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Oxy-fuel Combustion Components Relative to a Future MHD Concept

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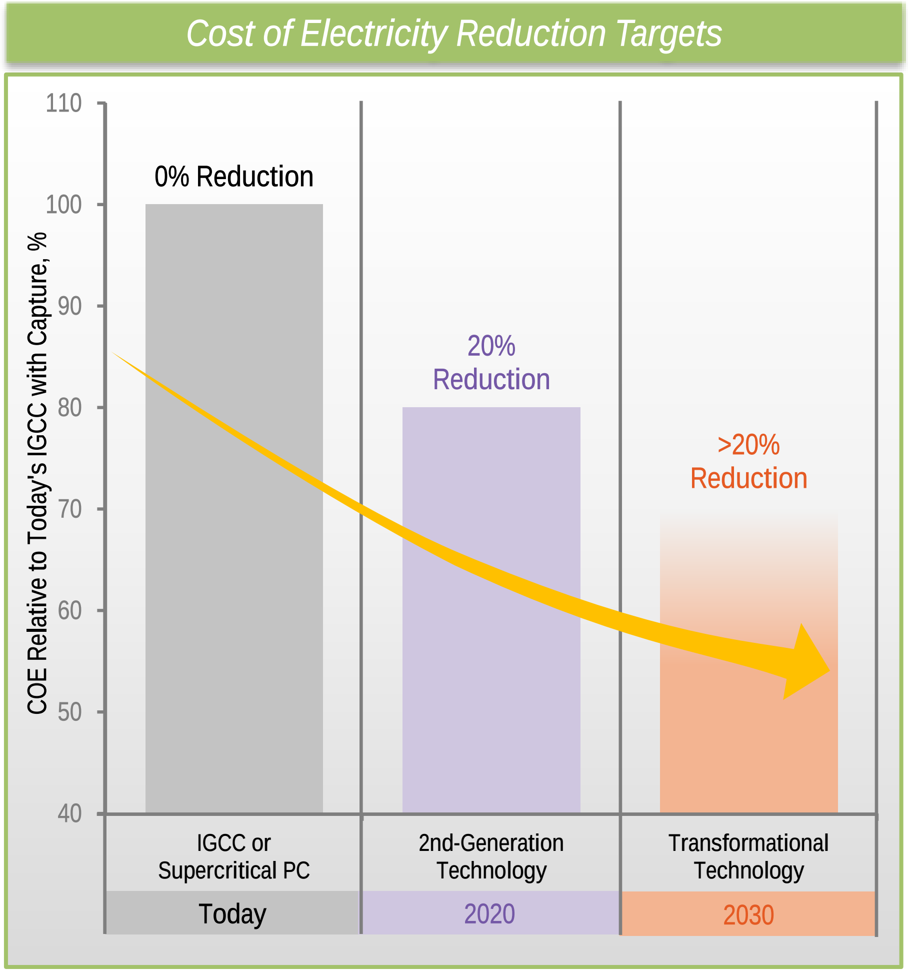
Presentation Outline

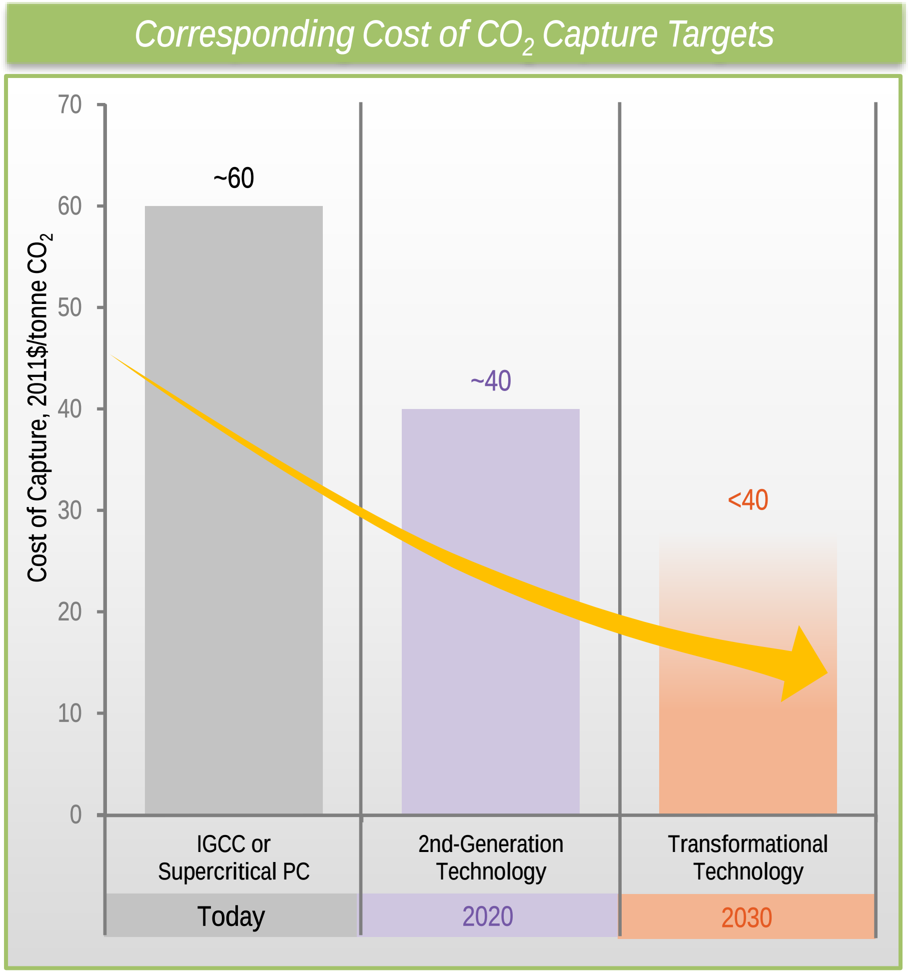
Oxy-fuel Combustion Components Relative to a Future MHD Concept

- **Advanced Combustion Systems (ACS) Goals**
- **Current ACS Technology Approaches**
- **ACS Unit Operators Relevant to MHD – Performance and Cost**
- **Summary/Conclusions**

