POLITECNICO DI MILANO





Pianeta 3000
La ricerca scientifica per l'Ambiente e il Territorio

Problematica e Tecnologie per la cattura di CO_2

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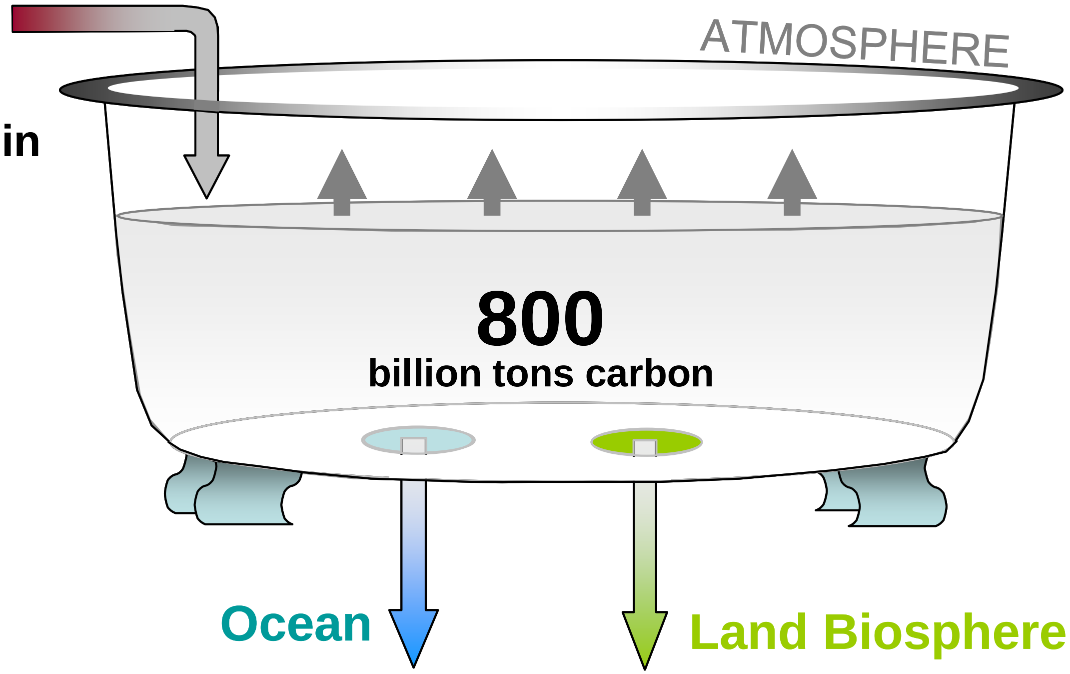
Outline of this talk

- The scale of the greenhouse issue: quantitative targets for Carbon Capture & Storage
- Pre-combustion capture
- Oxy-fuel
- Post-combustion capture
- Performance and economic comparison

The greenhouse problem

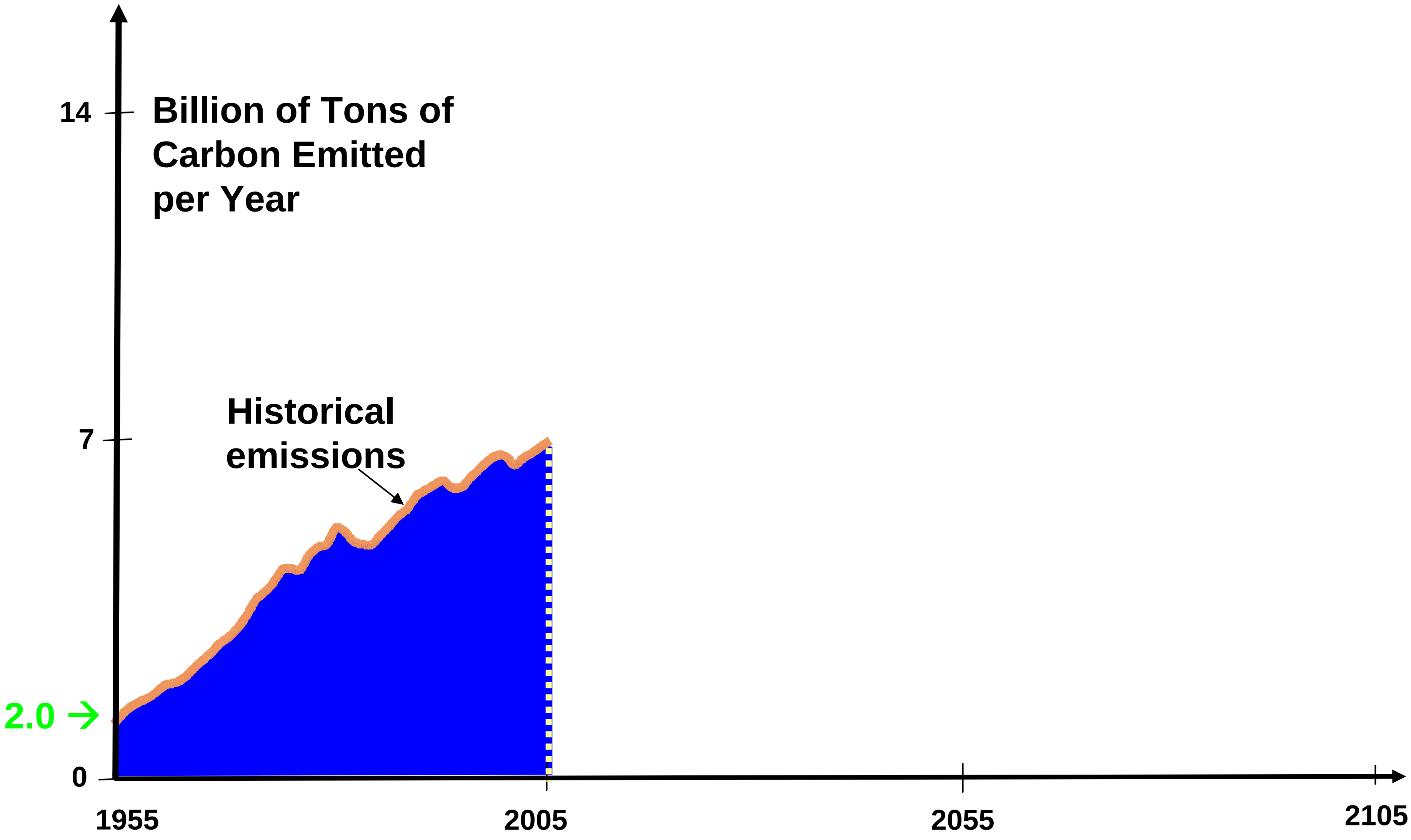
The atmosphere as a bathtub: current inputs and outputs of carbon



