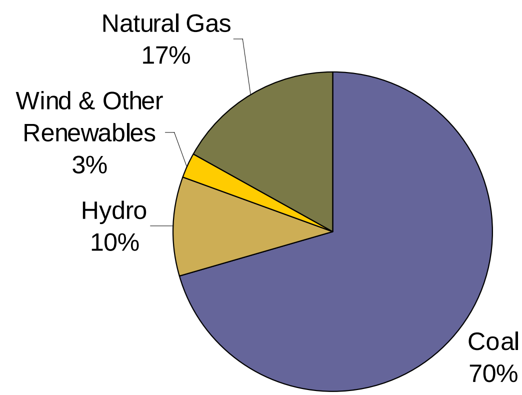
Wyoming Carbon Sequestration Working Group

CO_2 Capture – Power Generation

June 26, 2008

PacifiCorp – Service Territory

PacifiCorp Fuel Mix 2007



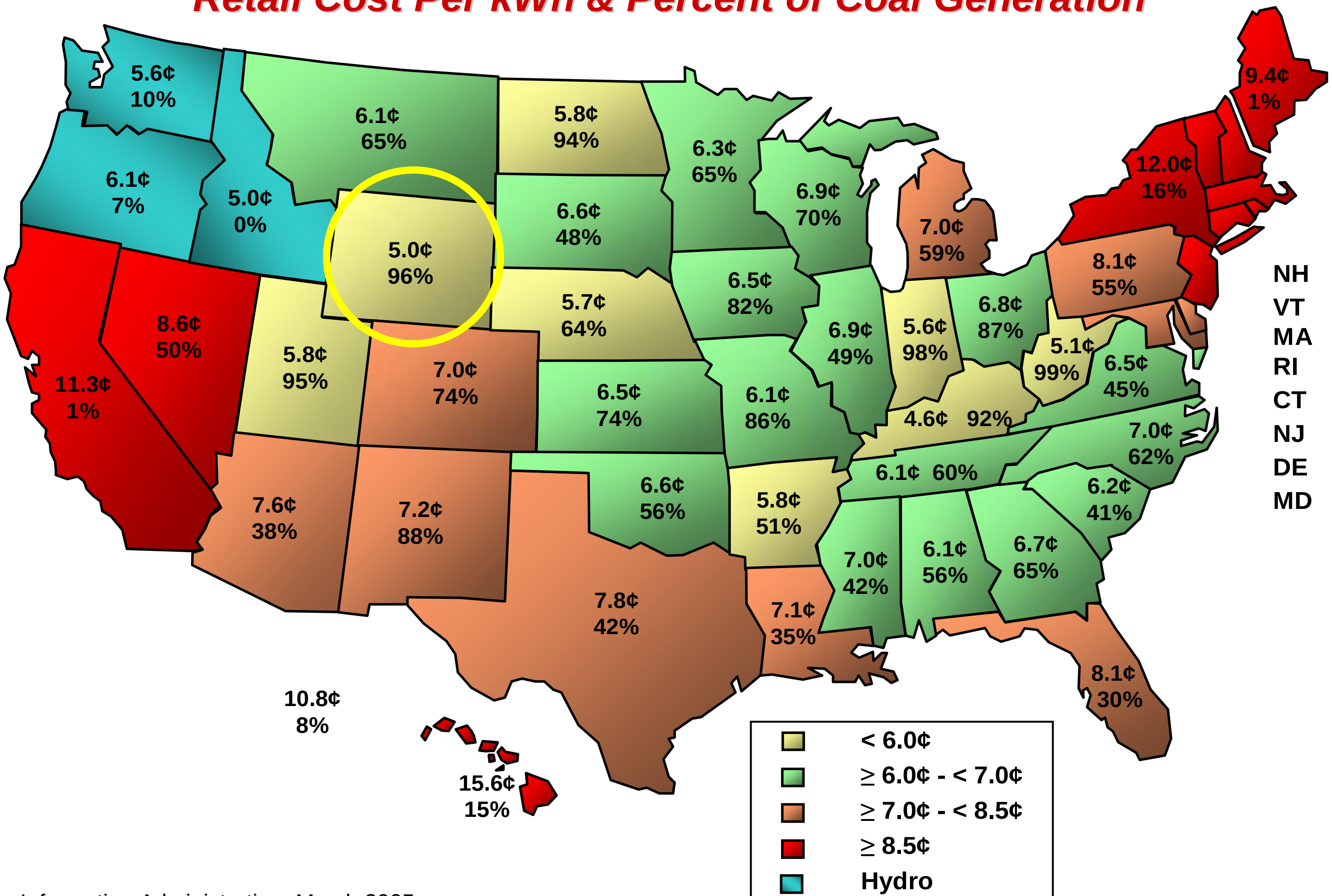
PacifiCorp

- Supply and distribute electric energy in six states: California, Idaho, Oregon, Utah, Washington, and Wyoming
  - **PacifiCorp Energy**: Generation, Mining, and Commercial & Trading
  - **Rocky Mountain Power:** Provide transmission & distribution services in Idaho, Utah, and Wyoming
  - **Pacific Power**: Provide transmission & distribution services in California, Idaho, and Oregon
- Over 9,600 MW of generating resources
  - Thermal ~8,000 (coal and gas)
  - Hydro ~1,200
  - Renewables ~450+ operating (wind and geothermal)
  - Contracts (Includes wind, coal, and gas)
- Another 600+ MW of new wind to be brought on by the end of 2008

Major Resources & Development Areas

Importance of Coal (Cost of Energy Comparison)

