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Performance Evaluation of a Supercritical CO_2 Power Cycle Coal Gasification Plant

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Structure

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- Background
  - Base Case IGCC
  - Base Case IGCC with Capture
- Brayton Power Cycle
- Plant Design Basis
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- Results
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  - Design Considerations
- Conclusions

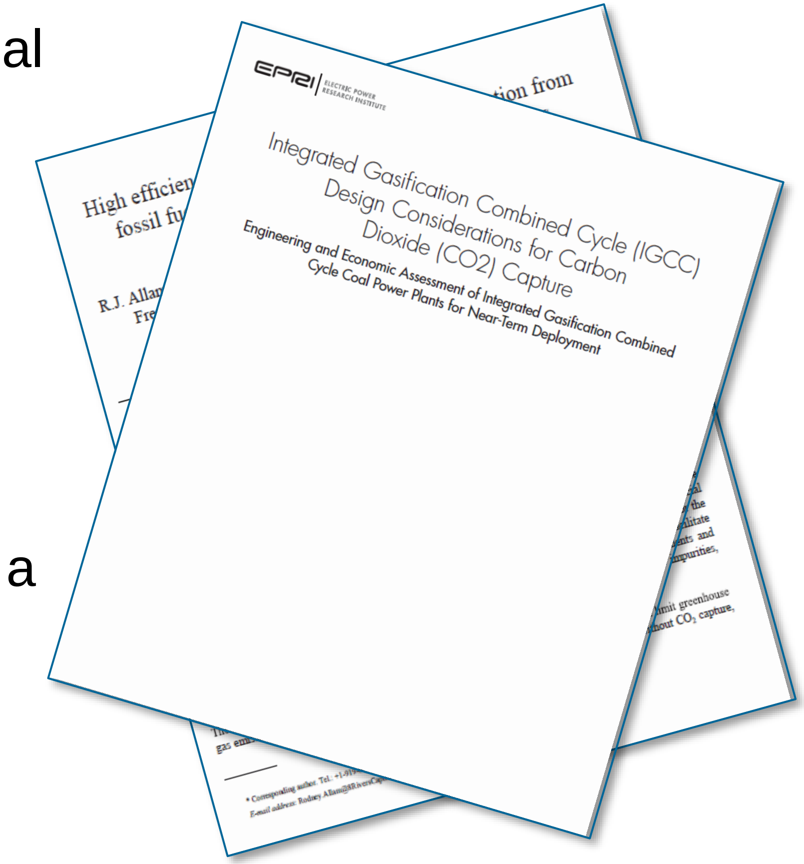
Introduction

- Supercritical CO_2 Cycles offer the potential for high net efficiency of 48.9% (HHV) [1] from coal

- Advanced IGCC design, novel plant components

- Investigation of sCO_2 Brayton coupled to a 'conventional IGCC gasifier design'

- IGCC Plant based on EPRI report 1015699 (2009) [2]



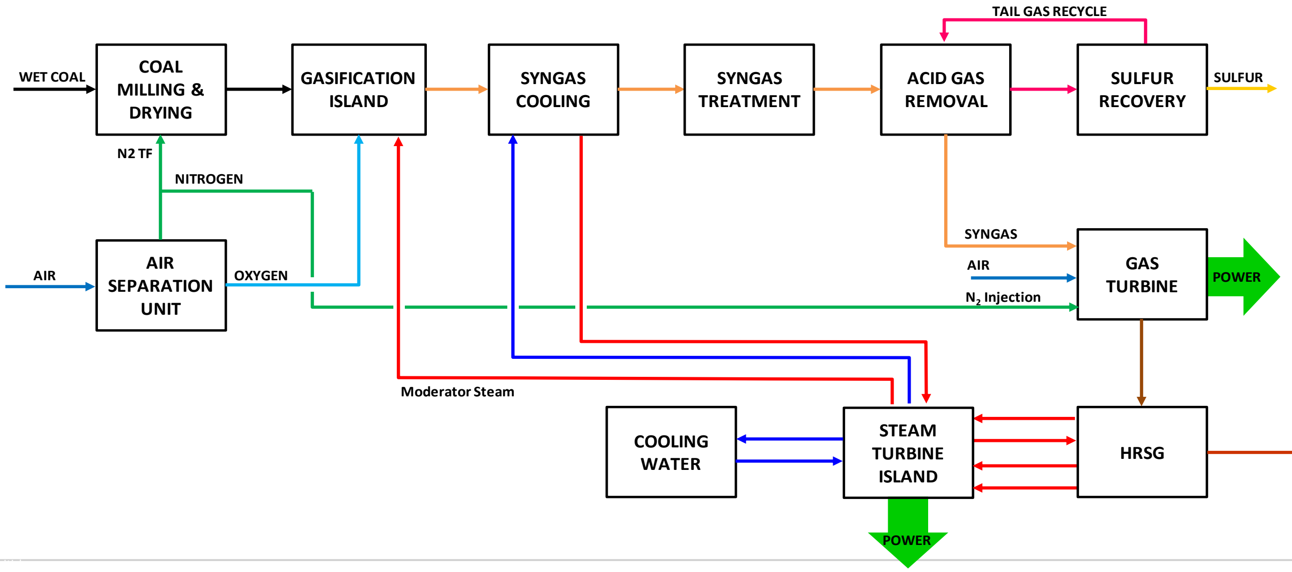
[1] – R.J. Allam et al, "High efficiency and low cost of electricity generation from fossil fuels while eliminating atmospheric emissions, including carbon dioxide"
GHGT-11 - 18th-22nd November 2012, Kyoto International Conference Center, Japan