Graphic courtesy of Rob Socolow

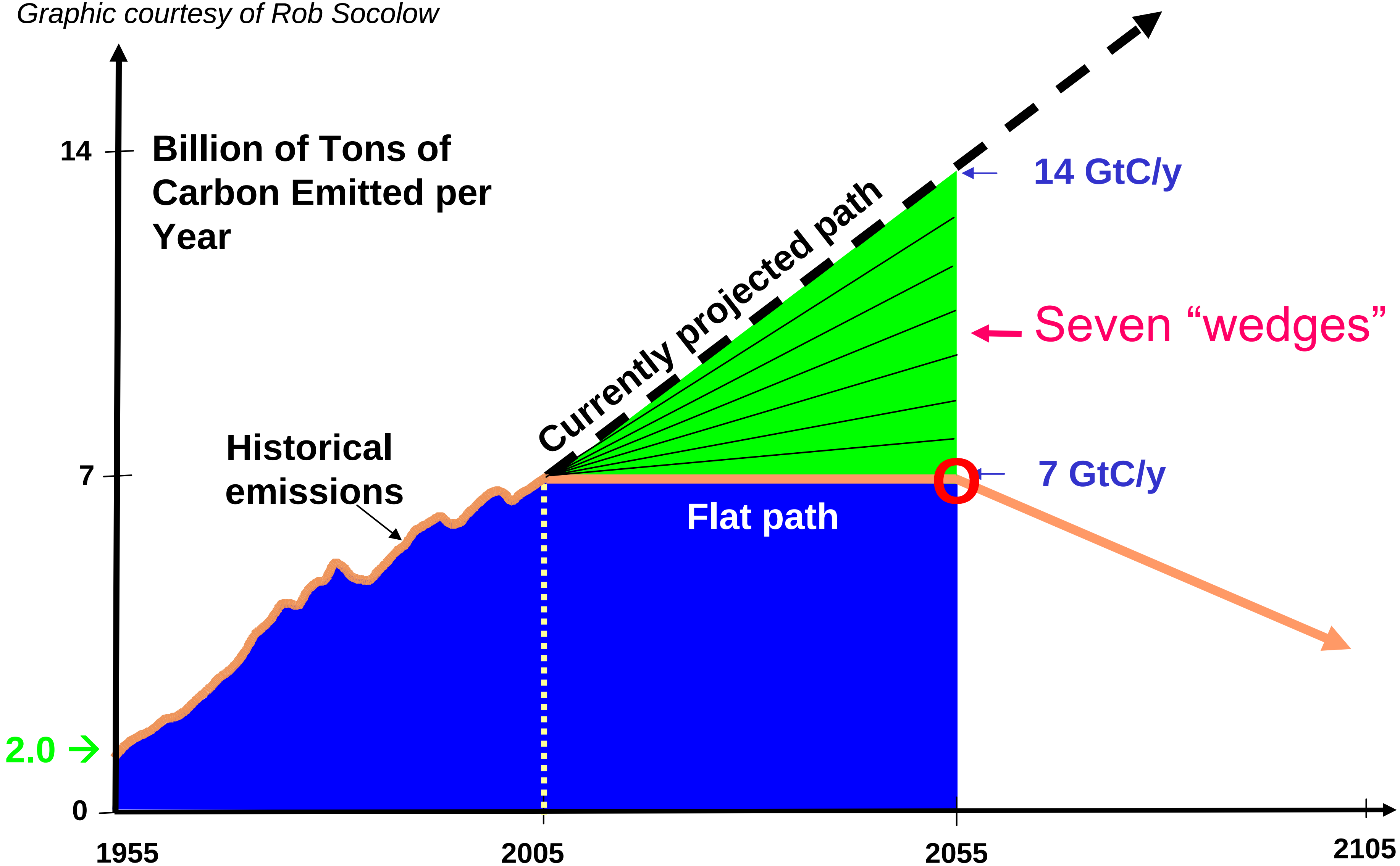
The Wedges approach: past emissions

Graphic courtesy of Rob Socolow



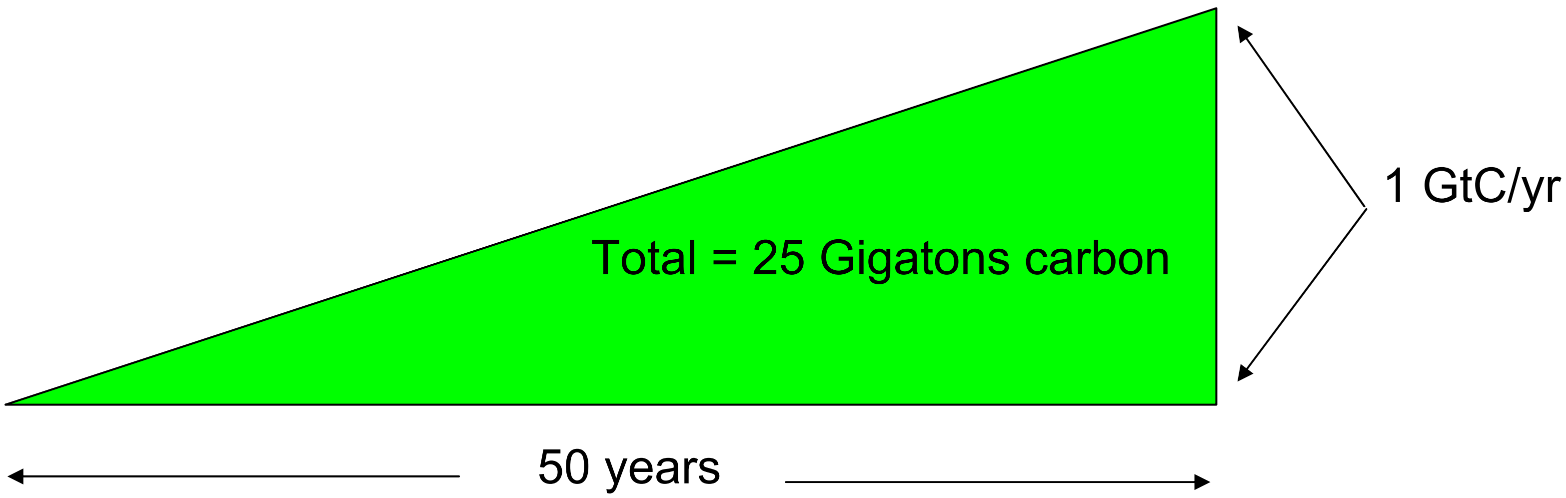
The Wedges

Graphic courtesy of Rob Socolow



What is a "Wedge"?

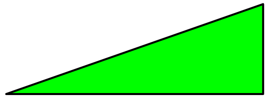
A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr.



Cumulatively, a wedge redirects the flow of 25 Gt(C) in its first 50 years.

A "solution" to the Greenhouse problem should have the potential to provide at least one wedge.

Making a Wedge: wind electricity



Effort needed by 2055 for 1 wedge:

One million 2-MW windmills (for a total of 2000 GW) displacing coal power.

Today: 50 GW (1/40)

Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)

Making a Wedge: efficient use of fuel

Effort needed by 2055 for 1 wedge:

Note: 1 car driven 10,000 miles at 30 mpg emits 1 ton of carbon.

2 billion cars driven 10,000 miles per year at 60 mpg instead of 30 mpg.

2 billion cars driven, at 30 mpg, 5,000 instead of 10,000 miles per year.

Property-tax systems that reinvigorate cities and discourage sprawl

Video-conferencing

Coal electricity Wedge

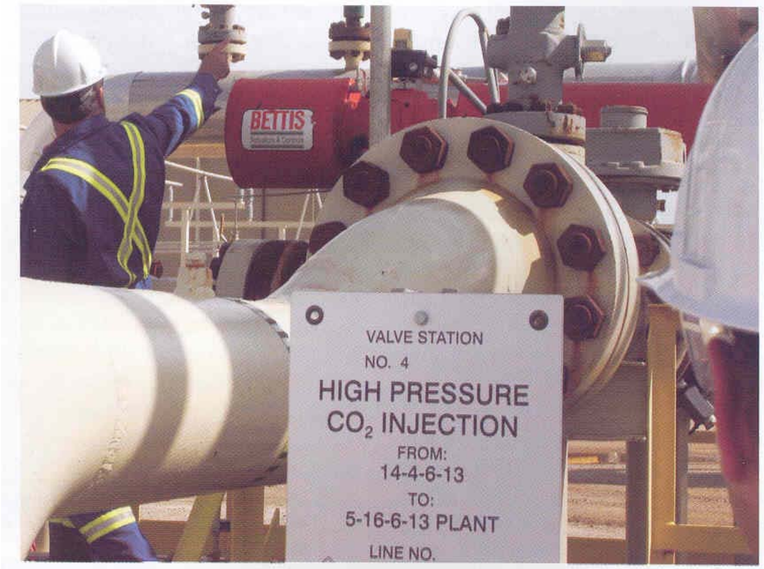
600 modern (90% capacity factor, 42% efficient) 1-GW coal plants, with CO_2 vented, will emit 1 GtC each year.

An electricity-carbon wedge results from not building these plants.

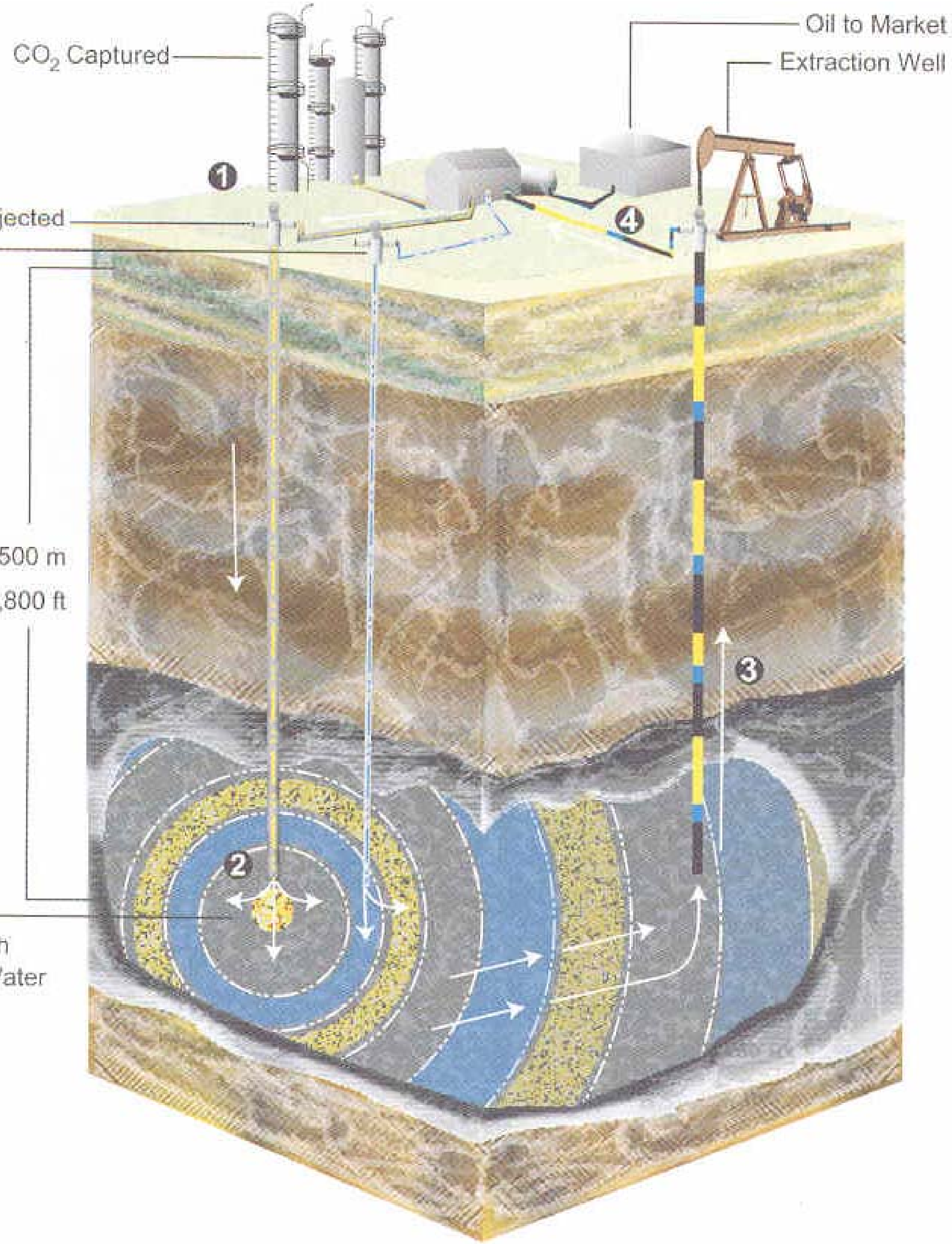
The IEA 2004 Reference Scenario showed 1400 GW of new coal plants built between now and 2030; the 2006 Reference Scenario shows 1800 GW.