Retail Cost Per kWh & Percent of Coal Generation



NH	11.4¢	17%
VT	11.1¢	0%
MA	10.8¢	22%
RI	10.8¢	0%
CT	10.4¢	13%
NJ	10.2¢	19%
DE	7.3¢	65%
MD	7.2¢	52%

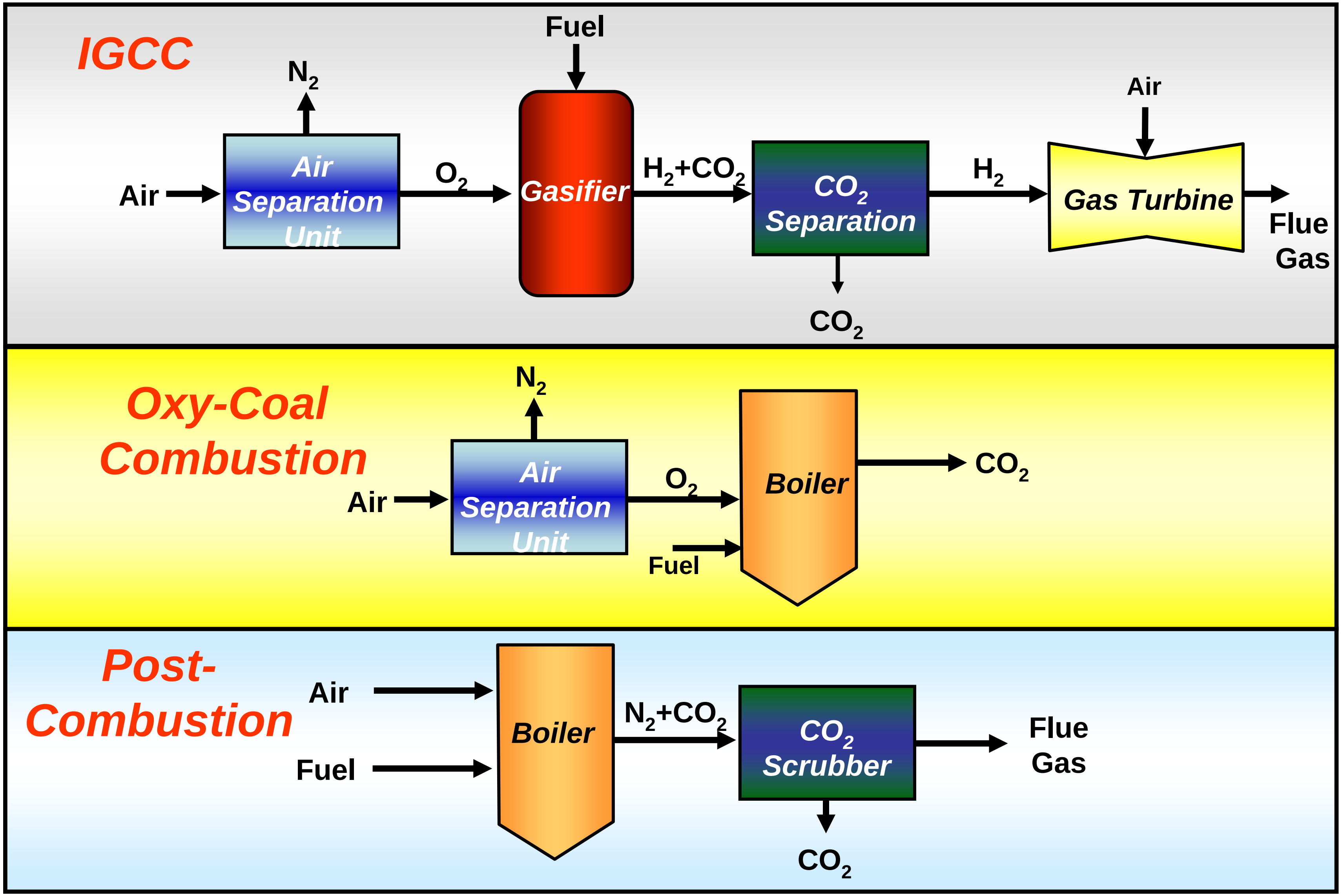
Source: Energy Information Administration, March 2005.

PacifiCorp Facilities - 2007 CO_2 Emissions

- Dave Johnston: 7.6 million tons
- Jim Bridger: 16.1 million tons
- Naughton: 6.1 million tons
- Wyodak: 3.4 million tons

Produced approximately 29 million MWhs

Carbon Capture Technologies



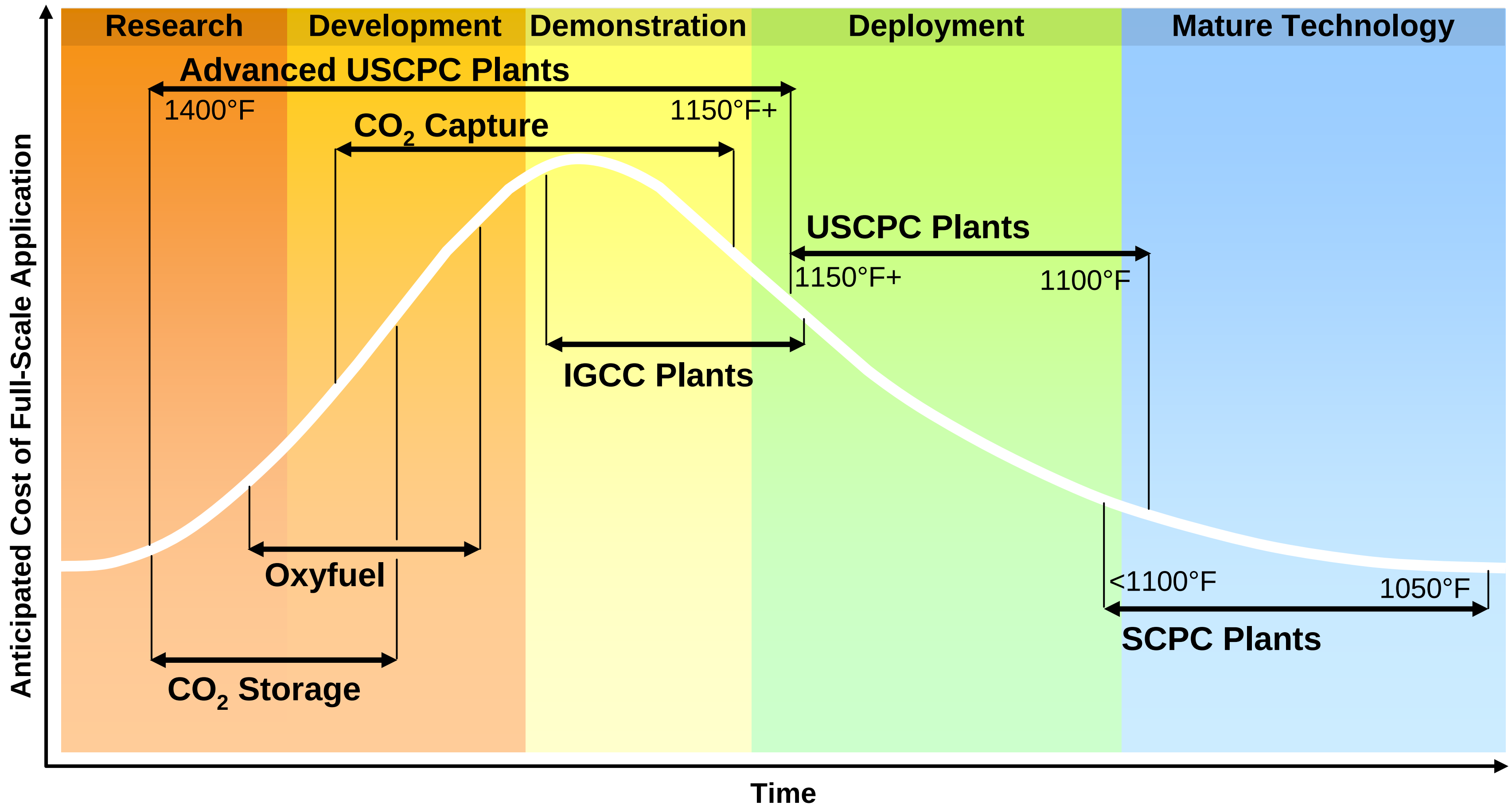
Existing Generation CCS – EPRI:

