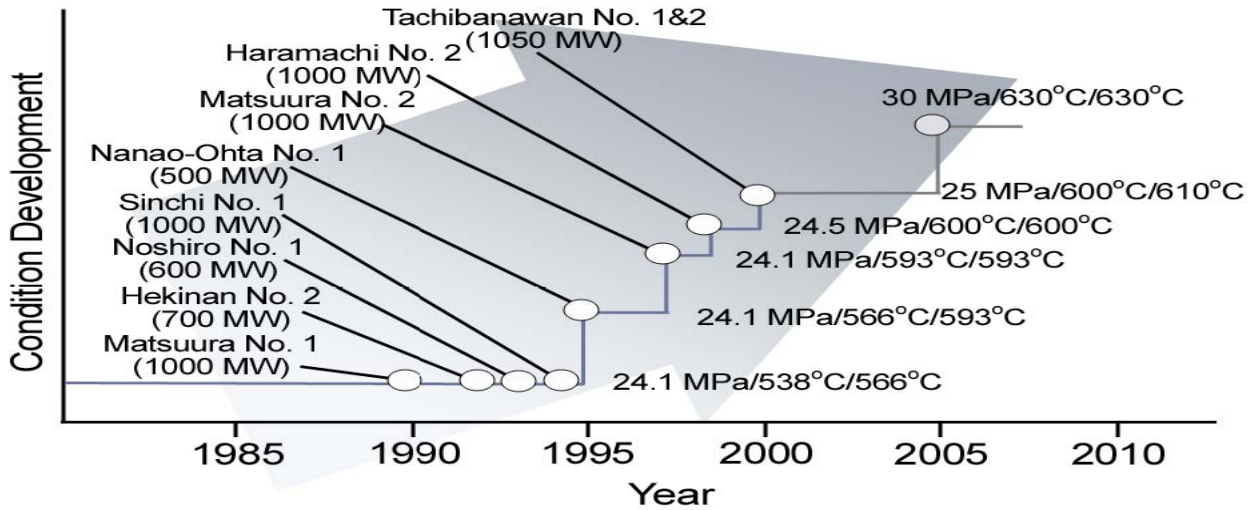
# Japanese Vision - Development for 21st Century

| | 1990 | 2000 | 2010 | 2020 |
|---|---|---|---|---|
| **Environment limitation** | **$CO_2$ reduction rate:10%** | **10 - 20 %** | **20 - 30 %** | **30 - 40%** |
| **Resource limitation** | Efficiency increase:<br>1st generation<br>- PFBC<br>- PC (USC) | Efficiency increase:<br>2nd generation<br>- coal combustion & gasification combined cycle power generation (IGCC, etc.)<br>- DIOS, SCOPE21<br>- Reduction of emissions: 3 Tens | Efficiency increase:<br>Hybrid Generation<br>- fuel cell power generation based on coal gasification<br>- simultaneous power generation & chemical feedstock gas production<br>- hydrogen production from coal ($CO_2$ recovery and fixation)<br>- elimination of emissions | Zero-emission generation<br>- hydrogen from coal: fuel cell & hydrogen turbine combined cycle power generation, hydrogen driven automobiles<br>- concept of new coal industries: energy, iron and steel, and chemicals unified centre<br>- $CO_2$ conversion and utilization |