The principal reason for the upward revision: Coal is now expected to have less competition from natural gas.

The Weiburn project (Canada)

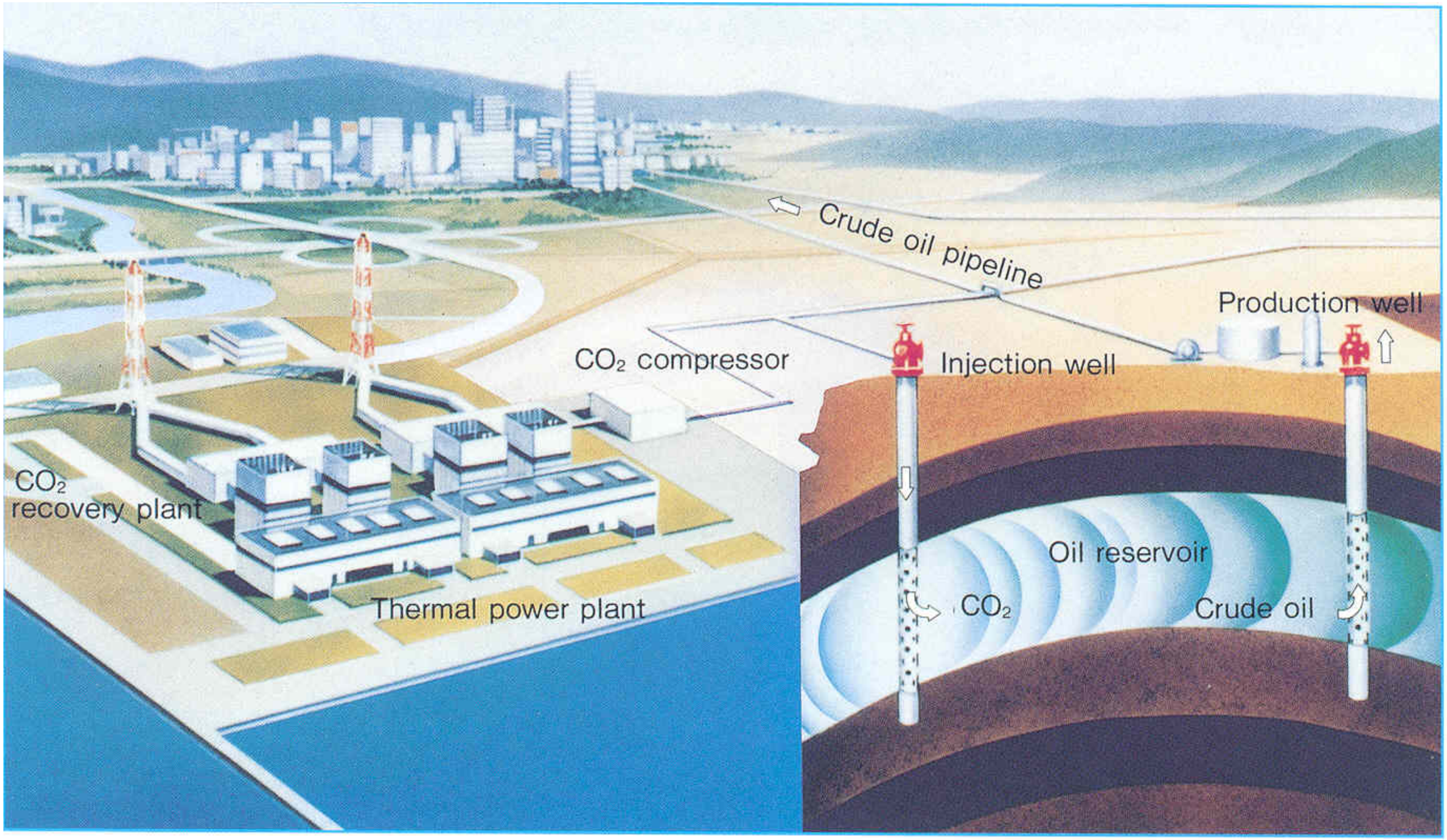


The CO_2 Pipeline Close-up. More than seven million tonnes of CO_2 captured from the Dakota Gasification Plant in Beulah, North Dakota has been transported 320 km via pipeline to the Weyburn field, where it is now securely stored 1500 metres underground in depleted oil and gas reservoirs.

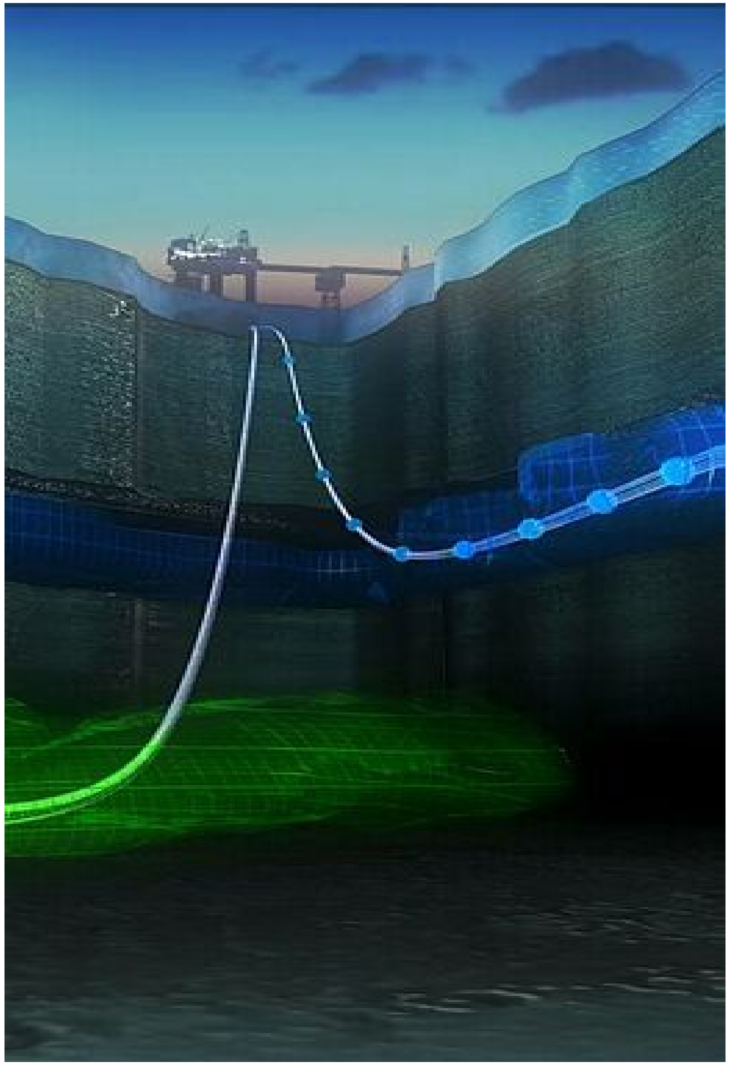


The In-Salah project (Algeria)

Capture + Enhanced Oil Recovery (EOR)



Making a Wedge with carbon storage



Sleipner project, offshore Norway

Graphic courtesy of Statoil ASA

Effort needed by 2055 for 1 wedge:

- 3500 Sleipners @1 $MtCO_2$/yr
- 100 x U.S. CO_2 injection rate for EOR
- A mass flow of CO_2 into the Earth equal to the mass flow of oil out of the Earth today