Clean Coal Research Program Goals

Driving Down the COE and Cost of Coal Power CCS

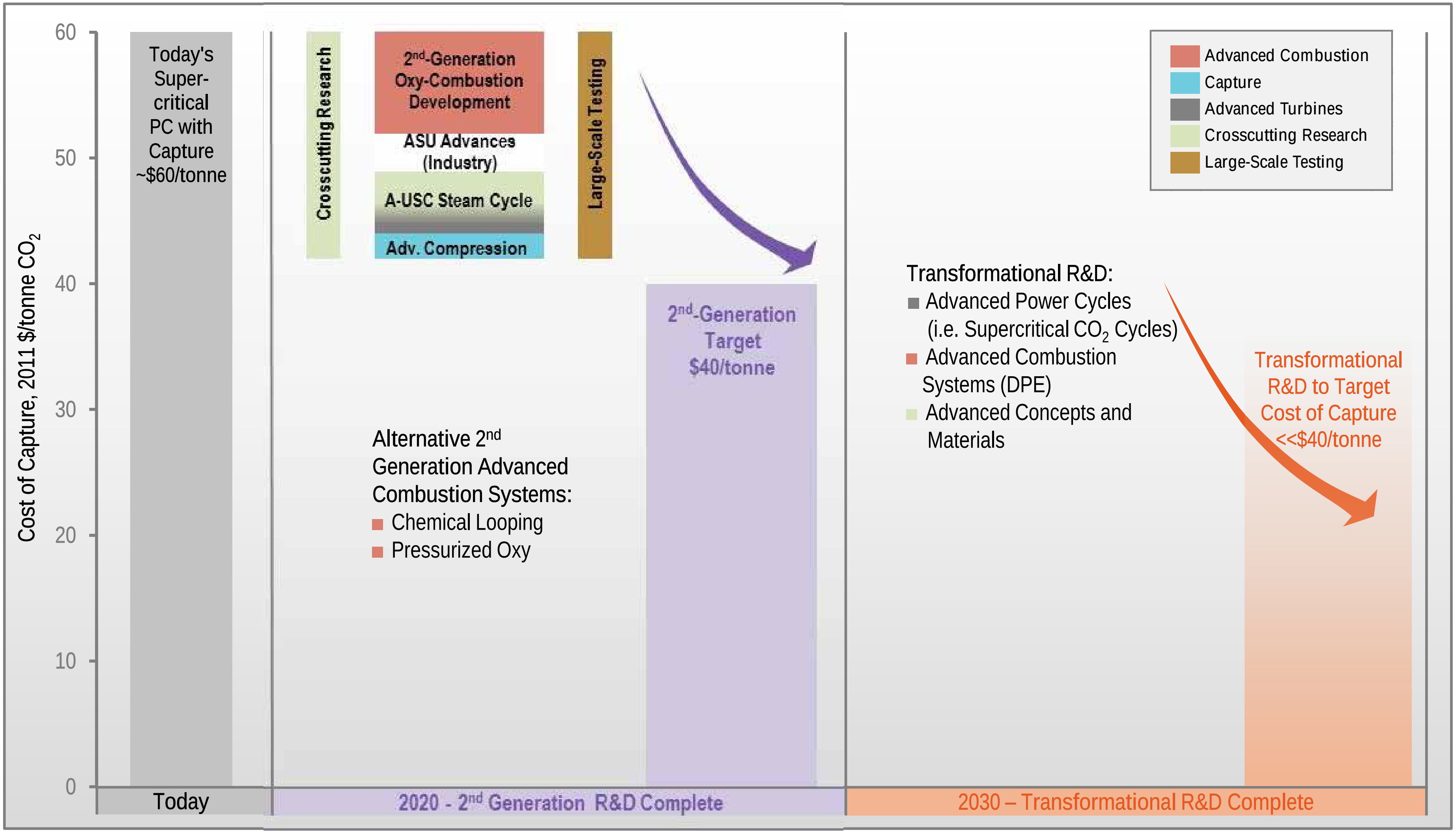




Goals shown are for greenfield plants. Costs are for nth-of-a-kind plants, during first year of plant operation, and include compression to 2215 psia but exclude CO_2 transport and storage costs. Today's capture costs are relative to Today's SCPC without CO_2 capture. 2020 and 2030 capture costs are relative to an A-USC PC without CO_2 capture.

R&D Driving Down the Cost of CO_2 Capture

Oxy-combustion Plants



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Active ACS Projects

- **Oxy-fuel Pressurized Combustion**
  - Oxy-Fired Pressurized Fluidized Bed Combustor, *Aerojet Rocketdyne*
  - Staged, High-Pressure Oxy-Combustion, *Washington University in St. Louis*
  - OTM for Industrial Applications, *Praxair, Inc.*
- **Chemical Looping Combustion**
  - Limestone Chemical Looping Combustion, *Alstom Power*
  - Iron-Based Coal Direct Chemical Looping, *Babcock & Wilcox Power Group*
  - ICMI Chemical Looping Combustion, *NETL-ORD*
- **Recuperators for SCO2 Power Cycles**
  - Low-Cost Recuperative HX for SCO2 Systems (Altex Tech. Corp)
  - Mfg. Process for Low-Cost HX Applications (Brayton Energy)
  - Microchannel HX for FE SCO2 cycles (Oregon State U)
  - HT HX for Systems with Large Pressure Differentials (Thar Energy)
  - Thin Film Primary Surface HX for Advanced Power Cycles (SwRI)
  - HX for SCO2 Waste Heat Recovery (Echogen / PNNL, SBIR)

Advanced Combustion Systems
Current Project Portfolio

Participant	Project	Scale	TRL	FY14	FY15	FY16	FY17
Chemical Looping Combustion Projects							
Alstom	Calcium-Based Limestone Chemical Looping Combustion	1 MWe	4	→	→	→	
Babcock & Wilcox	Iron-Based Coal Direct Chemical Looping	100 kWth	3	→	→		
NETL-ORD	ICMI – Chemical Looping	50 kWe	4	→	→		
Oxy-combustion Projects							
Aerojet Rocketdyne	Pressurized Oxy-PFBC Development	1-3 MWth	3	→	→	→	→
Washington University in St. Louis	Staged Pulverized Coal Oxy-combustion	100 kWth	3	→	→	→	
Praxair	Oxygen Transport Membrane (OTM) for Industrial Applications	160,000 scfd	4	→	→		

Pressurized Oxy-Combustion

Avoid back end separation while taking advantage of pressurization

Advantages of Pressurized Oxy-combustion:

In pressurized oxy-combustion, the mass and volume of flue gas are reduced relative to atm. combustion in air:

- Latent heat recoverable and heat transfer rates increased… *increases efficiency*
- Reduces equipment size…*decreases capital costs*
- No air in-leakage… *increases CO_2 purity*
- Developer's projected CO_2 capture costs exceed program goals