- Since New Coal plant costs are so high CCS Retrofit to some Existing PC plants may be considered
- Existing boilers >300 MW and <35 years old represent 184 GW. 90% CO_2 capture applied to these units would provide a 50% reduction in US coal power CO_2 emissions (~1 Billion mt/year).
- Criteria for CCS Retrofit Candidates
  - Space available
  - Sequestration site identified
  - Sufficient remaining plant life
  - Probably with FGD & SCR in place
- Preliminary analysis for 600 MW SCPC suggests LCOE of retrofitted plant lower than new coal plant even with the cost of the replacement power, and while dispatch cost higher than for new coal it is still lower than NGCC at NG >5$/Mbtu

Stages of Process Development

- Concept
- Lab bench
- Pilot
- Demonstration
- Semi-commercial
- Commercial

New Technology Deployment Curve for Coal



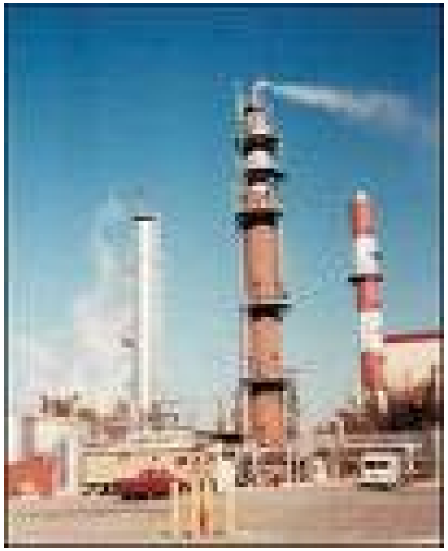
Post Combustion Processes

- Absorption ◀
- Adsorption
- Membrane
- Cryogenic
- Biological

Absorption Processes

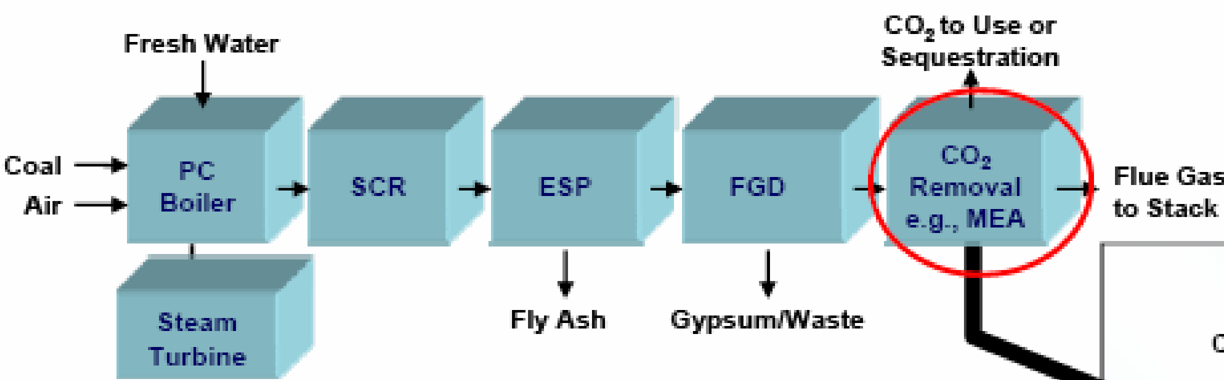
- Chemical Solvents
  - Amines, Ammonia, Potassium Carbonates
  - *Small scale testing for pulverized coal power plants*
- Physical Solvents
  - Selexol, Rectisol
  - *New to IGCC power plants*

Amine Process

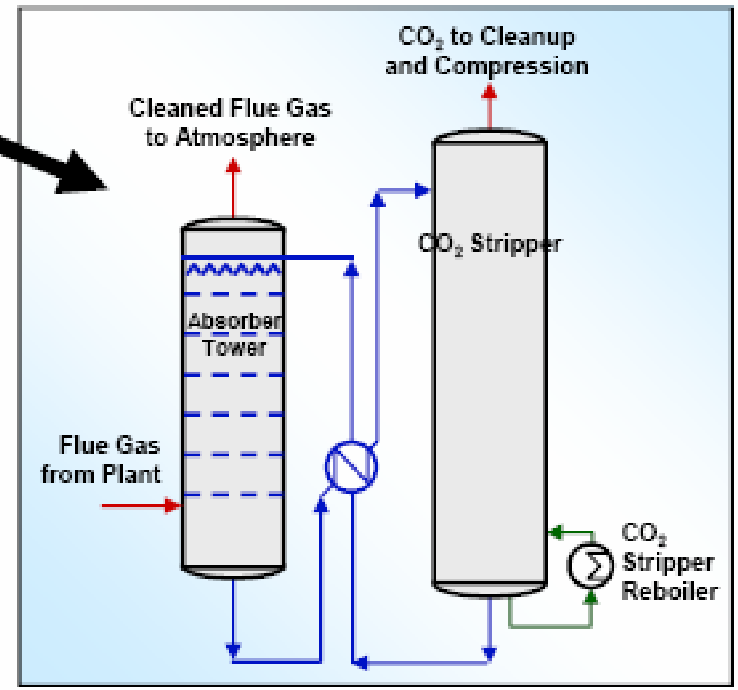


- ~70 yrs in Oil & Gas industry on smaller scale
- Pulverized Coal Plant: ***29+%*** Energy penalty for retrofits
- Expensive reagent, heat regeneration, solvent degradation (O_2) and losses (SO_2 & NO_2), corrosion
- 3 x <15 MW_t coal installations in U.S.