[2] – Integrated Gasification Combined Cycle (IGCC) Design Considerations for Carbon Dioxide (CO2) Capture, Schoff, R EPRI Report 1015690, 2009

Background - Base Case IGCC Plant

- Shell Syngas Cooler (SGC) design
- Medium pressure technology (43 barg)
- Oxygen purity 95% v/v
- Pressurized dry gas feed
- No CO shift or CO_2 removal
- Selexol acid gas removal
- GE 7FB combustion turbine + HRSG

System Fuel Input	1470
Gas Turbine Output	464
Steam Turbine Output	235
CO2 LP Compression	-
HP Pumps	-
Fuel Compression	-
Oxygen Compression	-
IGCC Aux	16.2
ASU	74.4
Steam Cycle Aux	8.2
Cooling Water Aux	11.1
Net Power	587.9
Power Plant Efficiency (HHV)	40.0%
CO2 lb/MWh	1770



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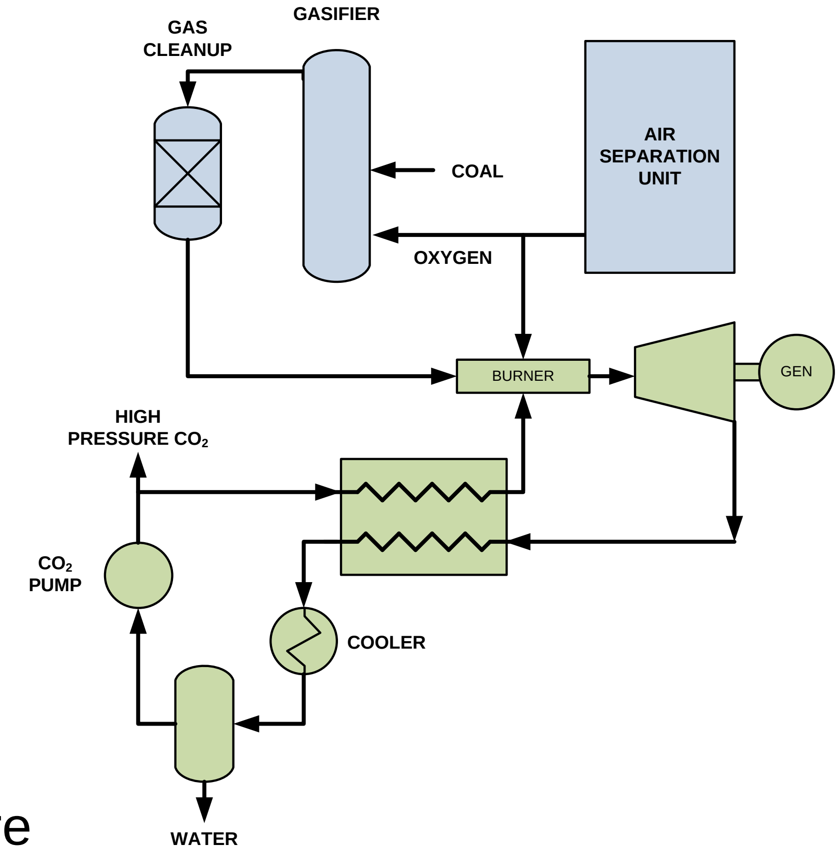
Gasification with sCO_2 Brayton Power Cycle

- Coal gasified
- Resultant 'Syngas' processed
- Syngas compressed to >300 bara
- Combusted at low excess O_2 levels
- Supercritical CO_2 working fluid
- Expanded to produce power
- Recuperative heat exchanger
- Moisture condensed out
- CO_2 Gas Recompressed / Pumped
- Semi - Closed Loop
  - Export CO_2 available at high pressure