R&D Challenges

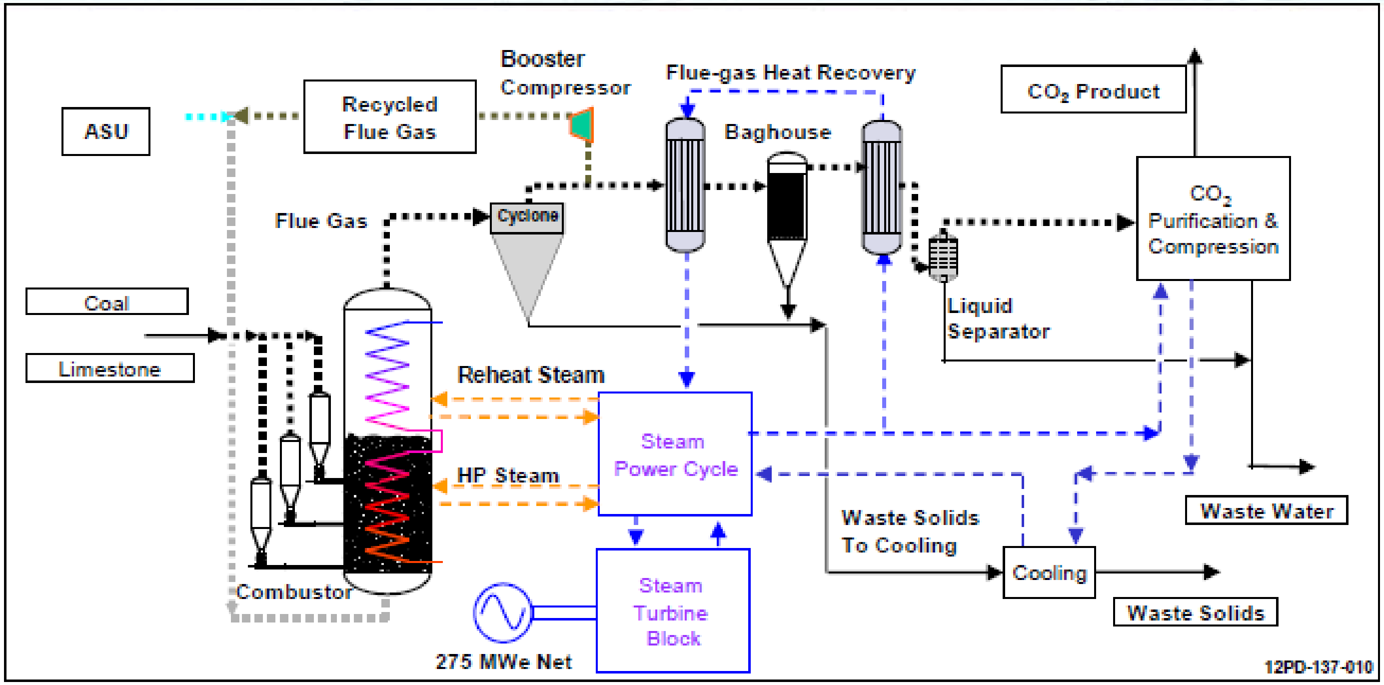
- Pressurized Combustor Design
- Fuel Feeding
- Emissions Control
- Heat Recovery & Integration

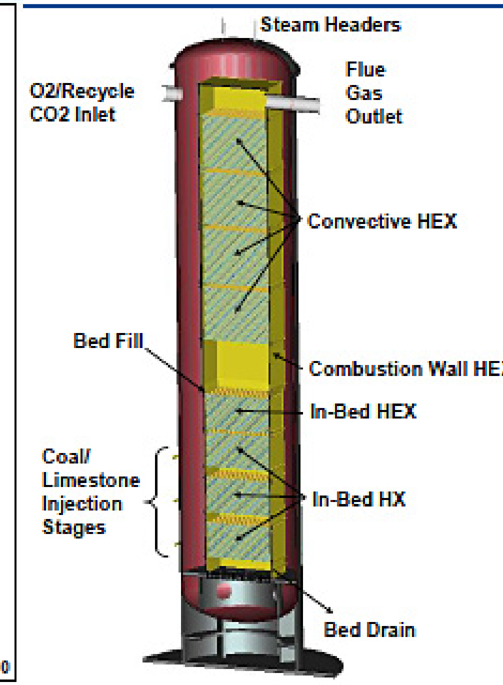
Two (current) Approaches

- Oxy-fired Pressurized Fluidized Bed Combustion (Oxy-PFBC) – Aerojet Rocketdyne
- Staged Pressurized Oxy-Combustion (SPOC) – Washington University in St. Louis

Pressurized Oxy-Combustion

Oxy-fuel Pressurized Fluidized Bed Combustion – Aerojet Rocketdyne





Efficiency Enhancement

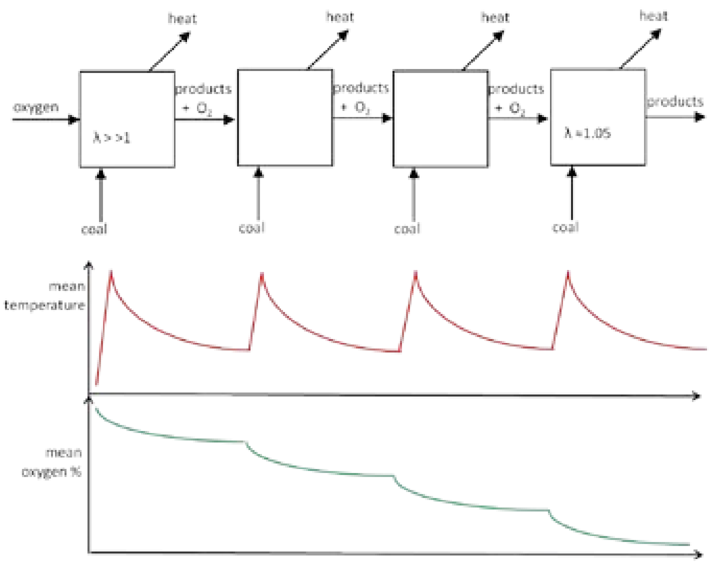
- Staged combustion with elutriation – Reduces O_2 consumption, with high sulfur capture
- Oxy-combustion – Reduces energy required for CO_2 purification
- Pressurized – Reduces CO_2 compression required for sequestration