Amine Process



Energy Penalty ~29%



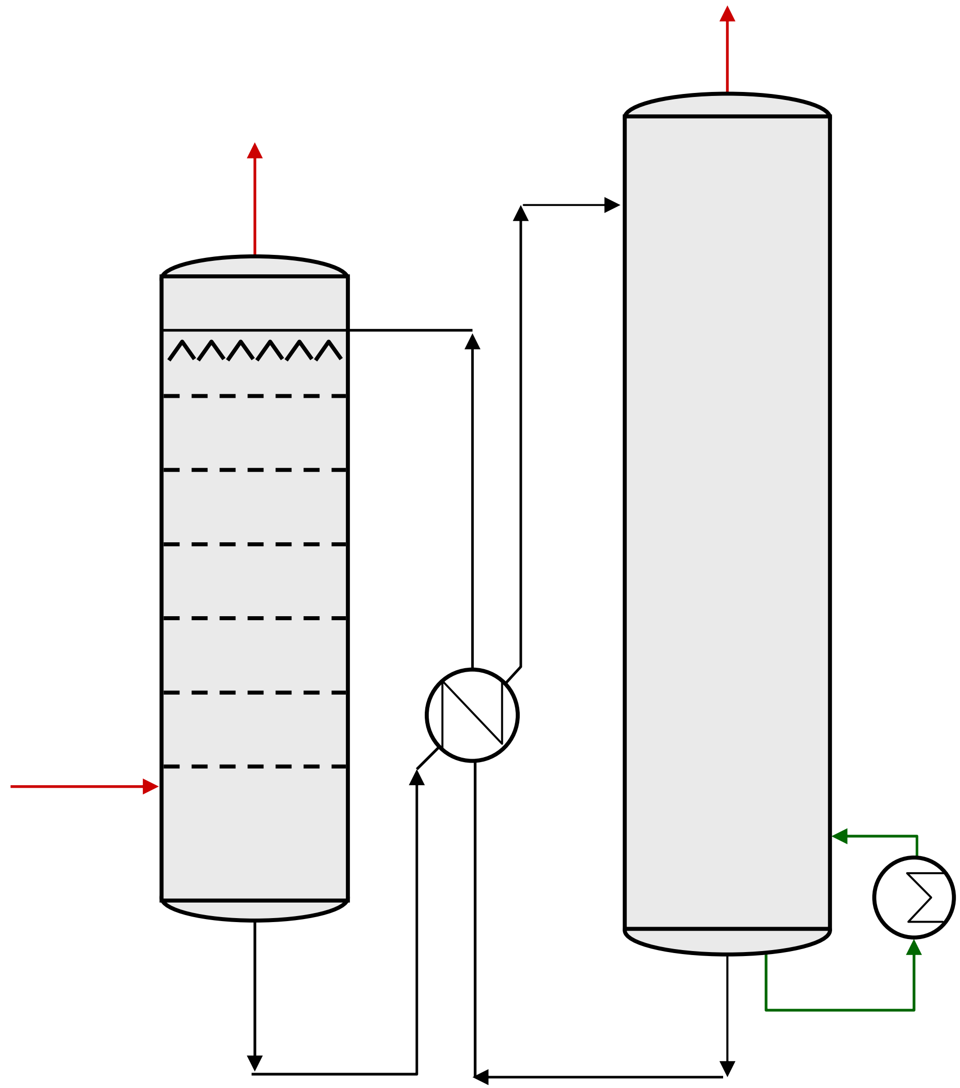
- Amine commercially available (multiple suppliers)
- 3 U.S. plants in operation:
  - MEA, <15 MWe, >90% ΔCO_2
- Key requirements:
  - ~5–6 acres for 600 MW plant
  - Near-zero SO_2 and NO_2
  - Large reboiler steam (MEA>KS-1>Ammonia)
- Many new process options being explored

Needs Space, Integration and Energy

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Chemical Absorption Basics

- Absorb CO_2 in solution
- Release CO_2 from solution
- Similarities for amine and ammonia