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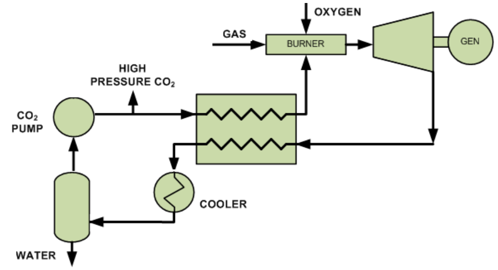
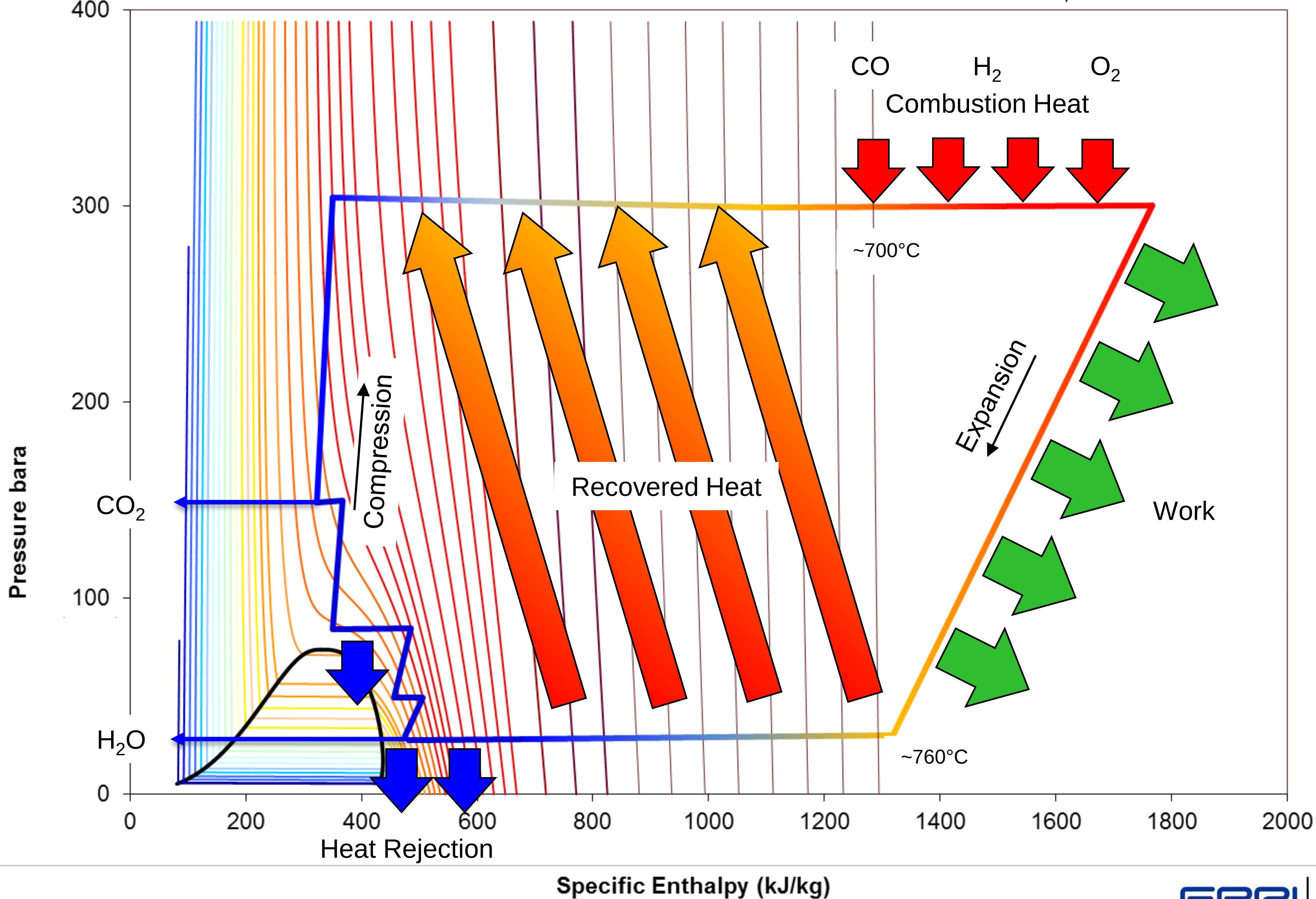
‘Closed’ Brayton Cycle





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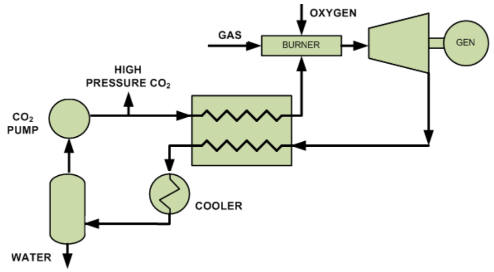
Plant Design Basis