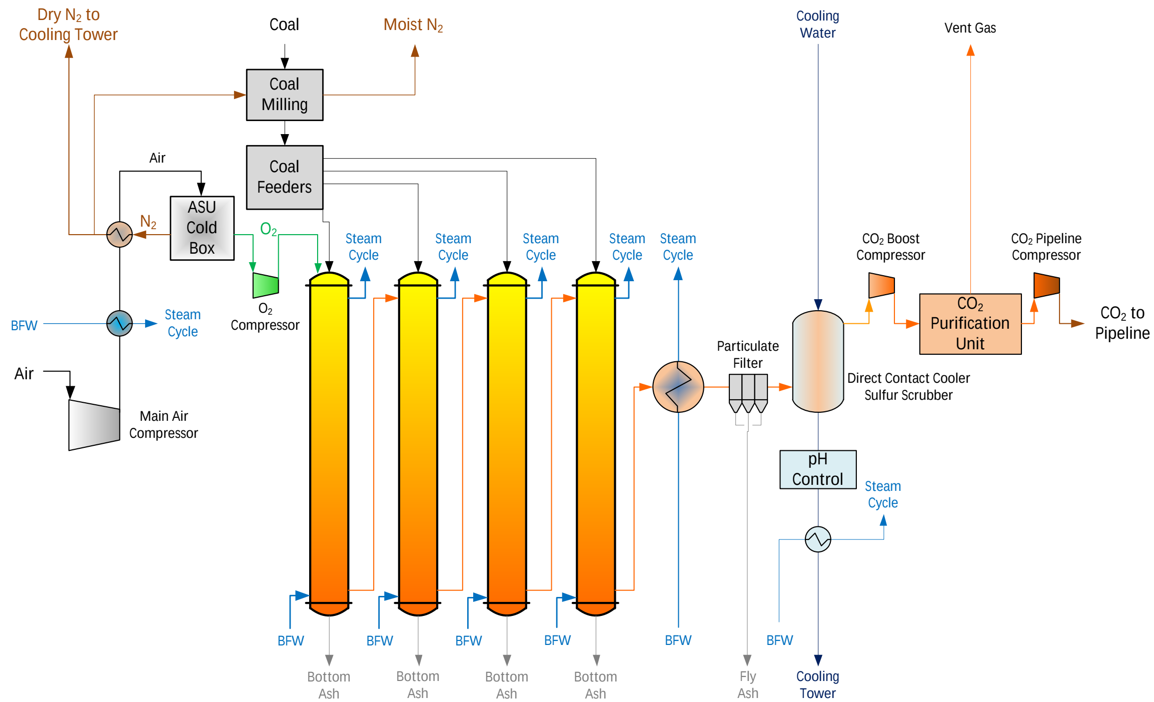
Cost Reductions

- PFBC – More compact combustor with lower cost
- Simpler, lower-cost CPU
- Elimination of FGD (Potentially)

Pressurized Oxy-Combustion

Staged, Pressurized Oxy-Combustion – Washington University in St. Louis

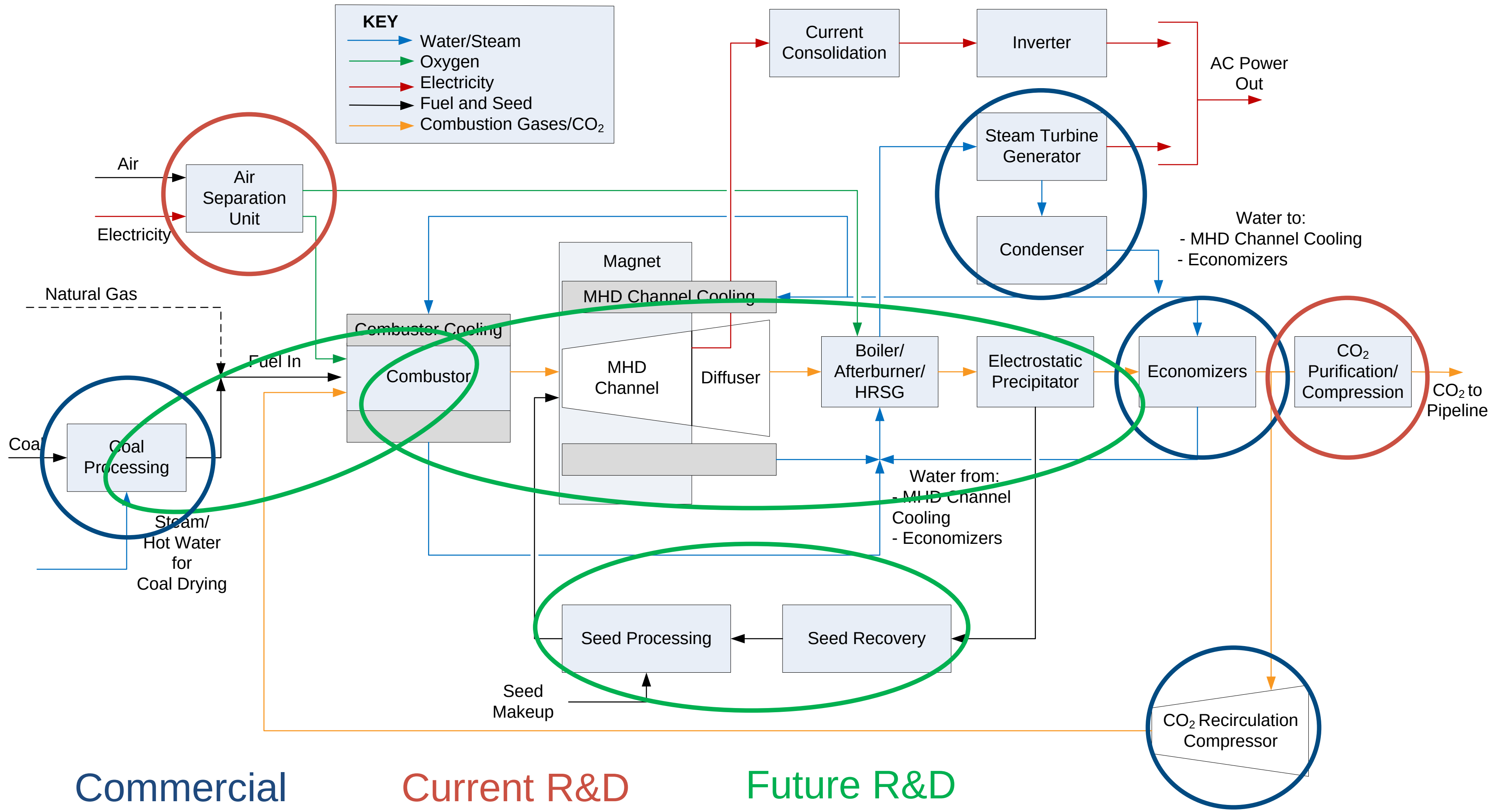




Staged Combustion Strategy

- Fuel-staged combustion to manage peak combustion temperatures
- Excess oxygen acts as the diluent rather than recycle
- Near-zero flue gas recycle
- Reduced flue gas volume, equipment size, and system cost
- Novel direct contact cooler combines latent heat recovery with SOx and NOx removal