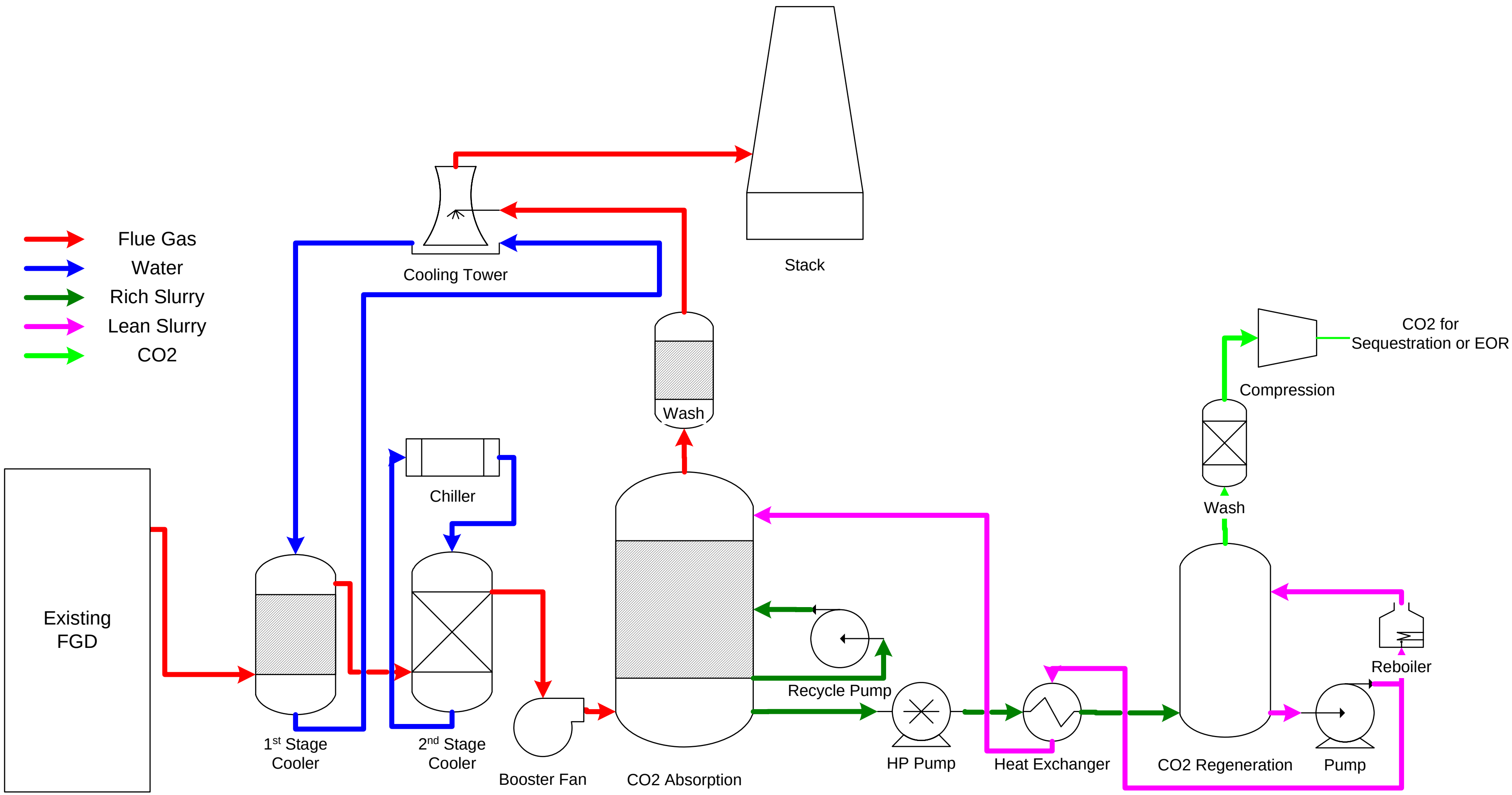
Alstom Chilled Ammonia

- Modifications:
  - Chiller for absorption, ~40 F
  - Solids in absorption
  - Pressurized regeneration, ~300 psi
  - Integration
- Targets:
  - 20-25% Energy requirement (lower than amine processes)
  - 2015 Commercial

Alstom Chilled Ammonia Pilot Plant

- 1.7 MWe slipstream
- Pleasant Prairie, Wisconsin
- 9 month construction
- Currently: in start-up
- Testing began May-June
- 1 year operation

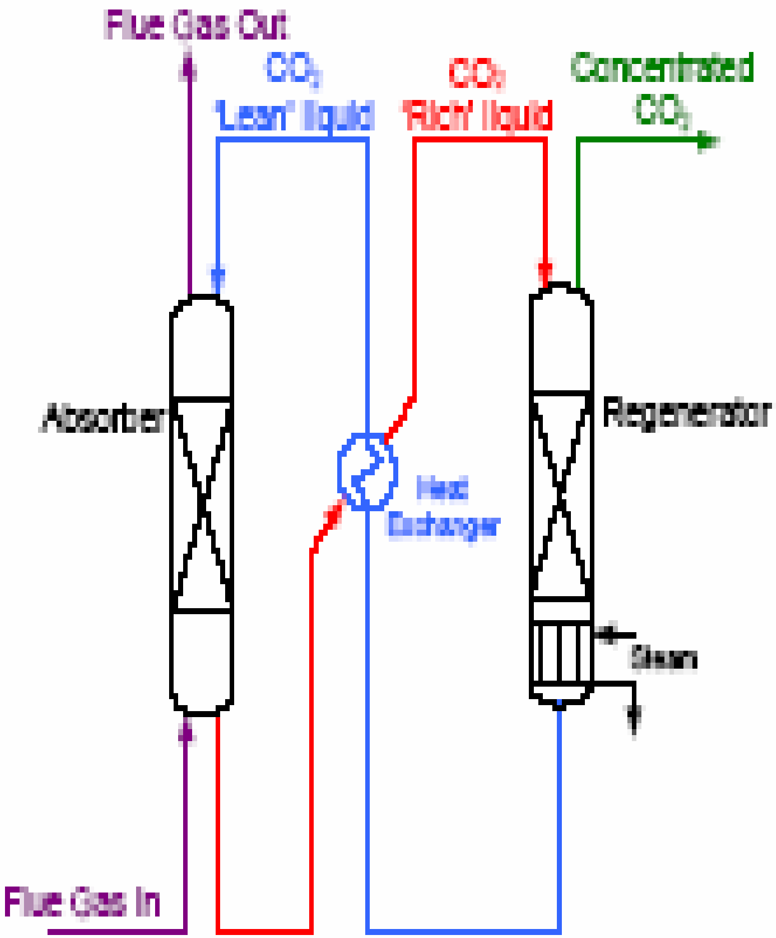
Alstom Chilled Ammonia Process



Alstom Chilled Ammonia Program

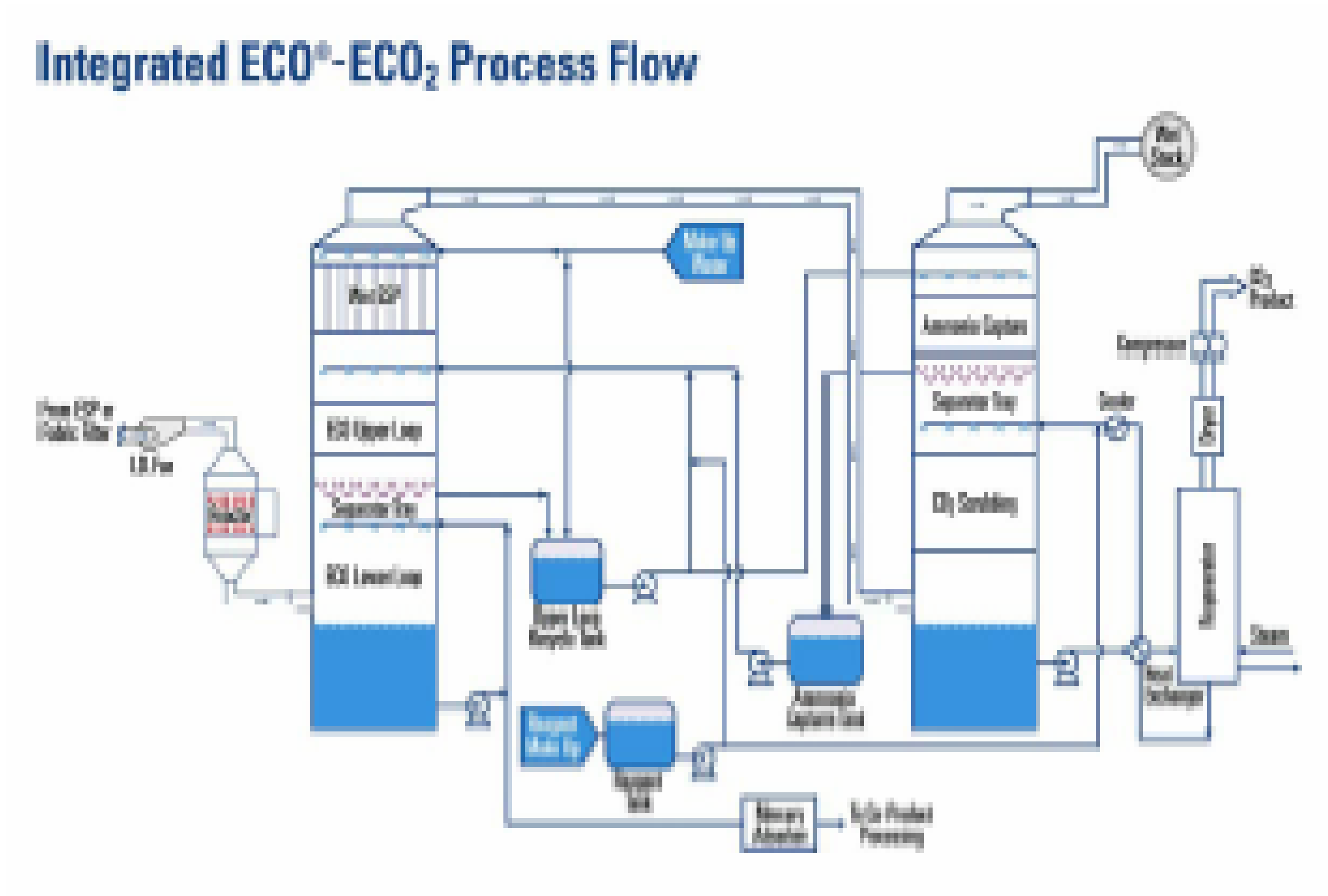
Yr	MW	Ton/Yr	Disposal	Host	Location
2008	1.7	15k	Vent	WE Pleasant Prairie	Wisconsin
2011	20	100k	Saline Aquifer	AEP Mountaineer	West VA
2012-13	>200	1.5 M	EOR	AEP N. Easten	OK
2008	5			EON Karlsamn	Sweden
2009-10	40	80k		Statoil Mongstad Refinery	Norway