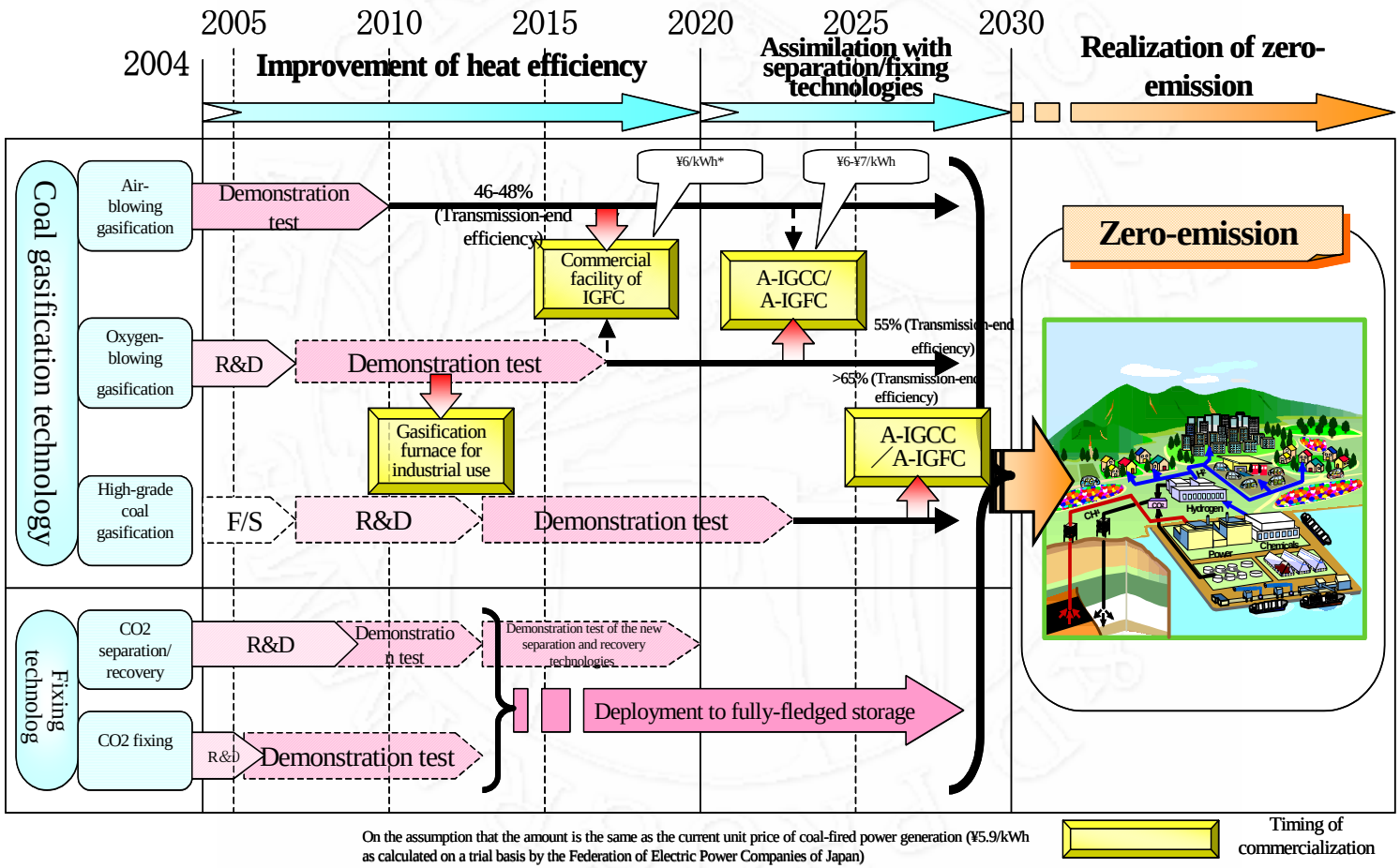
Note: Reduction rates are on an intensity basis

(Source: Michiaki, 2002)