Coal/Natural Gas-Fired MHD System



Source: NETL

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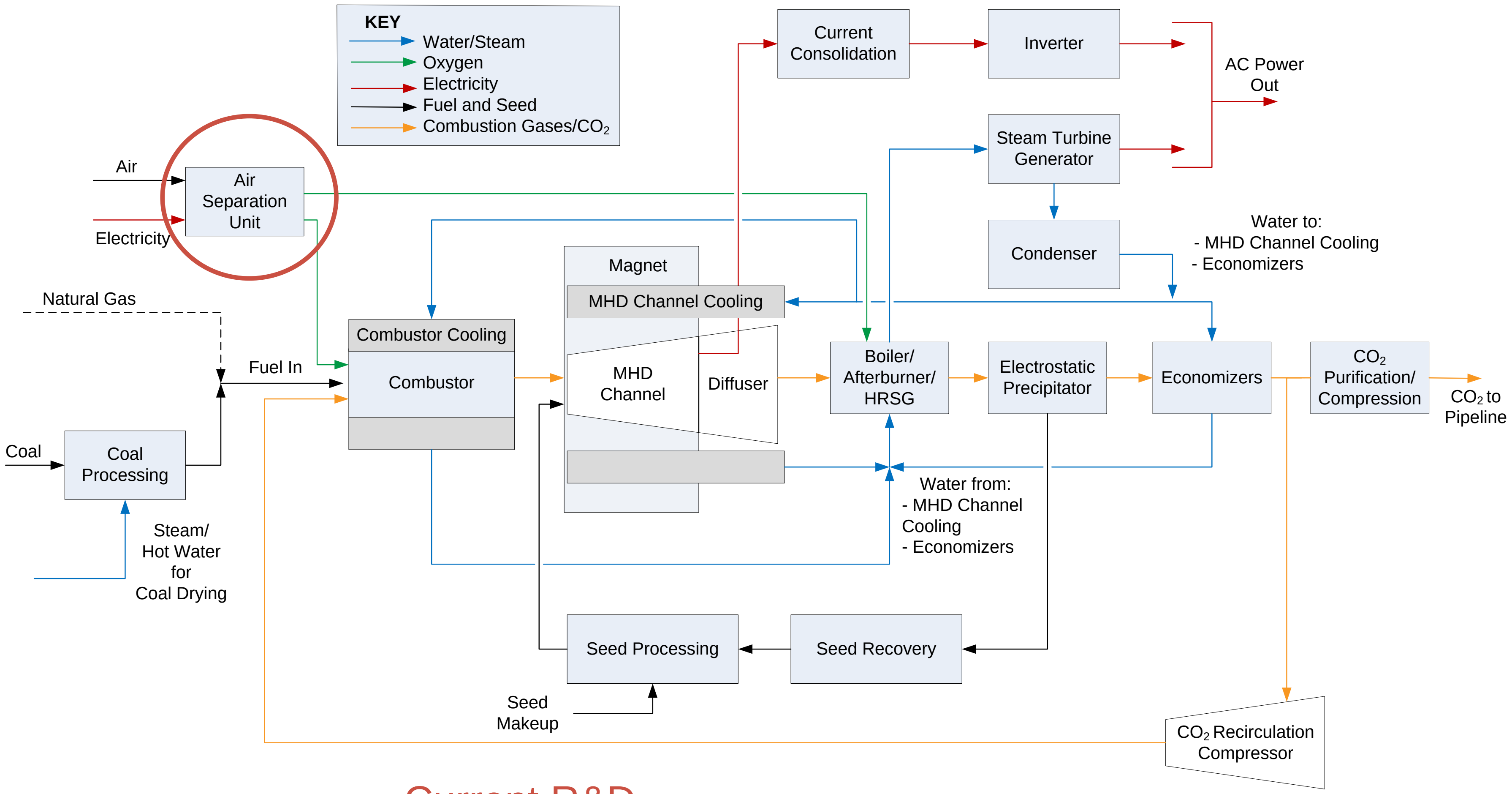
Coal/Natural Gas-Fired MHD System



Current R&D

Source: NETL

Oxygen Production

Current Oxy-combustion Plant (550 Mw_{net}, Supercritical, Atmospheric Pressure, Current Cryogenic ASU)	
O_2 Demand	14,000 tpd (12,700 tonne per day)
O_2 Purity	95%
ASU Capital Cost	$410M (20% of total plant cost)
Aux Power Load	96 MW_e (41% of auxiliaries)
Cost of Oxygen[1]	$37 per ton O_2

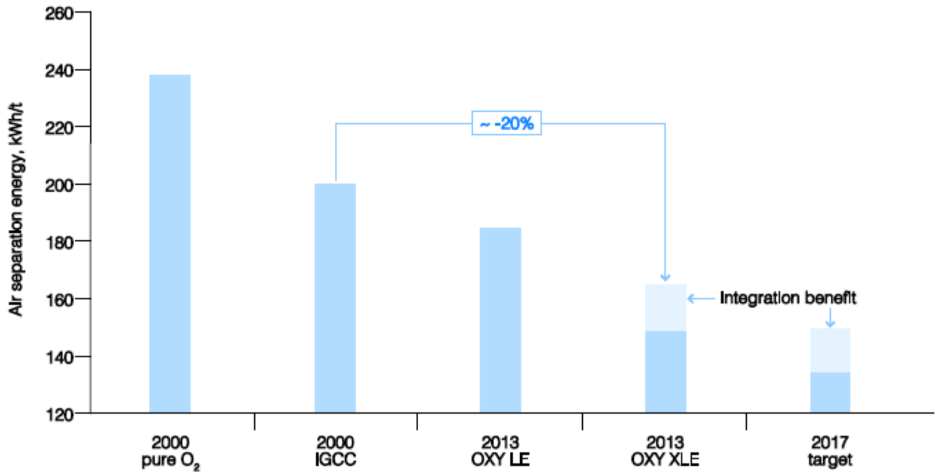
[1]O_2 cost per ton is highly dependent on the price of electricity used since the cost is heavily dependent on the power required to run the ASU. Using the NETL Bituminous Baseline Case 13 NGCC plant without capture cost of electricity ($60/MWh), a cost of about $25 per ton O_2 would be reasonable. If the power cost from the oxy-combustion plant was used ($142/MWh), the O_2 cost would go up to about $37 per ton O_2.

Source: "Advanced Oxy-combustion Technology for Pulverized Bituminous Coal Power Plants", NETL, 2014, Unpublished

Oxygen Production Improvements

ASU Improvements

- Ø Approx. 20% reduction in energy requirements



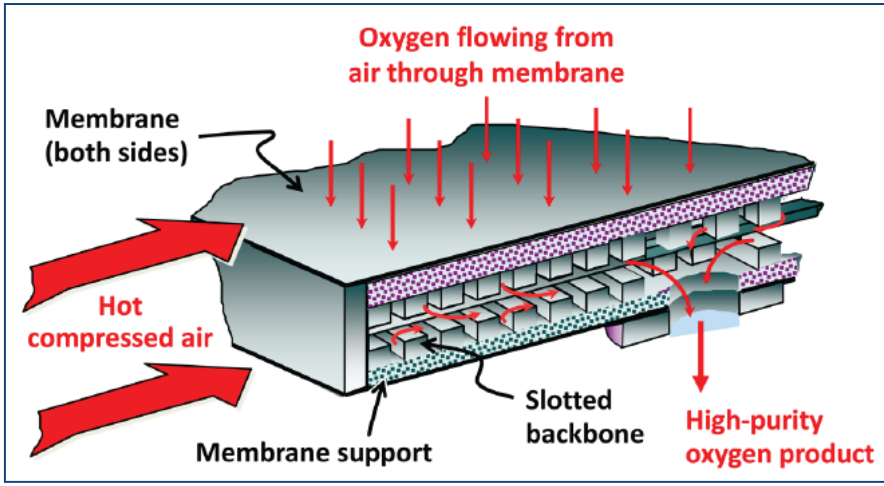
The reduction in air separation energy (kWh/t) over time in Air Liquide ASU

Source: Reprinted from "Developments in oxyfuel combustion of coal," by Toby Lockwood, 2014, p. 40. Copyright 2014 by the IEA Clean Coal Centre.