ECO2 Ammonia Process



- PowerSpan Portsmouth, NH
- Multi Pollutant Process
- Plasma, SO_x, NO_x, Hg, WESP

ECO2 Ammonia Process

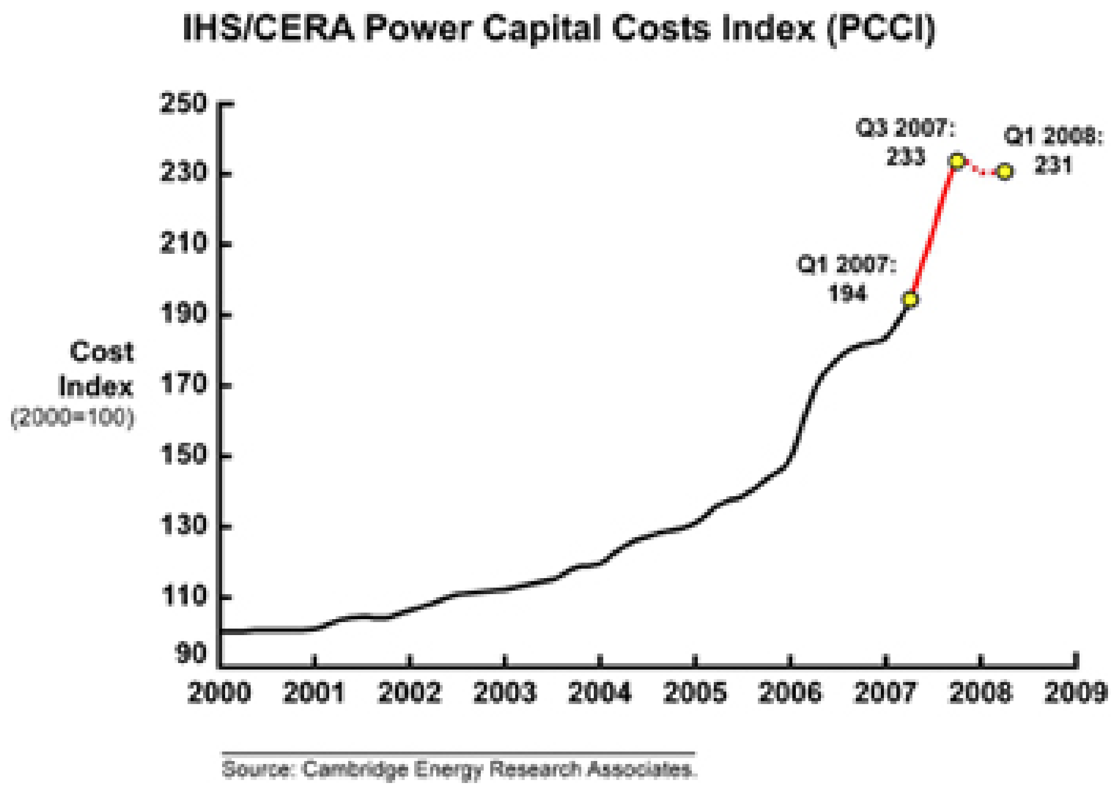


Post Combustion CO_2 Summary

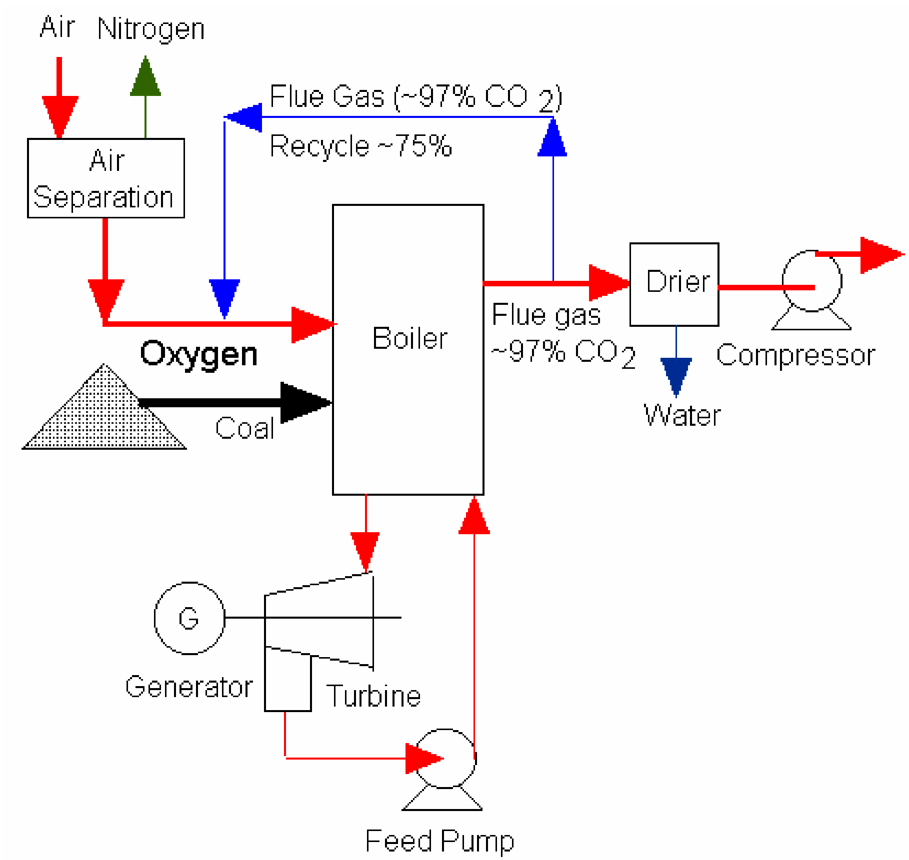
- Near Term
  - Adapt chemical absorption processes
    - Ammonia
    - Amines
    - Potassium Carbonates
  - Demonstrate w/Sequestration 1 million ton/yr
- Mid to Long Term
  - Adsorption, membranes, cryogenic