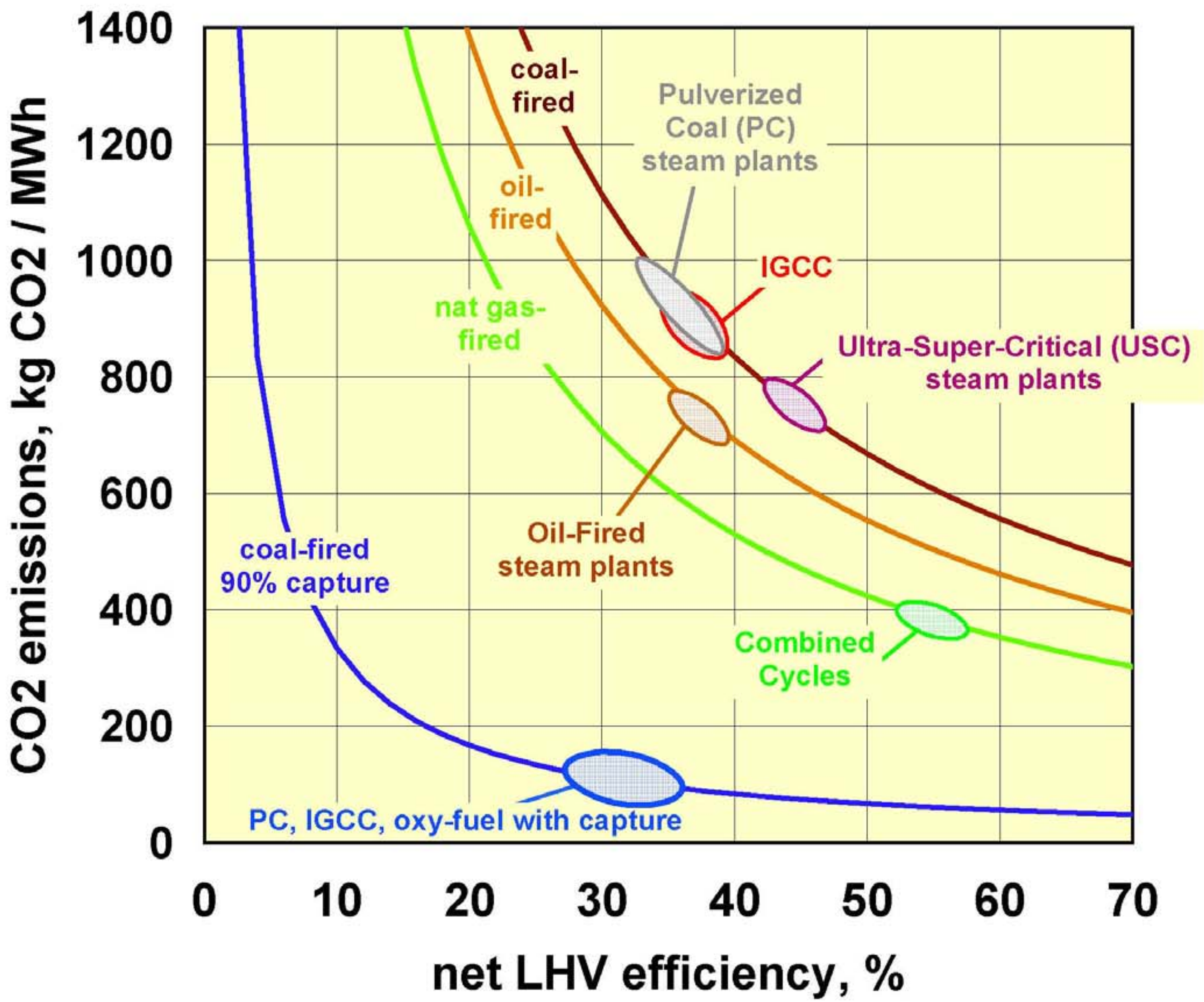
Graphic courtesy of David Hawkins

Rationale and approaches for CO_2 capture

- CO_2 capture: a strategy to manage the transition toward carbon-free energy sources and carriers

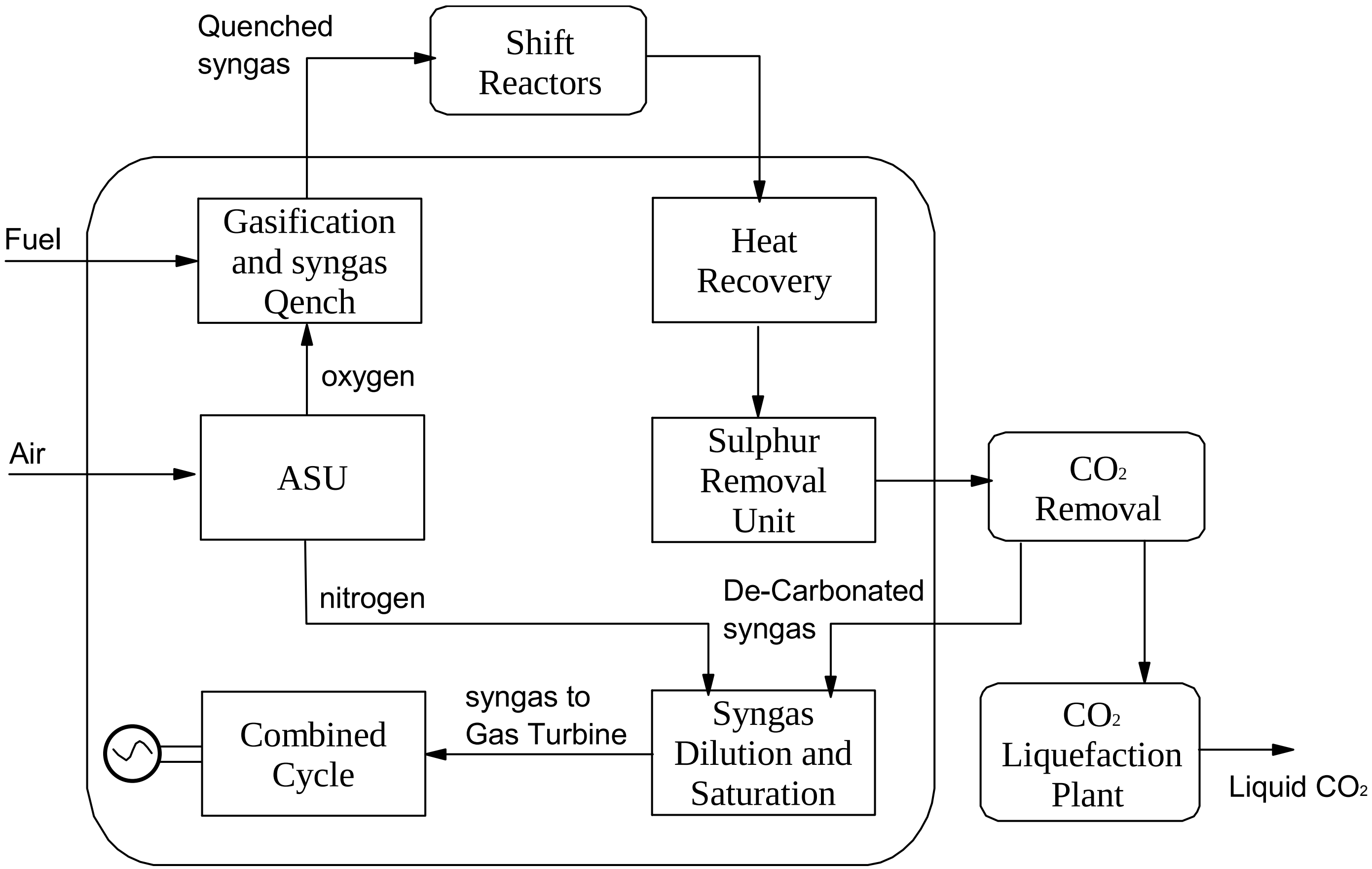
- Conceptually, CO_2 capture from fossil fuel-fired power plants can be accomplished in three ways:
  - treat the fuel → pre-combustion capture (IGCC with fuel decarbonization)
  - treat the oxidant → oxy-fuel
  - treat the flue gases → post-combustion capture (amine chemical absorption)