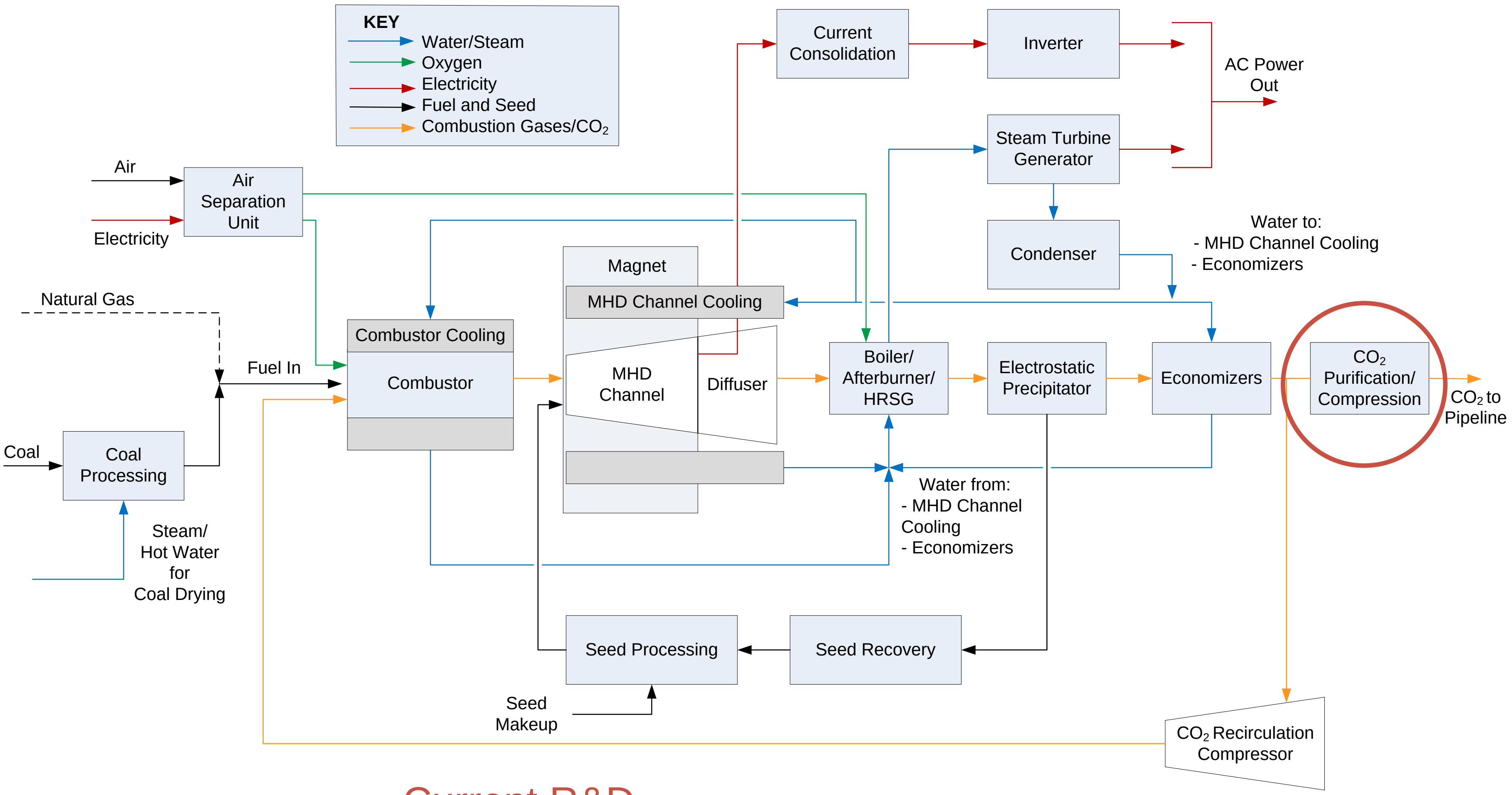
Ion Transport Membrane (ITM)

Air Products and Chemicals, Inc. (APCI)

- Supported thin-film, ceramic planar devices
- Fast, solid state electrochemical transport of oxygen
- Pressure-driven; compact



Coal/Natural Gas-Fired MHD System



Current R&D

Source: NETL

CO_2 Compression and Purification

Oxy-fuel combustion of coal produces a flue gas containing:

- CO_2+ H_2O
- Any inerts from air in leakage or oxygen impurities
- Oxidation products and impurities from the fuel (SOx, NOx, HCl, Hg, etc.)

Purification requires:

- Cooling to remove water
- Low Temperature Purification
  - Low purity-> bulk inerts removal
  - High purity-> Oxygen/CO removal
- Compression to pipeline pressure (~2200 psi)

CO_2 Compression & Purity Requirements

- Compressed to 2200 psi for transport and storage
- Minimum 95% CO_2 content

Component	Unit (Max unless Otherwise noted)	Carbon Steel Pipeline		Enhanced Oil Recovery		Saline Reservoir Sequestration		Saline Reservoir CO_2 & H_2S Co-sequestration		Venting Concerns (See Section 3.0)
		Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	
CO_2	vol% (Min)	95	90-99.8	95	90-99.8	95	90-99.8	95	20 – 99.8	Yes-IDLH 40,000 ppmv
H_2O	ppm$_v$	500	20 - 650	500	20 - 650	500	20 - 650	500	20 - 650	
N_2	vol%	4	0.01 - 7	1	0.01 - 2	4	0.01 - 7	4	0.01 – 7	
O_2	vol%	0.001	0.001 – 4	0.001	0.001– 1.3	0.001	0.001– 4	0.001	0.001 – 4	
Ar	vol%	4	0.01 – 4	1	0.01 – 1	4	0.01 – 4	4	0.01 – 4	
CH_4	vol%	4	0.01 – 4	1	0.01 – 2	4	0.01 – 4	4	0.01 – 4	Yes-Asphyxiate, Explosive
H_2	vol%	4	0.01 - 4	1	0.01 – 1	4	0.01 – 4	4	0.02 – 4	Yes-Asphyxiate, Explosive
CO	ppm$_v$	35	10 - 5000	35	10 - 5000	35	10 - 5000	35	10 - 5000	Yes-IDLH 1,200 ppmv
H_2S	vol%	0.01	0.002 – 1.3	0.01	0.002 – 1.3	0.01	0.002 – 1.3	75	10 - 77	Yes-IDLH 100 ppmv
SO_2	ppm$_v$	100	10 - 50000	100	10 - 50000	100	10 - 50000	50	10 - 100	Yes-IDLH 100 ppmv
NO_x	ppm$_v$	100	20 - 2500	100	20 - 2500	100	20 - 2500	100	20 - 2500	Yes-IDLH NO-100 ppmv, NO_2 - 200 ppmv