Post Combustion CO_2 Summary – EPRI:

- Added capital costs for Capture are significant but it is the reduced power that is the greatest economic impact on COE- particularly when retrofitted to SCPC
- Capital Cost Escalation has continued. IHS CERA DCCI suggests 15% from 3rd Q 2006 to 3rd Q 2007.

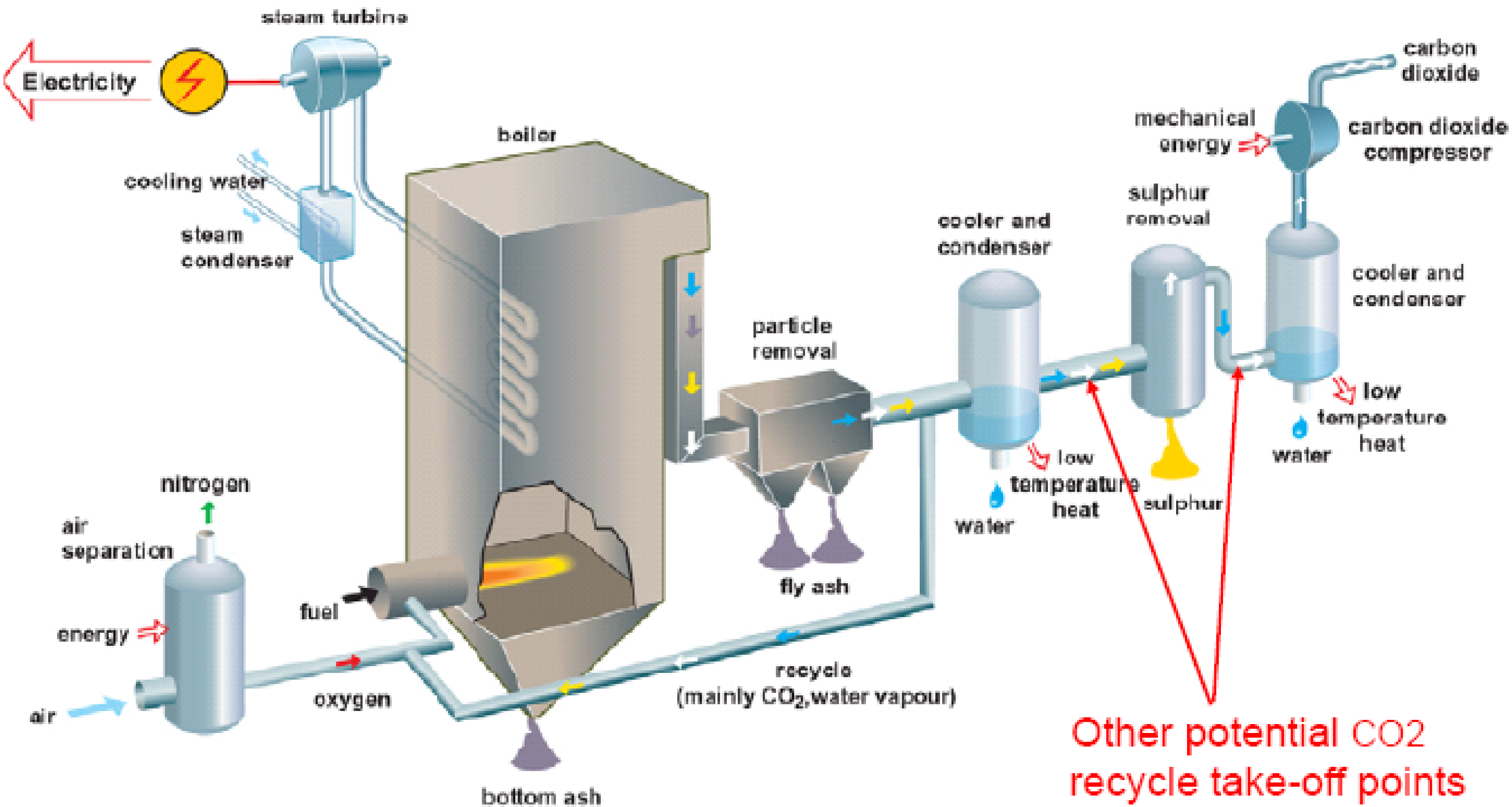


OxyFuel Combustion



- 95% O_2 ASU vs 21% O_2 Air
- Concentrated CO_2 fluegas stream
- Heat transfer
- Flame stability
- Pollutant formation

OxyFuel Combustion



Source: Vattenfall (GHGT7 2004)