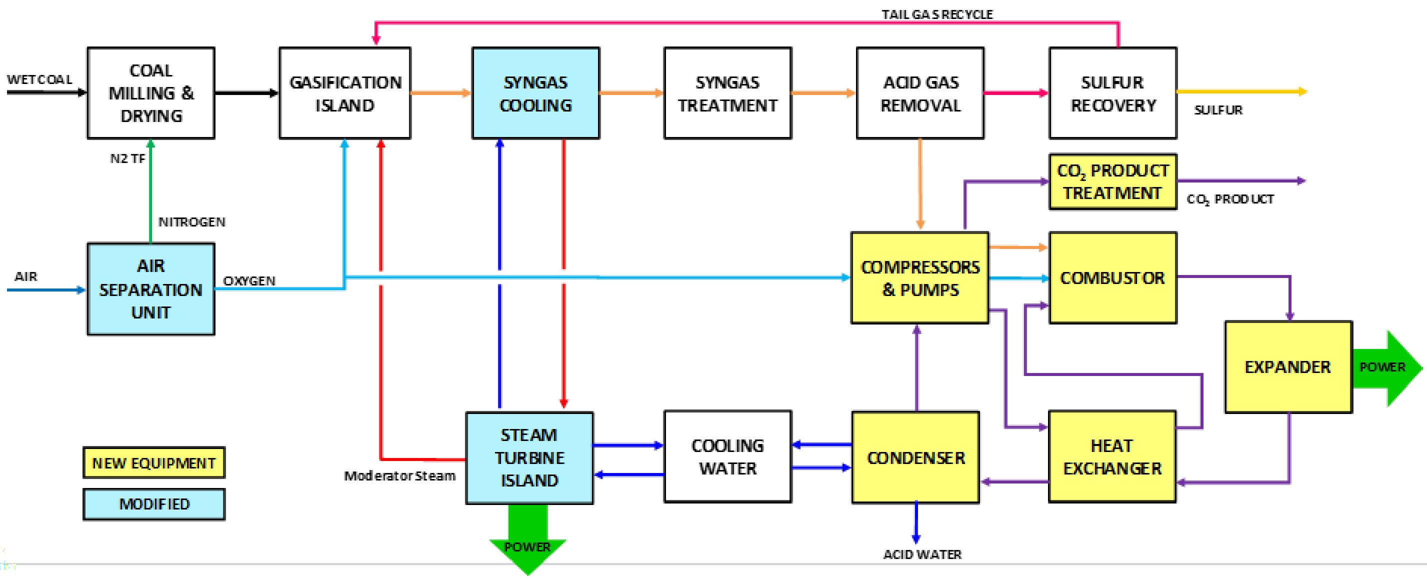


- Conventional gasification system
- PRB Fuel
- 273 tonnes/hr feed (1470MWth HHV)
- NH_3, COS, H_2S, Mercury removal
- Steam Cycle 565°C / 125 bara
- Max 700°C CO_2 feed to burner
- Turbine Inlet Temperature ~1150°C
- Max 760°C gas turbine exhaust
- Heat Exchanger min 20°K approach
- CO_2 delivered pressure ~150 bara
- 3 cases developed:
  - 1 Conventional Nitrogen Transfer Fluid
  - 2 Carbon Dioxide Transfer Fluid
  - 3 Case 2 except with High Purity Oxygen

Case 1 – N2TF

- Nitrogen transfer fluid (as before)
- Gasification plant – Syngas production unchanged
- New power block – ultra high pressure gas turbine
- Syngas cooler – complete boiler unit
- ASU capacity increased, oxygen purity 95% v/v
- Moderator steam remains

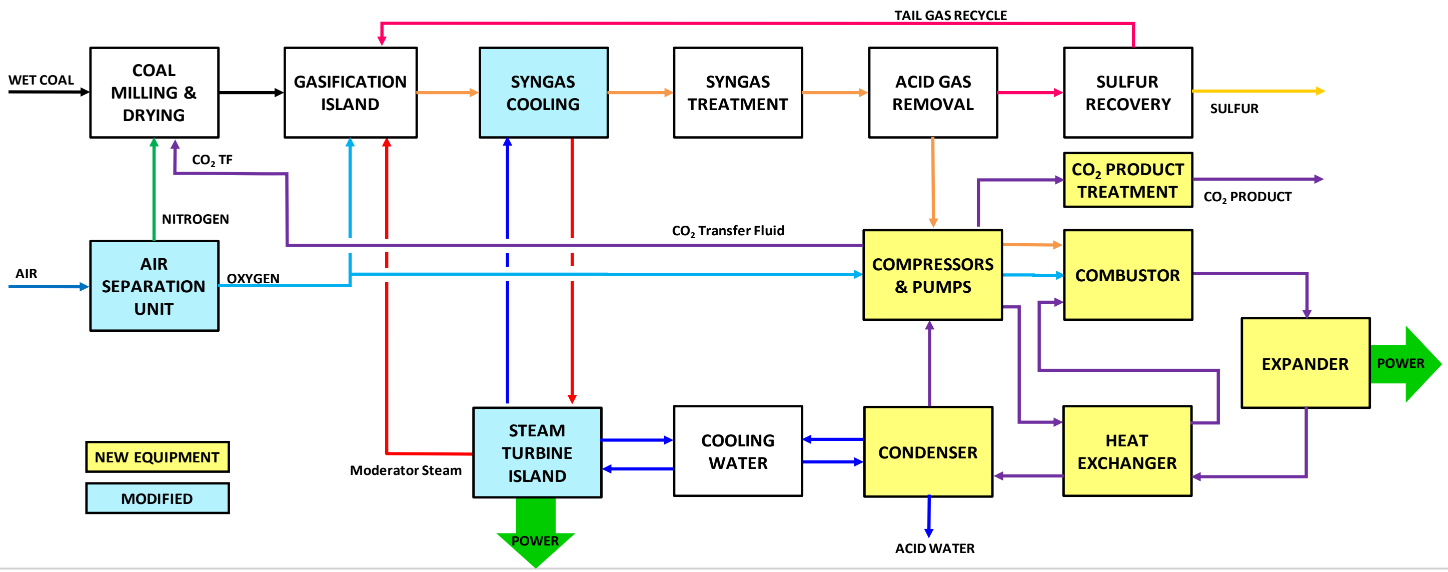
IGCC Output:	Syngas Product	
Compostion	CO	58.32% v/v(w)
	H2	27.91% v/v(w)
	CO2	1.56% v/v(w)
	N2	11.21% v/v(w)
	Ar	0.86% v/v(w)
	Others	0.15% v/v(w)
Massflow		375407 kg/hr