Primary concerns for oxy-fuel combustion systems

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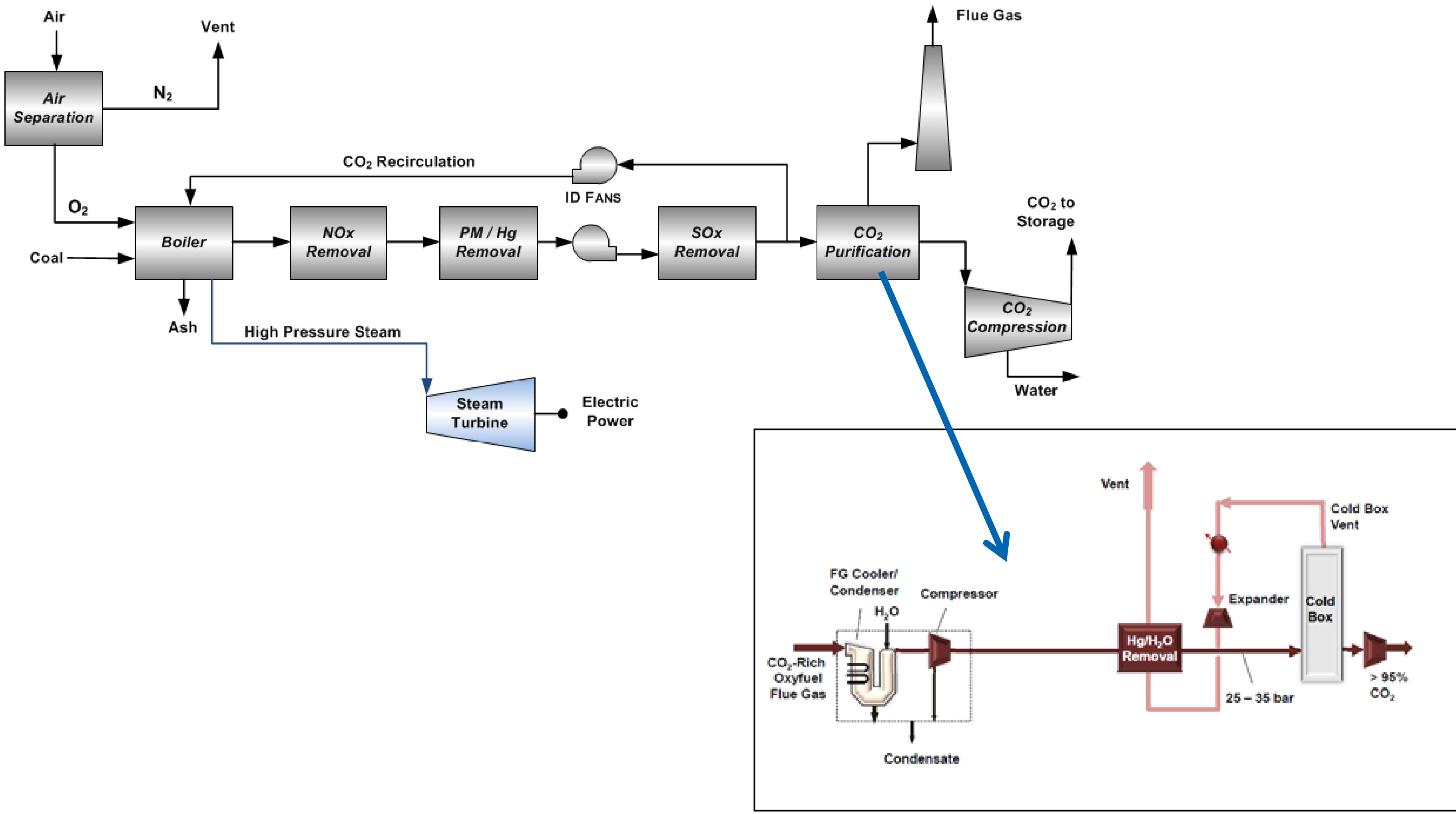
Conventional CO_2 Processing Unit (CPU)



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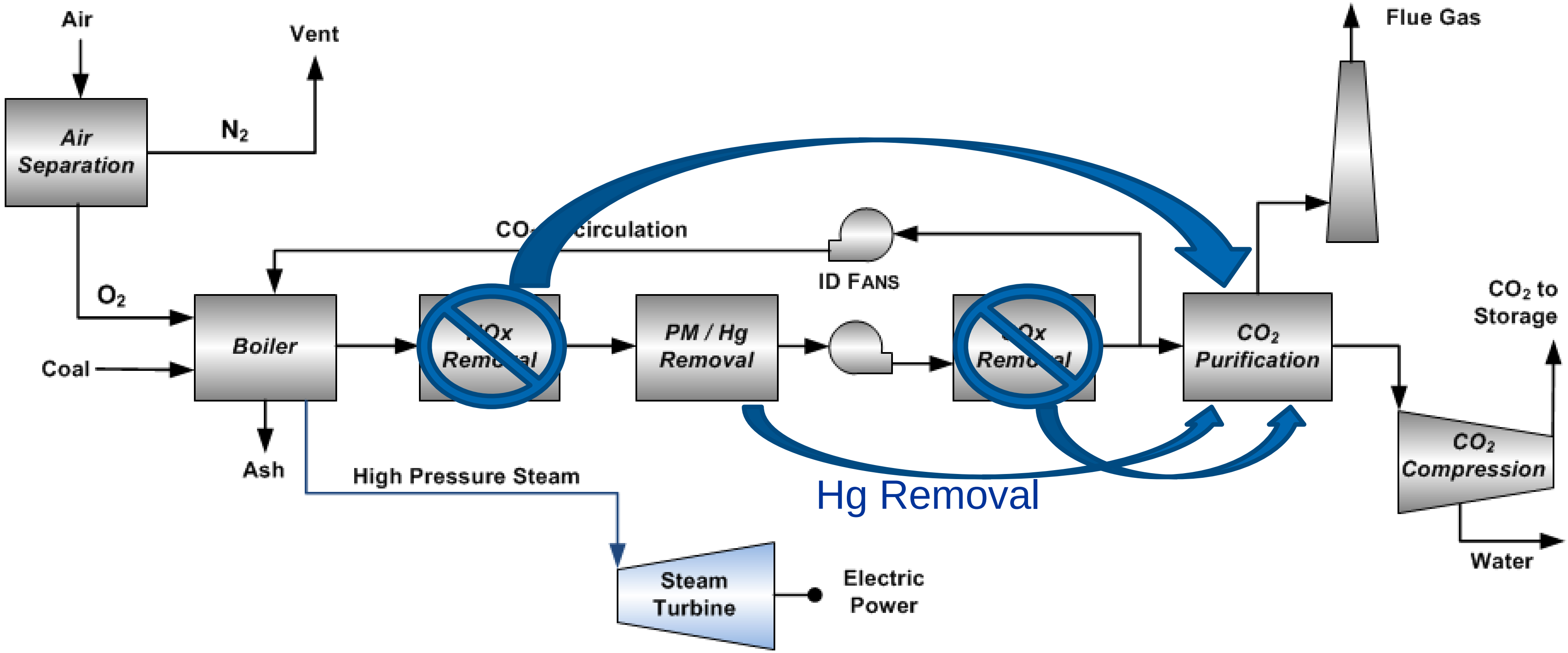
Oxy-combustion with Advanced CPU