CO_2 emissions: coal vs oil and natural gas

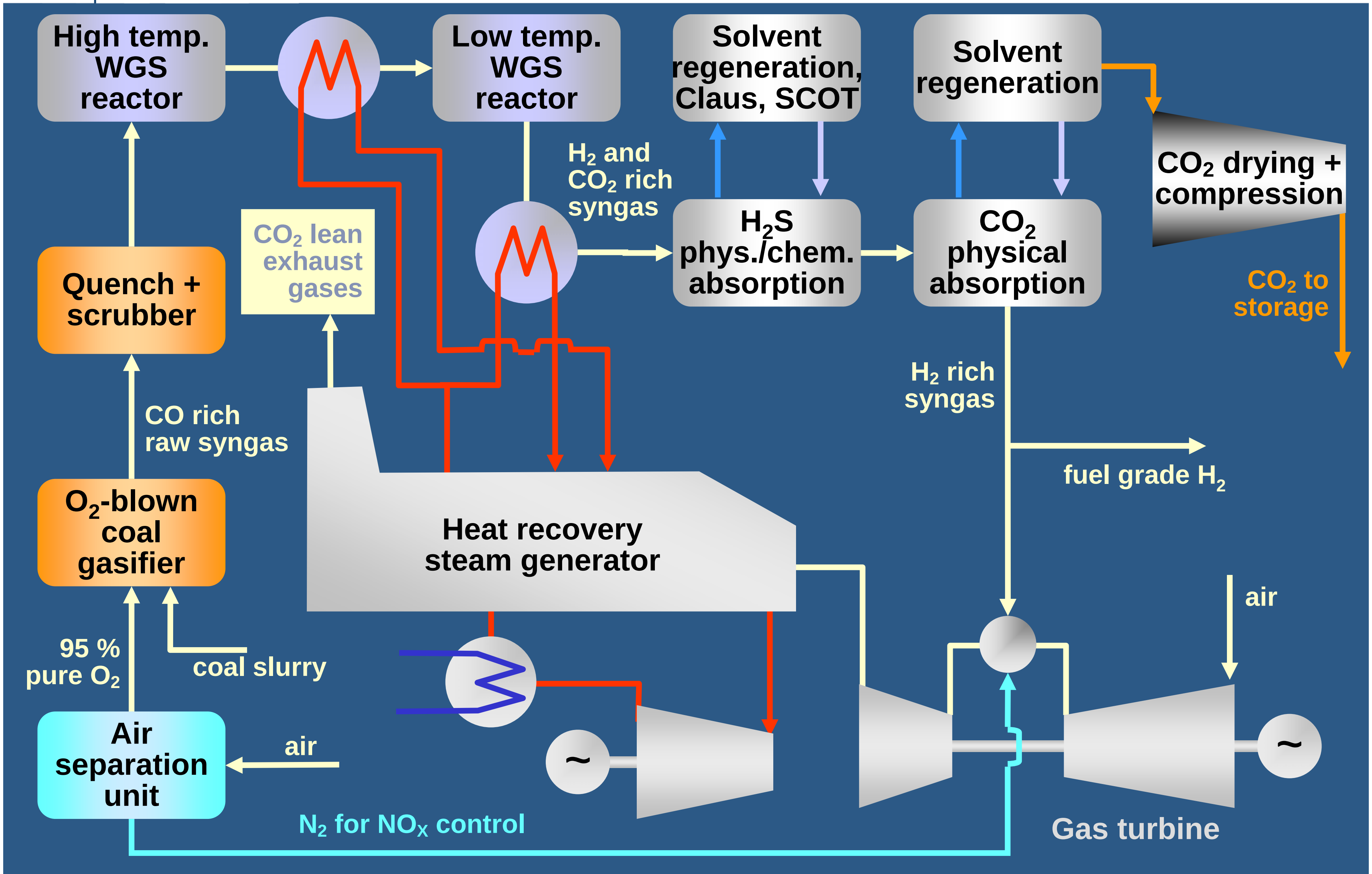


IGCC with fuel decarbonization

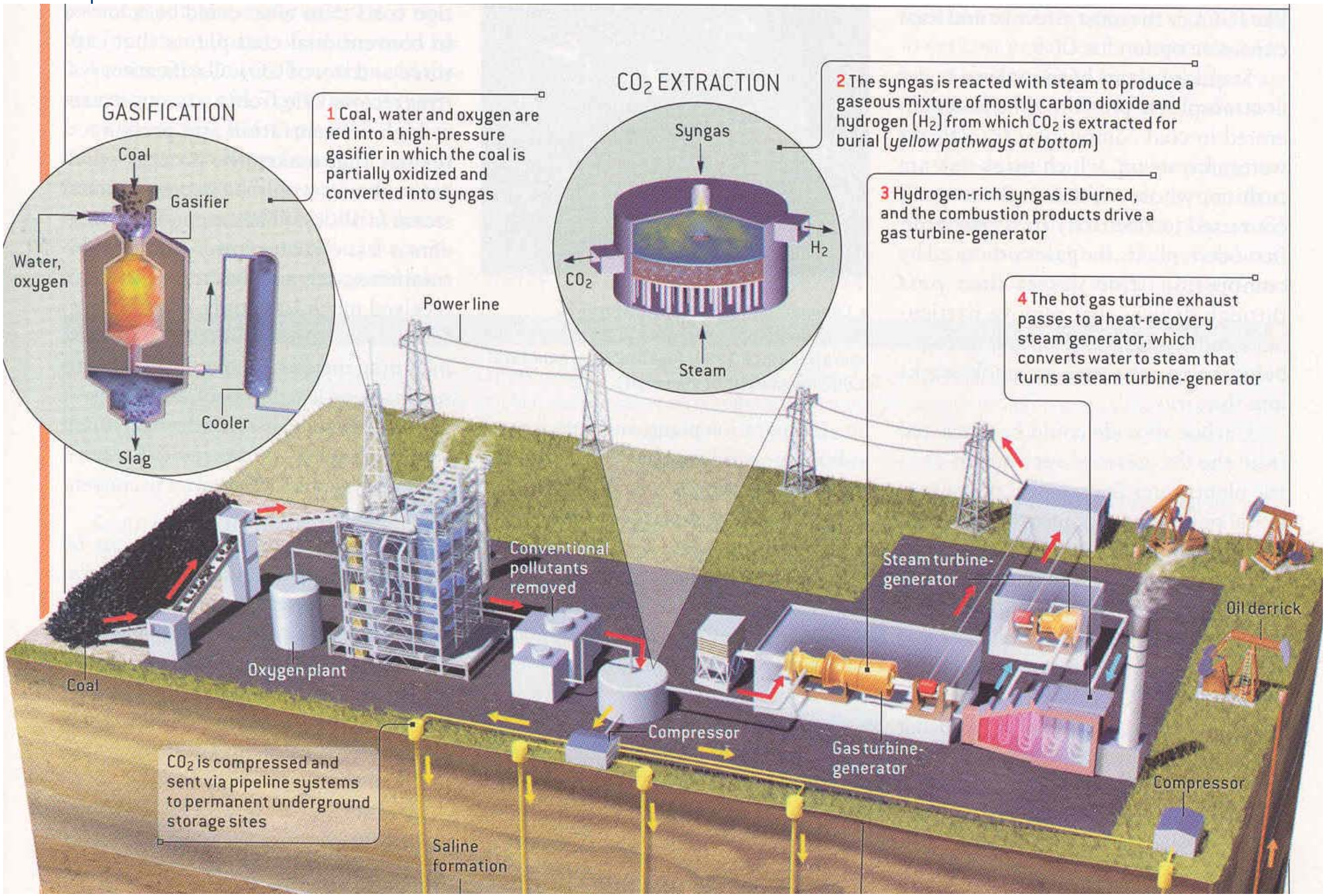
In an IGCC, coal is converted into a synthetic fuel gas (syngas) in a gasifier; CO_2 capture can be accomplished by syngas Water-Gas Shift (WGS) followed by CO_2 physical absorption



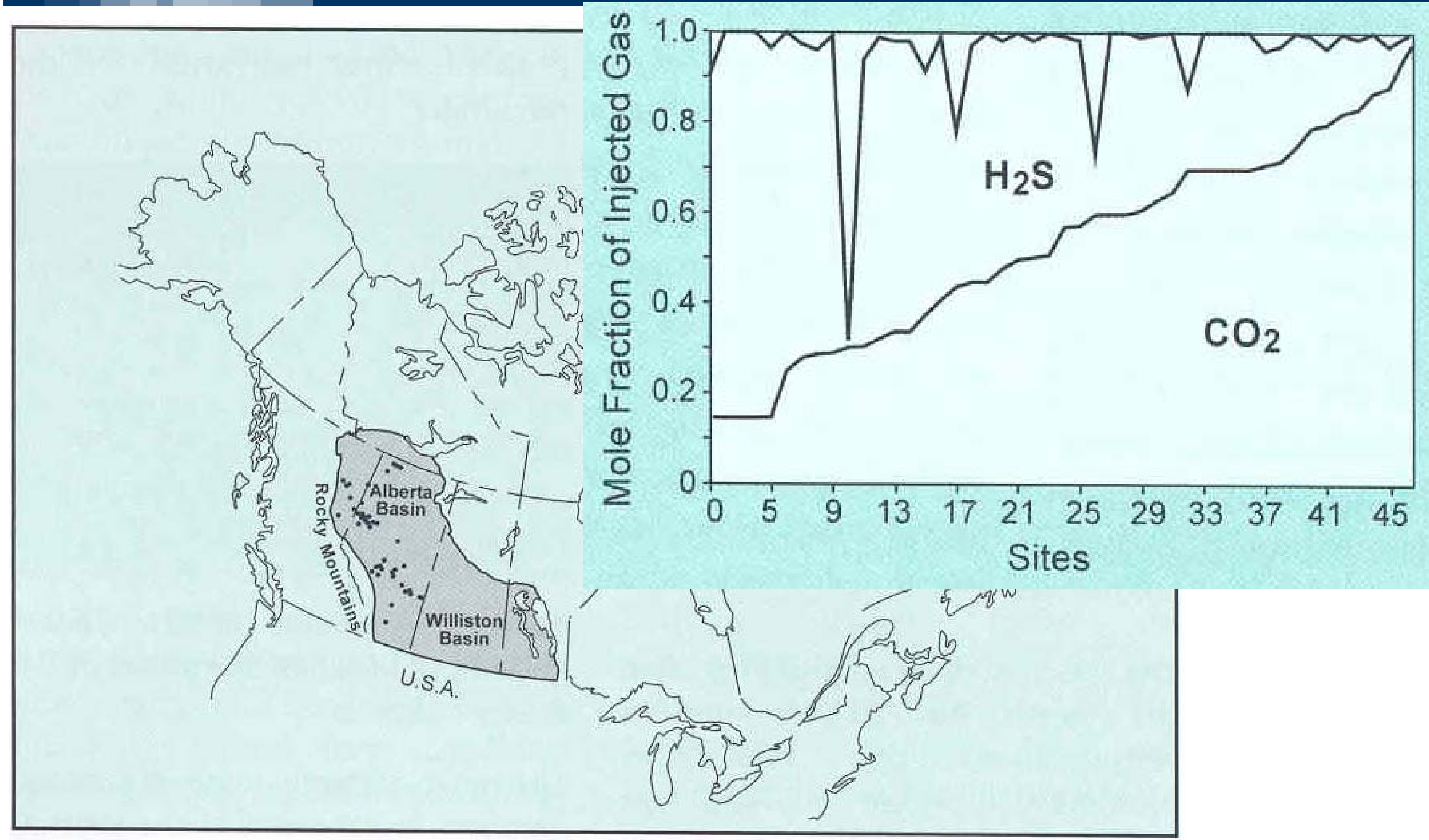
IGCC with CO_2 capture and production of hydrogen