Case 2 – CO2TF

- Transfer Fluid sourced from CO_2 working fluid
- Nitrogen content reduced over 90% from Case 1
- Gasifier process changed – increased CO content
- No moderator steam, syngas CO_2 content higher
- Lower hydrogen content
- Oxygen purity at 95% v/v

IGCC Output:	Syngas Product	
Compostion	CO	68.32% v/v(w)
	H2	22.58% v/v(w)
	CO2	6.56% v/v(w)
	N2	1.06% v/v(w)
	Ar	1.39% v/v(w)
	Others	0.09% v/v(w)
Massflow		388165 kg/hr



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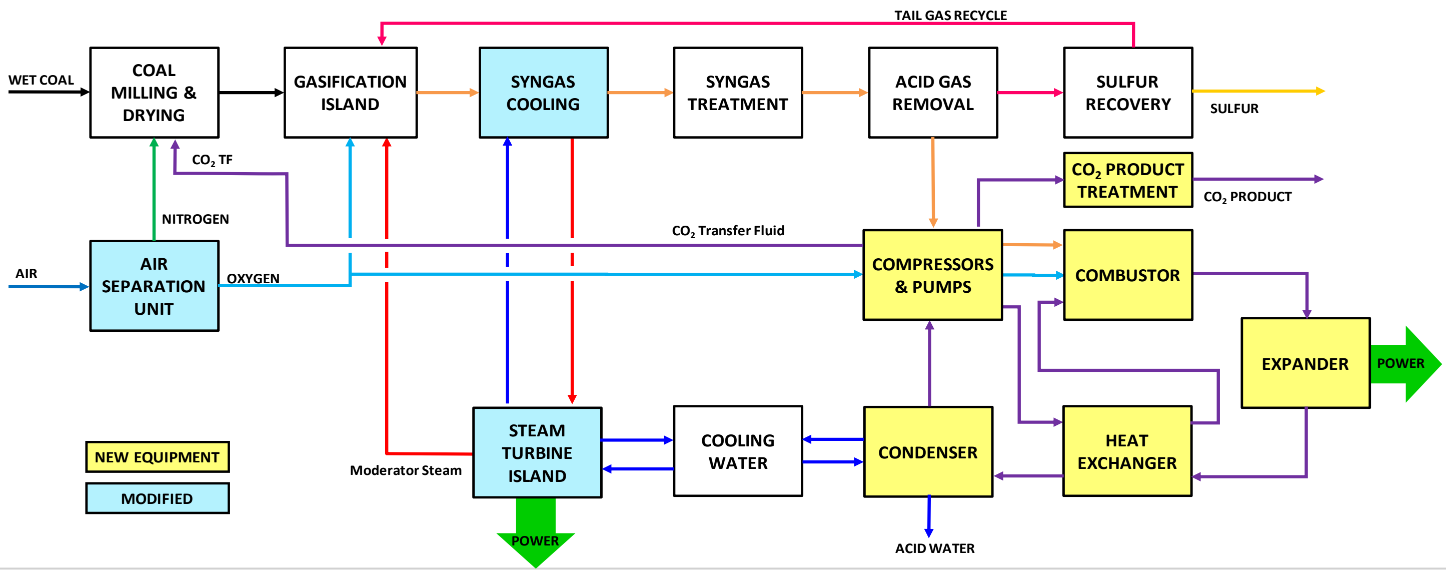
Case 3 – CO2TF (HPO)

- Similar to Case 2 except:

  ASU Oxygen purity increased to 99.5% v/v
- Nitrogen content reduced further by over 50%
- Argon content very low

IGCC Output:	Syngas Product	
Compostion	CO	69.59% v/v(w)
	H2	22.71% v/v(w)
	CO2	6.94% v/v(w)
	N2	0.50% v/v(w)
	Ar	0.17% v/v(w)
	Others	0.09% v/v(w)
Massflow		380393 kg/hr