- Potential to integrate SOx, NOx, Hg, and inerts removal into CPU unit operation



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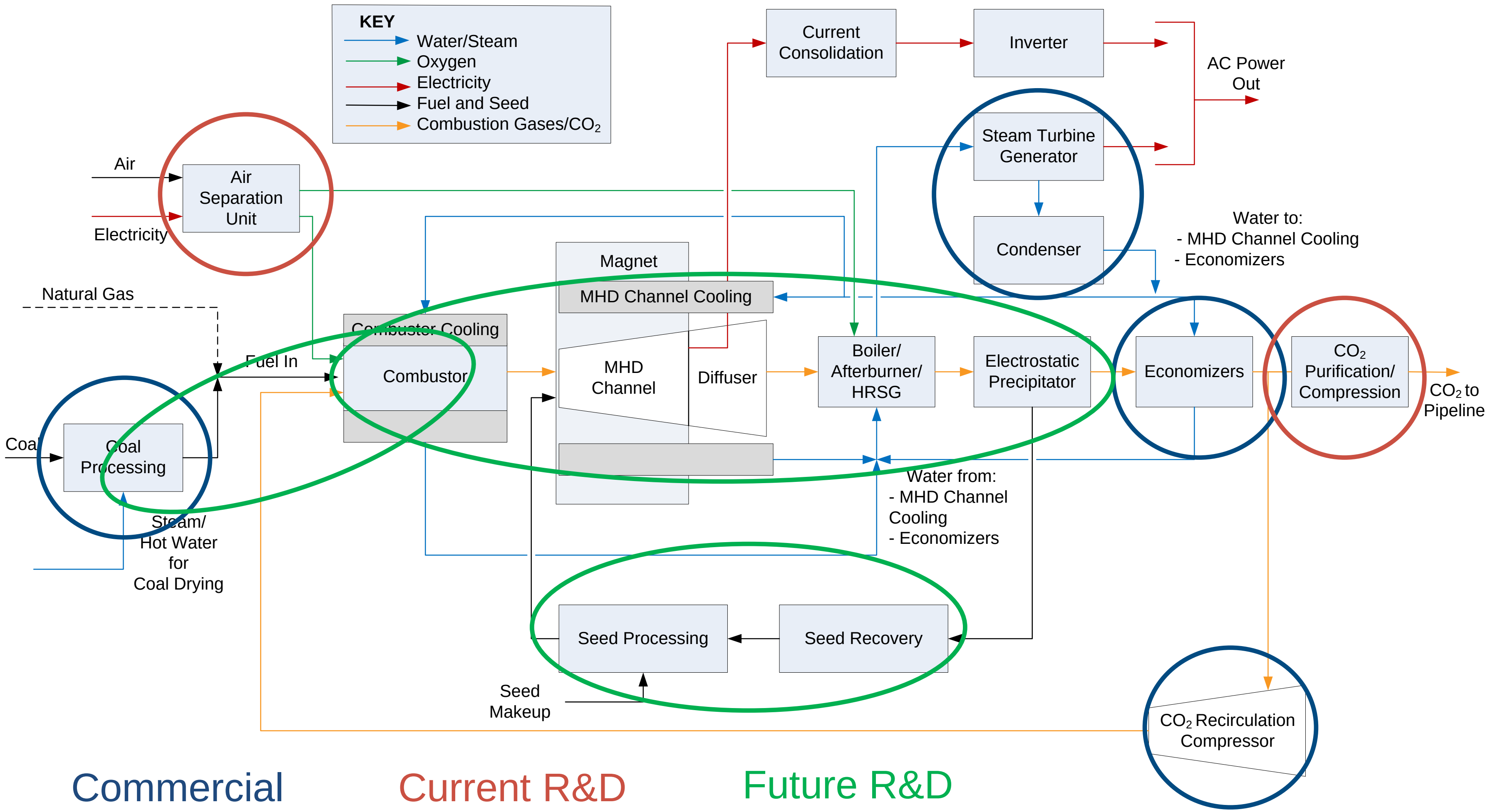
Coal/Natural Gas-Fired MHD System



Source: NETL

Summary of Unit Operation Status

- **Commercially available**
  - Coal processing
  - Steam turbine
  - Economizer
  - CO_2 Compressor
  - Power electronics
- **Current R&D in AES CCRP Programs**
  - Advanced oxygen production (oxygen membrane)
  - Advanced CPU
- **Subsequent to the FE Crosscutting Team and MHD community establishing a path forward**
  - Areas for potential R&D to support MHD
    - MHD channel / diffuser
    - Combustor & coal feeding
    - Boiler/afterburner/HRSG
    - Electrostatic precipitator
    - Seed recovery/processing

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Summary and Conclusion

Oxy-fuel Combustion Relative to a Future MHD Concept

- **Advanced combustion goals presented targeting ACS with affordable COE and CCS at less than $40 / tonne**
- **ACS projects in place supporting oxy-fuel combustion, CLC and SCO2 power cycles (in part)**
- **Current AES R&D relevant to MHD: ASU & CPU**
- **Areas for potential R&D to support MHD**
  - MHD channel / diffuser
  - Combustor & coal feeding
  - Boiler/afterburner/HRSG
  - Electrostatic precipitator
  - Seed recovery/processing
- **Next steps: R&D community needs to validate performance of MHD channel / components & system analysis to validate performance in terms of COE and CCS**

Acknowledgement/Disclaimer

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