IGCC + CCS

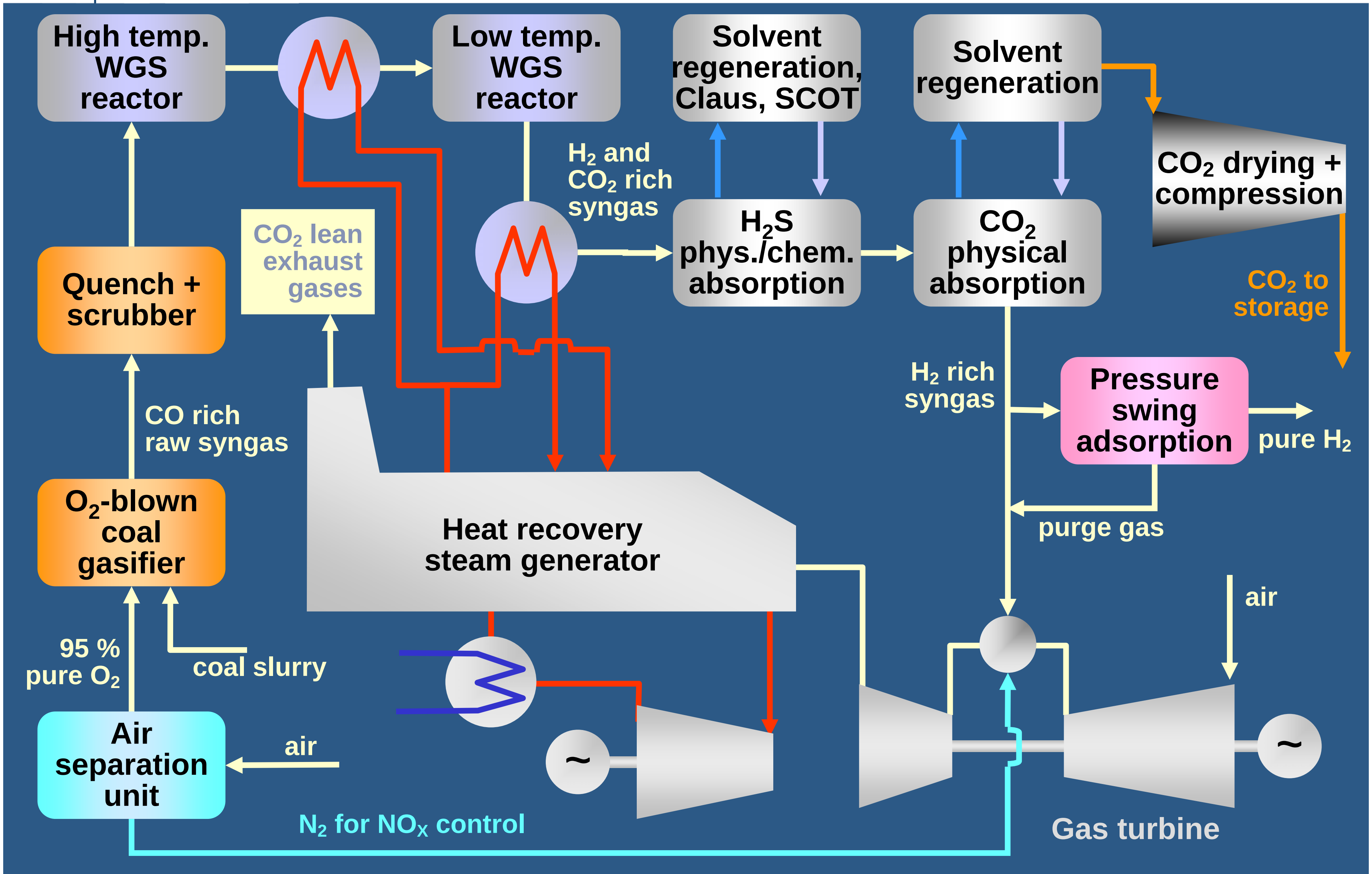

GASIFICATION
Coal
Gasifier
Water, oxygen
Cooler
Slag
1 Coal, water and oxygen are fed into a high-pressure gasifier in which the coal is partially oxidized and converted into syngas
CO_2 EXTRACTION
Syngas
H_2
CO_2
Steam
2 The syngas is reacted with steam to produce a gaseous mixture of mostly carbon dioxide and hydrogen (H_2) from which CO_2 is extracted for burial (*yellow pathways at bottom*)
3 Hydrogen-rich syngas is burned, and the combustion products drive a gas turbine-generator
4 The hot gas turbine exhaust passes to a heat-recovery steam generator, which converts water to steam that turns a steam turbine-generator
Power line
Conventional pollutants removed
Steam turbine-generator
Oil derrick
Coal
Oxygen plant
Compressor
Gas turbine-generator
Compressor
CO_2 is compressed and sent via pipeline systems to permanent underground storage sites
Saline formation

Co–sequestration of CO_2 and H_2S



Location of acid-gas injection operations in Canada

IGCC + CCS: co-production of electricity and H_2



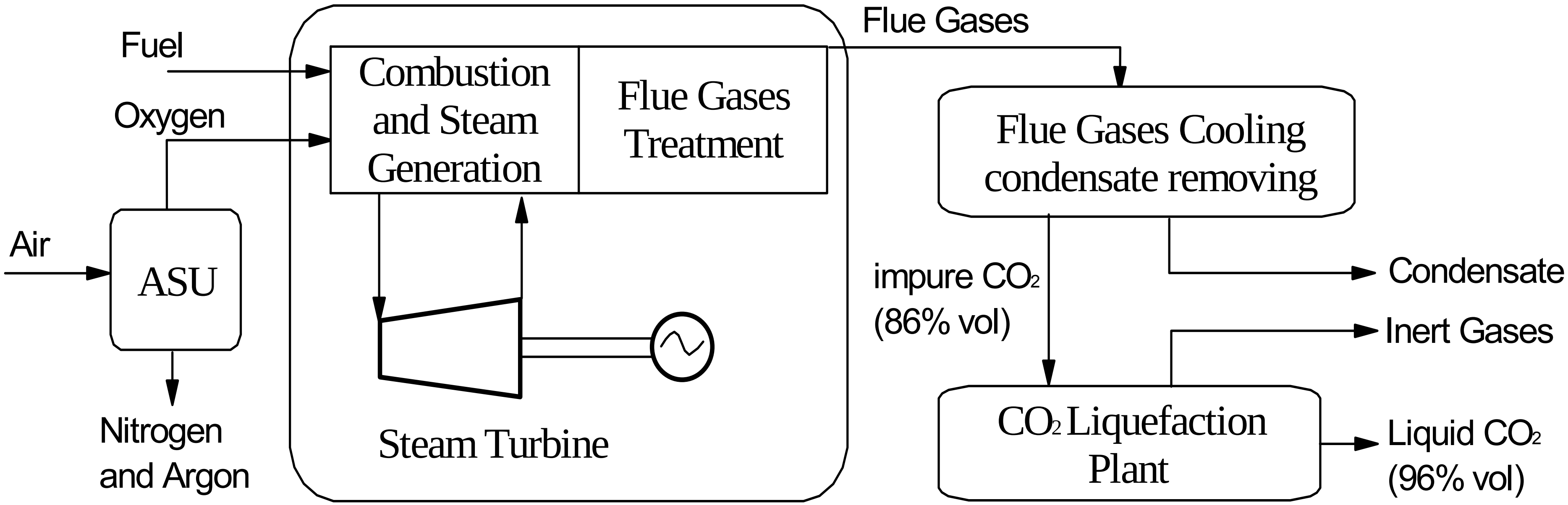
Selexol plant for H_2 production from coal

Urea production in Coffeyville, Kansas.
GE quench gasifier (former Cool Water)