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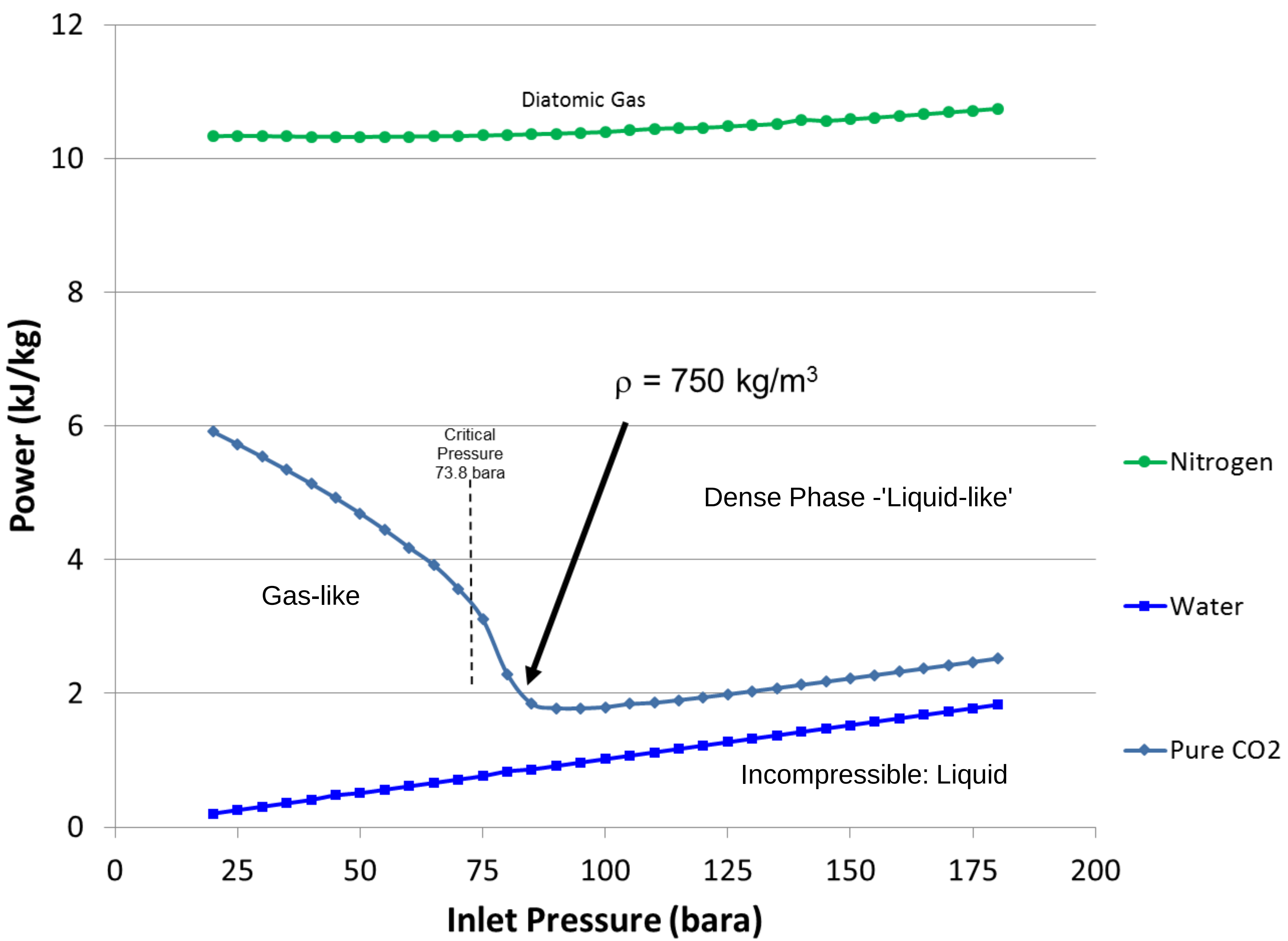
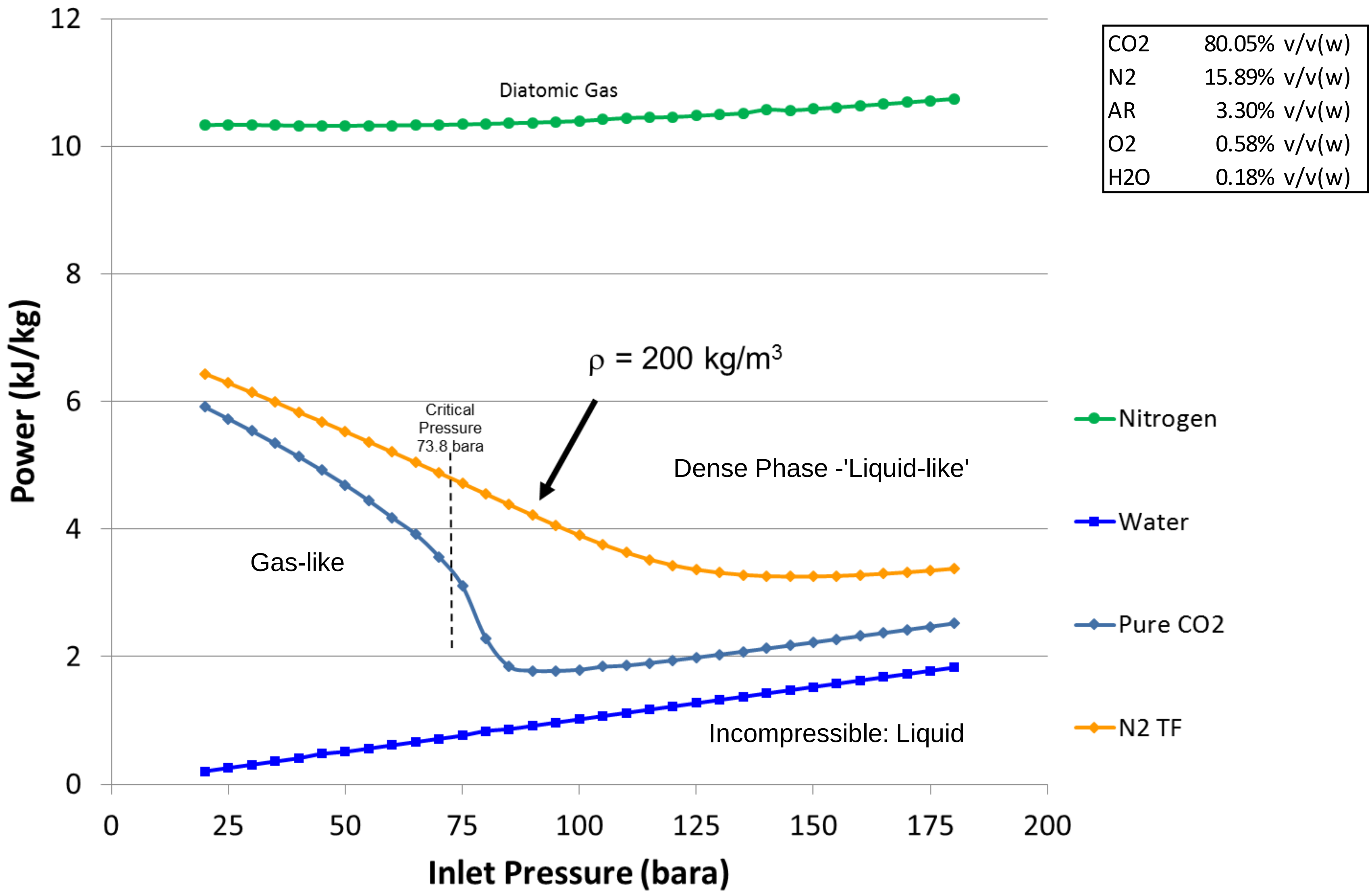
Compression Analysis – Pure CO_2