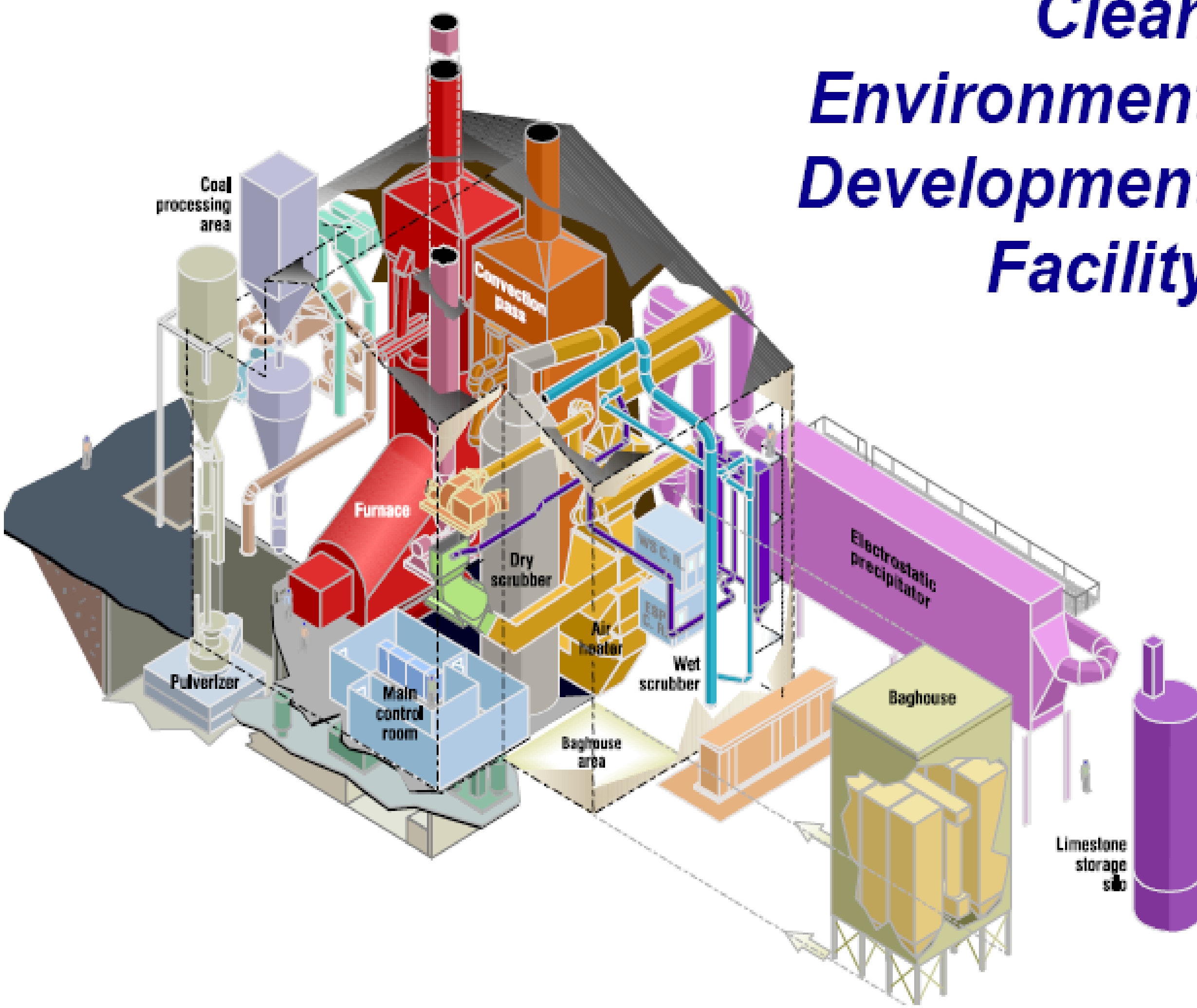
OxyFuel Pulverized Coal Pilot Plants

Year	Developer	MW_t	Site	CO_2	Status
2007-08	Babcock & Wilcox	30	Barberton, Ohio	Vent	Testing Underway
2008	VattenFall	30	Schwarze Pumpe, Germany	C&S	Start Up May 2008
2010	CS Energy	30	CS Energy, Queensland, Australia	C&S	2008 Construction

B&W 15 MW_t Oxyfuel

- B&W and Utility Advisory Group
- Test campaigns lignite, PRB and eastern bituminous coal

B&W 15 MW_{th}



Clean Environment Development Facility

B&W Lessons Learned

Oxy-coal Flame

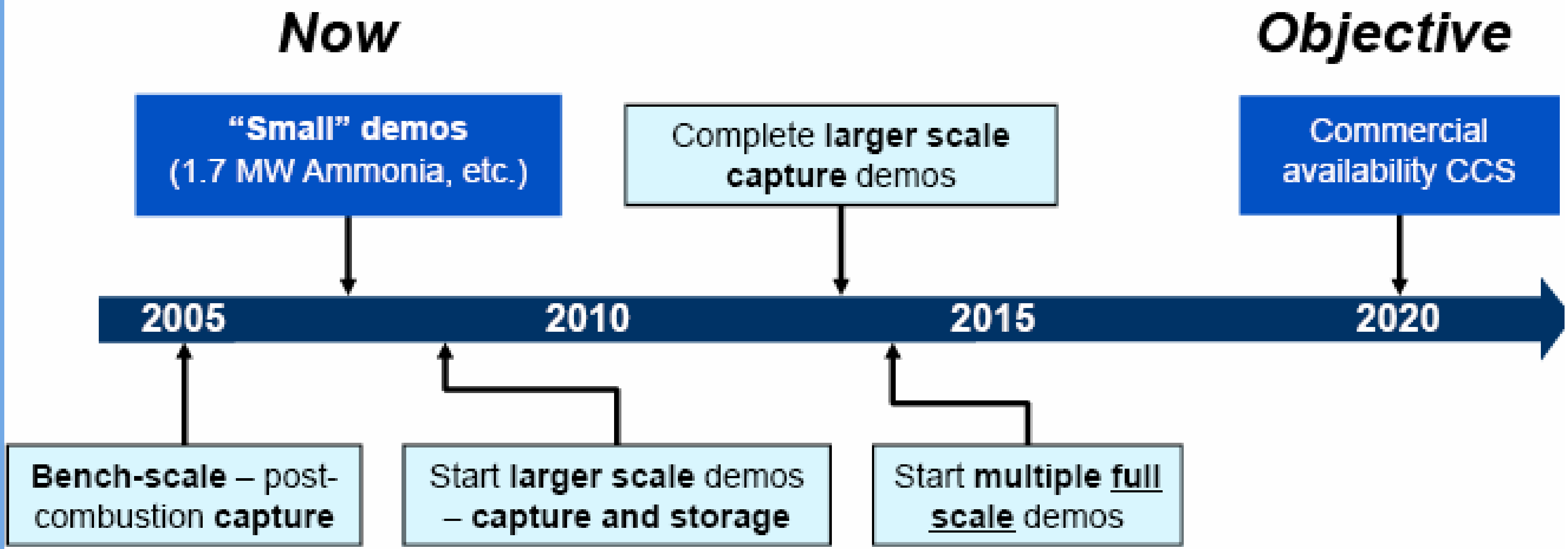
100+ hours in oxy mode (bituminous coal)

- Oxy flame is bright and stable
- NOx is significantly reduced (>50%)
- SO_2 removal not significantly different than with air
- **There's more air infiltration at CEDF than expected**

30 MWth Oxyfuel Steam Generator – Vattenfall Schwarze Pumpe Site (Erection Status)

IEAGHG Int. Oxy-Combustion Network, Yokohama, Japan, 5-6, March, 2008

ALSTOM 13



Needs: Multiple large-scale CAPTURE and STORAGE demos

Timing: 2020 objective → start today, parallel paths

Realistic? A challenge – need technical, policy, funding alignment

Source: DOE-NETL Carbon Sequestration R&D Roadmap
Modified to add Chilled Ammonia example