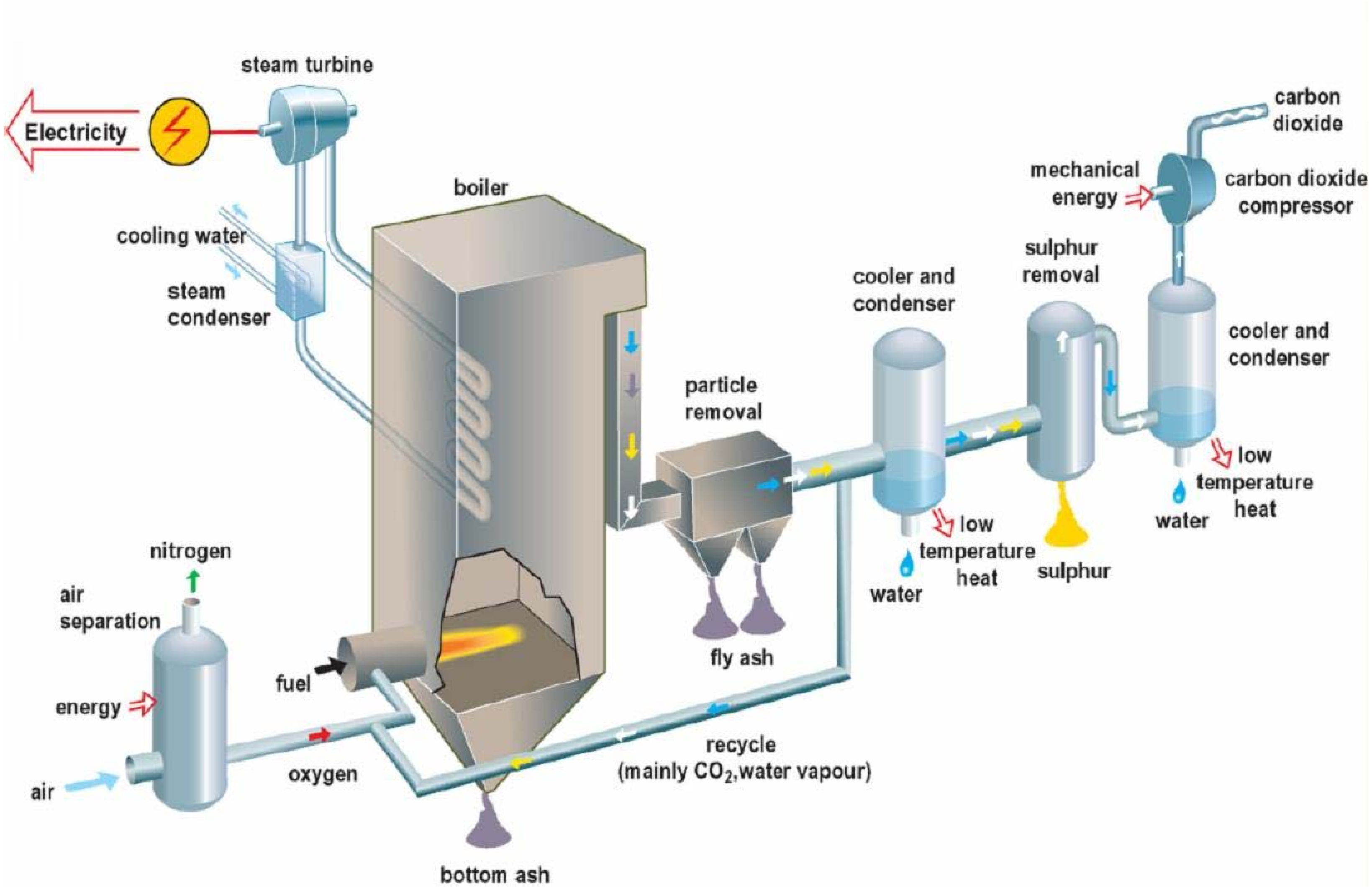
Oxy-fuel

The power plant consists of a steam power plant where combustion air is substituted by 95% pure oxygen.

Combustion gases are mainly composed of CO_2 and H_2O.
CO_2 can be segregated by simply cooling down the flue gases and knocking out the condensed water

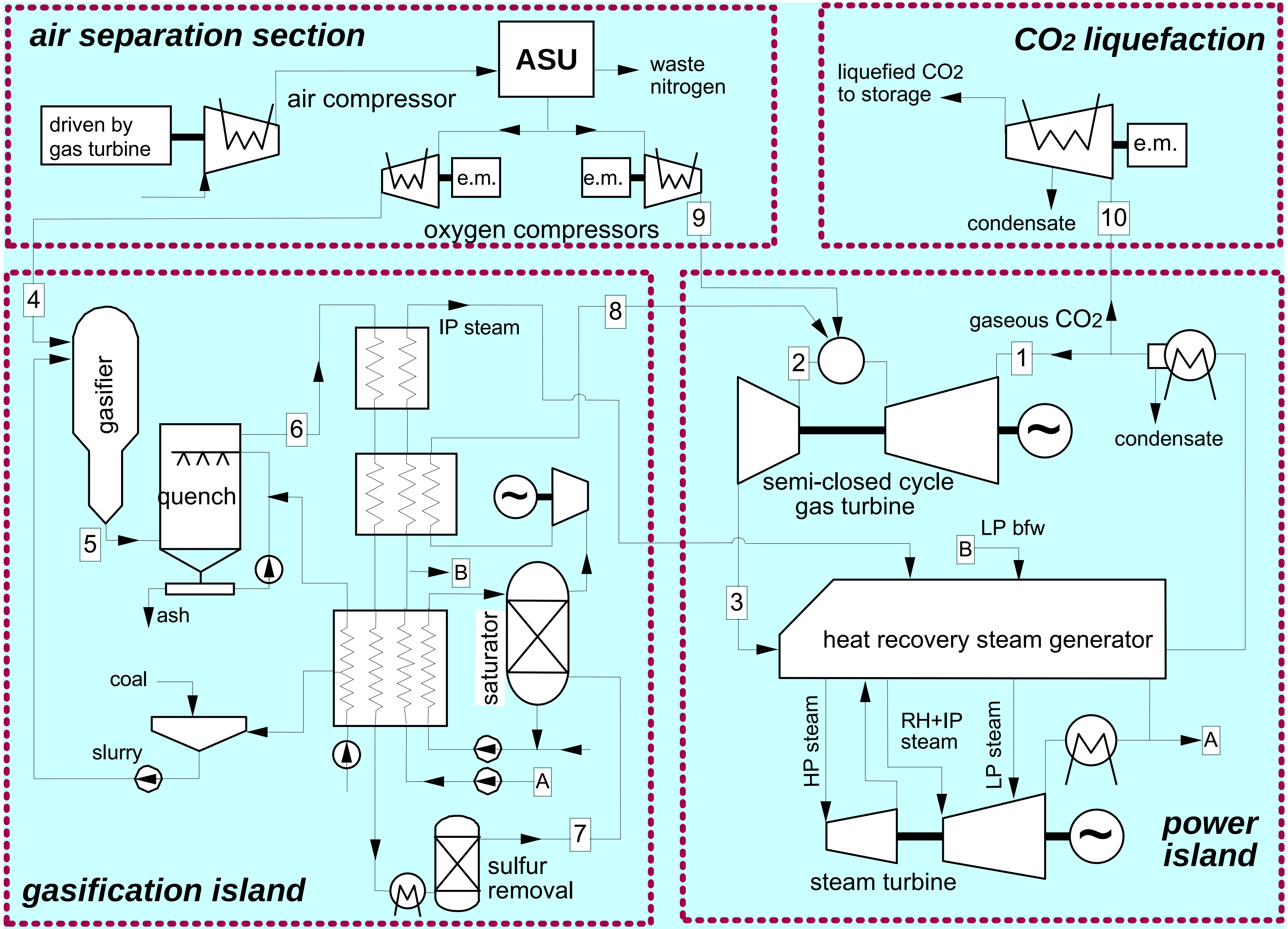


Vattenfal Oxy-fuel technology



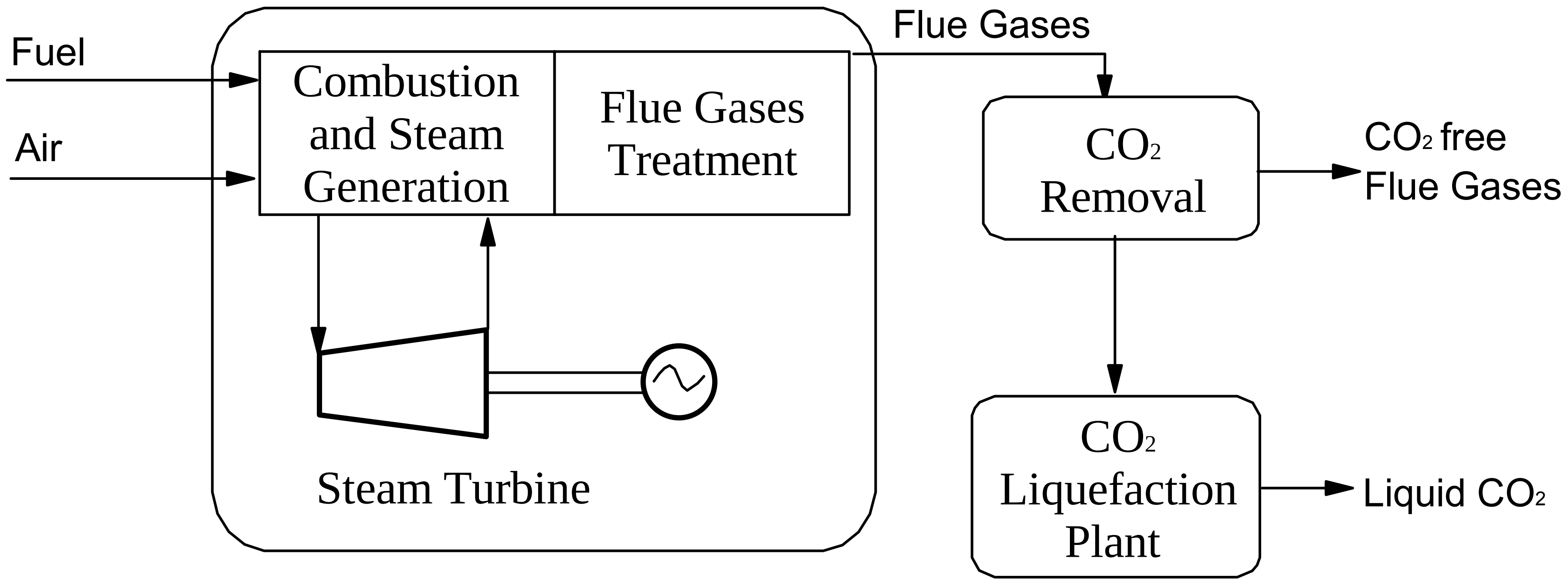
Graphic courtesy of John Topper - IEA Clean Coal Centre