# Japanese Roadmap Development – Starting Point



# Japanese C3 Initiative toward ZET Coal Utilisation

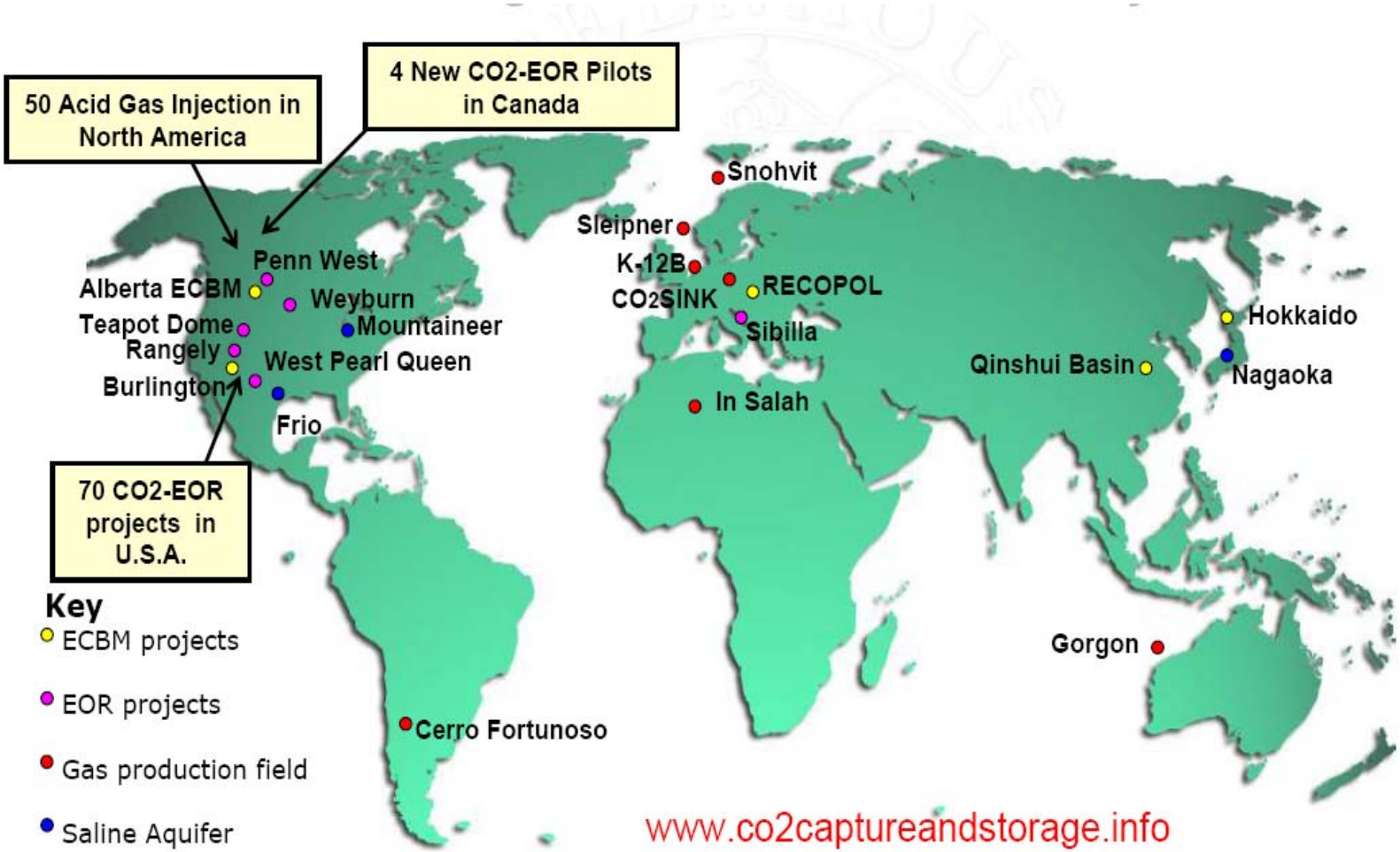


# Japanese R&D Programme

- IGCC Demonstration Project
  - Demonstration of 250 MW IGCC (based on oxygen enriched air blown gasifier) to be operational by 2007
  - Target efficiency (LHV basis) ~ 48%
- Energy Application for Gas, Liquid and Electricity (EAGLE) Programme
  - Target to deploy 50 MWe IGFC by 2010 (for distributed electricity)
  - Target to deploy 600 MWe IGFC by 2020
- Oxy-Combustion Development
  - International cooperation with Australia
- Hyper-Coal Project (Ultra Clean Coal Project)
  - International cooperation with Australia
  - Target to produce coal processed to remove ash and other undesirable components which will be fired directly in a turbine.

# Commercial Scale Capture Projects

# Storage Projects



# Summary

- Drivers for R&D in CCS
  - Capture cost
  - Storage: Optimization and MMV
- Several technology roadmaps from North America, Europe, Japan and Australia
- International and regional coordination networks
- Announced commercial-scale projects are far from an emission-reduction “wedge” by 2020