IGCC with oxy-fuel

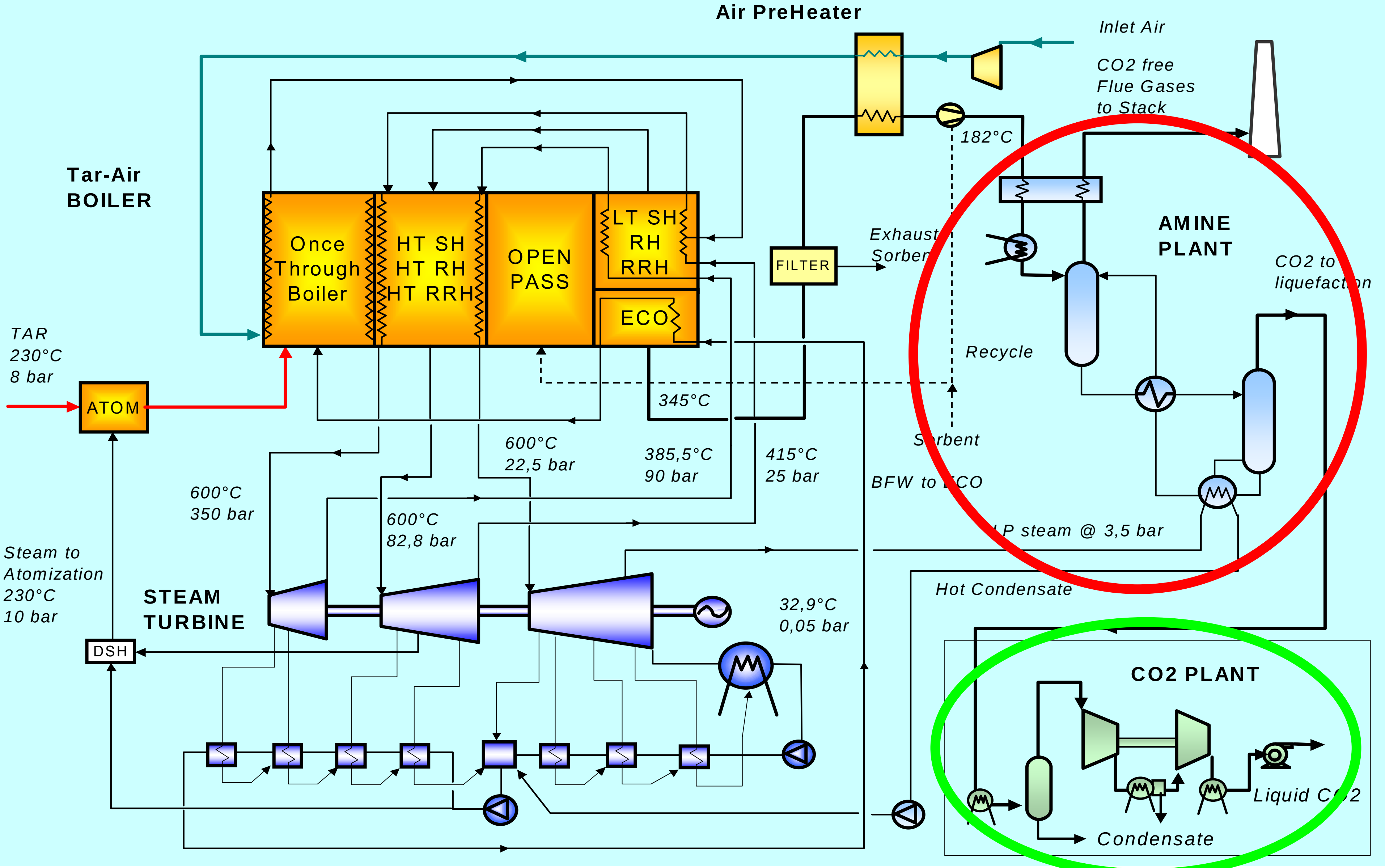


Post-combustion capture

This concept consists in treating the flue gas ahead of the stack while leaving the rest of the energy conversion system essentially unchanged



Post-combustion capture by chem. absorption



Chemical absorption - Malaysia

CO_2 Recovery Plant in Malaysia

Location: Keda, Malaysia   Start up: October 1999

Plant Outline

CO_2 recovery capacity	200 ton/day
Solvent	KS-1 solvent
Use of CO_2	Urea production
Client	Petronas Fertilizer (Kedah) Sdn Bhd
Flue gas source	Natural gas fired steam reformer flue gas

Process Description

CO_2 is recovered from the flue gas of the steam reformer of the ammonia plant and delivered to the CO_2 compressor for urea synthesis. The recovered CO_2 is used to increase urea production. The first commercial plant for flue gas CO_2 recovery using this advanced technology has been operating in Malaysia since October 1999 for urea production. The process achieves low steam consumption, very low solvent degradation, and low solvent loss.

Supplier: MHI, Japan
Capacity (flue gas treated): 47,000 m_n^3/h

Power output and efficiency: current technology

Current technology	oxy-USC/ wet FGR	USC / Amine	IGCC with CO2		Plants without CO2 capture USC 600	Plants without CO2 capture IGCC F
Thermal Power Inlet, MWth (LHV)	1967.2	1967.2	1967.2		1816.2	1816.2
Steam Turbine Gross Power, MWe	961.5	767.4	361.3		844.4	359.9
Gas Turbine Gross Power, MWe	-	-	587.5		-	588.7
Syngas Expander Power, MWe	-	-	19.7		-	19.0
Power Plant Auxiliaries, MWe	-39.8	-45.9	-44.0		-48.6	-30.7
ASU, MWe	-136.2	-	-150.3		-	-152.7
CO2 Liquefaction, MWe	-75.2	-62.9	-45.5		-	-
Net Power Output, MWe	710.4	658.6	728.7		795.8	784.2
Net Efficiency (LHV)	*36.1%*	*33.5%*	*37.0%*		*43.8%*	*43.2%*
Specific CO2 emissions, g/kWhe	*18.0*	*77.9*	*70.4*		*743.5*	*754.5*

From Consonni S. and Pelliccia G. (2004) "Comparative analysis of low CO_2 emission coal-fired power plants", Energy and Environment 2004, Sorrento (Italy)

Costs: current technology

	oxy-USC/ wet FGR	USC / Amines	IGCC with CO_2 capture		Plants without CO_2 capture: USC 600	Plants without CO_2 capture: IGCC F
Net Investment Cost before Interest	1071.1	1060.8	1048.8		735.1	867.0
Interest during construction	16.52%	16.52%	16.52%		16.52%	16.52%
Net Investment Cost	**1248.0**	**1236.1**	**1222.1**		**856.5**	**1010.3**
Specific Investment Cost, €/kW	1756.9	1876.9	1677.2		1076.3	1288.3
COE investment, c€/kWh	***3.74***	***3.99***	***3.57***		***2.29***	***2.74***
Variable Costs						
CO_2 Disposal, *c€/kWh*	*0.88*	*0.90*	*0.81*			
O&M and Consumables, *c€/kWh*	*0.94*	*0.98*	*0.82*		*0.57*	*0.63*
Fuel, *c€/kWh*	*1.3*	*1.4*	*1.2*		*1.0*	*1.1*
COE variable Cost, c€/kWh	***3.05***	***3.23***	***2.86***		***1.61***	***1.68***
TOTAL COE, c€/kWh	***6.79***	***7.22***	***6.42***		***3.9***	***4.42***
Cost Avoided CO_2, Capture, €/tonCO_2	27.7	36.5	25.5			
Cost Avoided CO_2, Disposal, €/tonCO_2	12.2	13.4	12.1			
Total Cost Avoided CO_2, €/tonCO_2	***39.9***	***49.9***	***37.6***			

From Consonni S. and Pelliccia G. (2004) "Comparative analysis of low CO_2 emission coal-fired power plants", Energy and Environment 2004, Sorrento (Italy)

Conclusion of 2004 study

- IGCCs with water-gas shift and CO_2 capture by physical absorption can apparently achieve the highest efficiency, the lowest COE and the lowest cost of avoided CO_2
- Oxy-fuel USCs exhibit slightly lower performances and slightly higher costs
- Amine-based systems appear significantly worse from the point of view of both efficiency and costs
- The gap between IGCCs is not large enough to give a definitive answer about their competition – a situation which does not change when going from "current" to "advanced" technology.
- CO_2 capture causes a decrease in net efficiency of about 7 percentage points and a COE increase between 2 and 3 c€/kWhe
- The cost of avoided CO_2 is the range 35-50 € per ton of CO_2

Additional considerations

- For electricity production, may expect tight competition between IGCCs and oxy-fuel
- Added advantage of oxy-fuel is its applicability to existing plants
- Added advantage of IGCC is its capability to generate decarbonized hydrogen

Thank you for your attention !