Compression Analysis – Case 1



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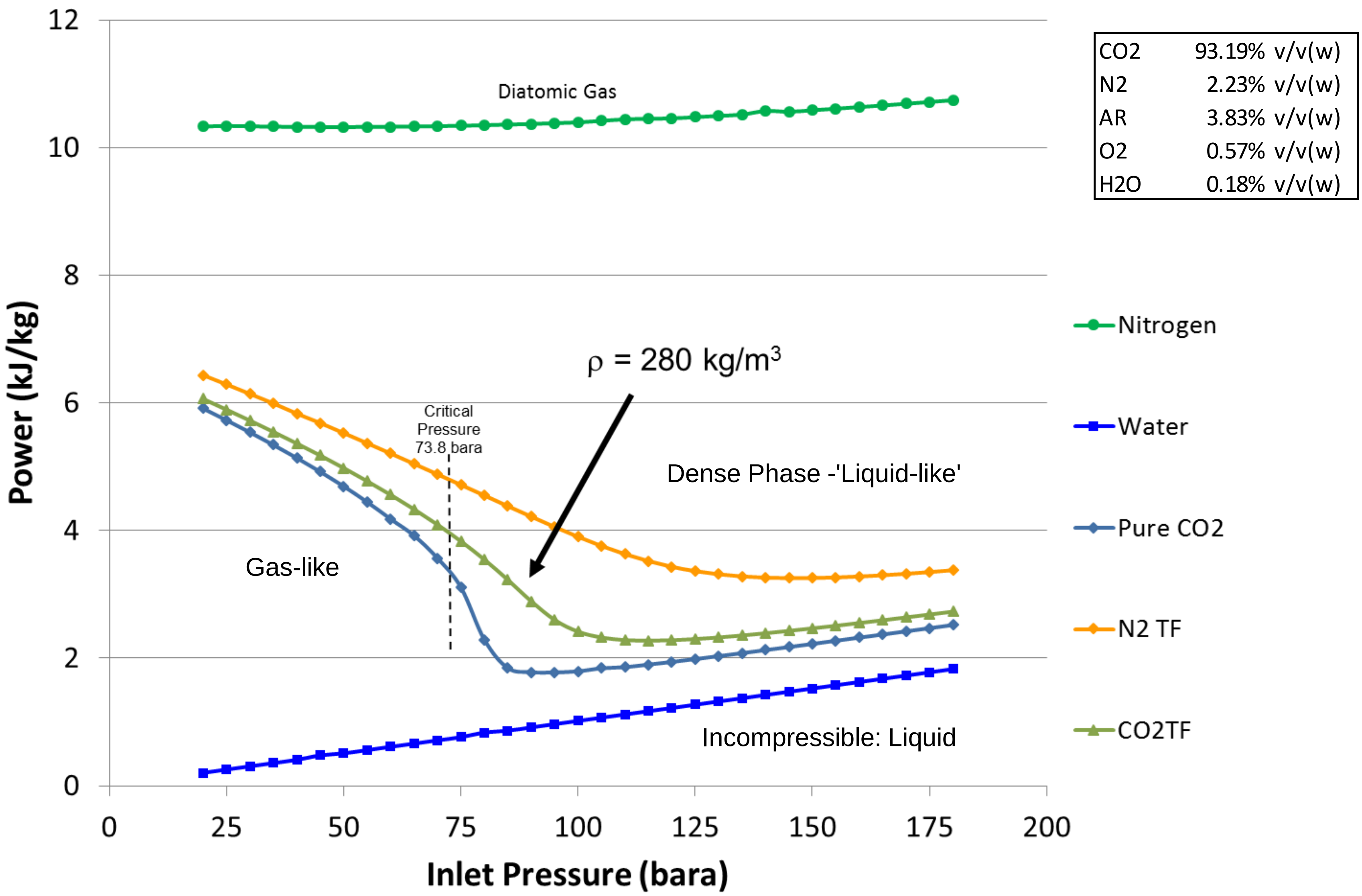
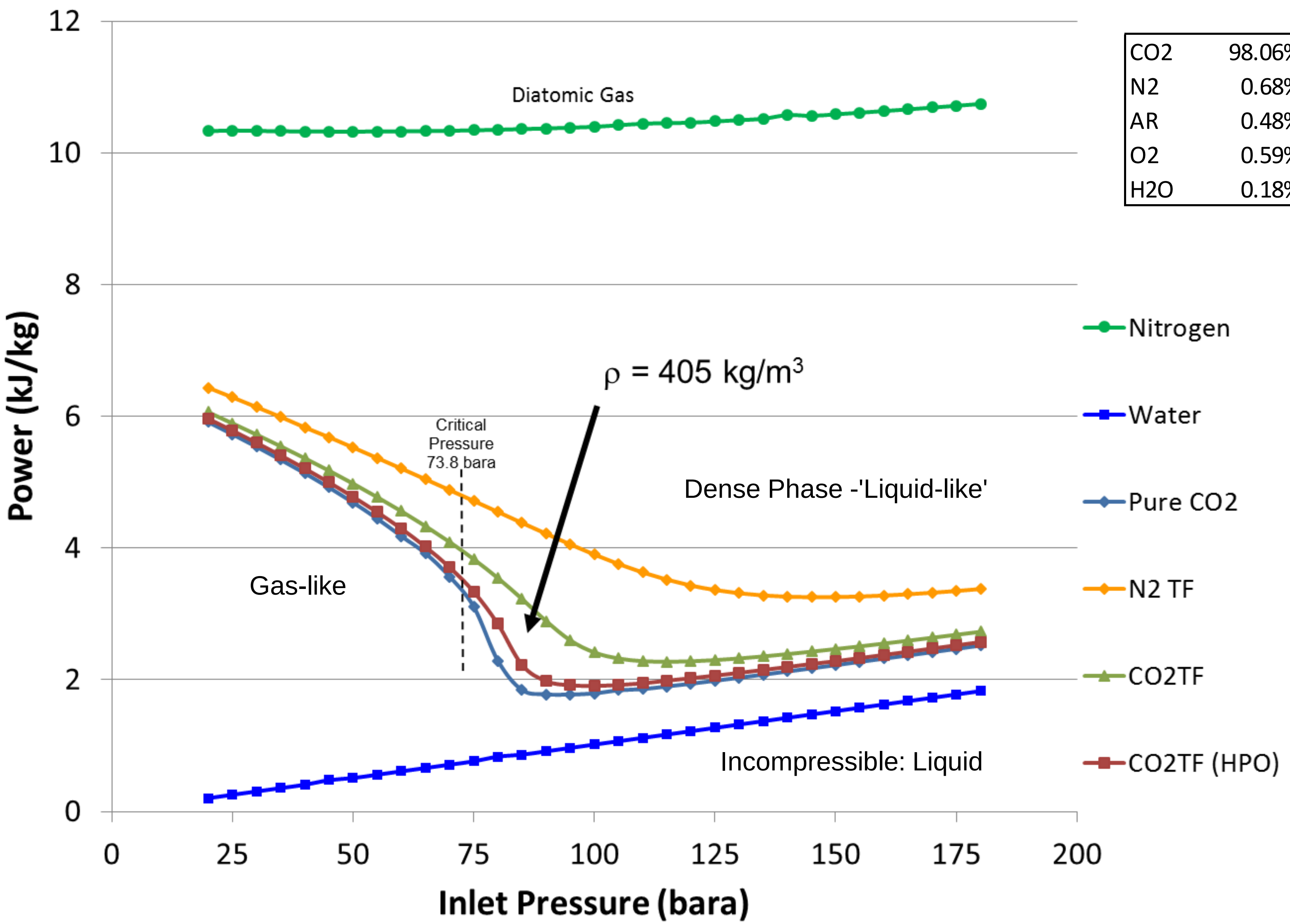
Compression Analysis – Case 2



Compression Analysis – Case 3



CO_2	98.06% v/v(w)
N_2	0.68% v/v(w)
AR	0.48% v/v(w)
O_2	0.59% v/v(w)
H_2O	0.18% v/v(w)

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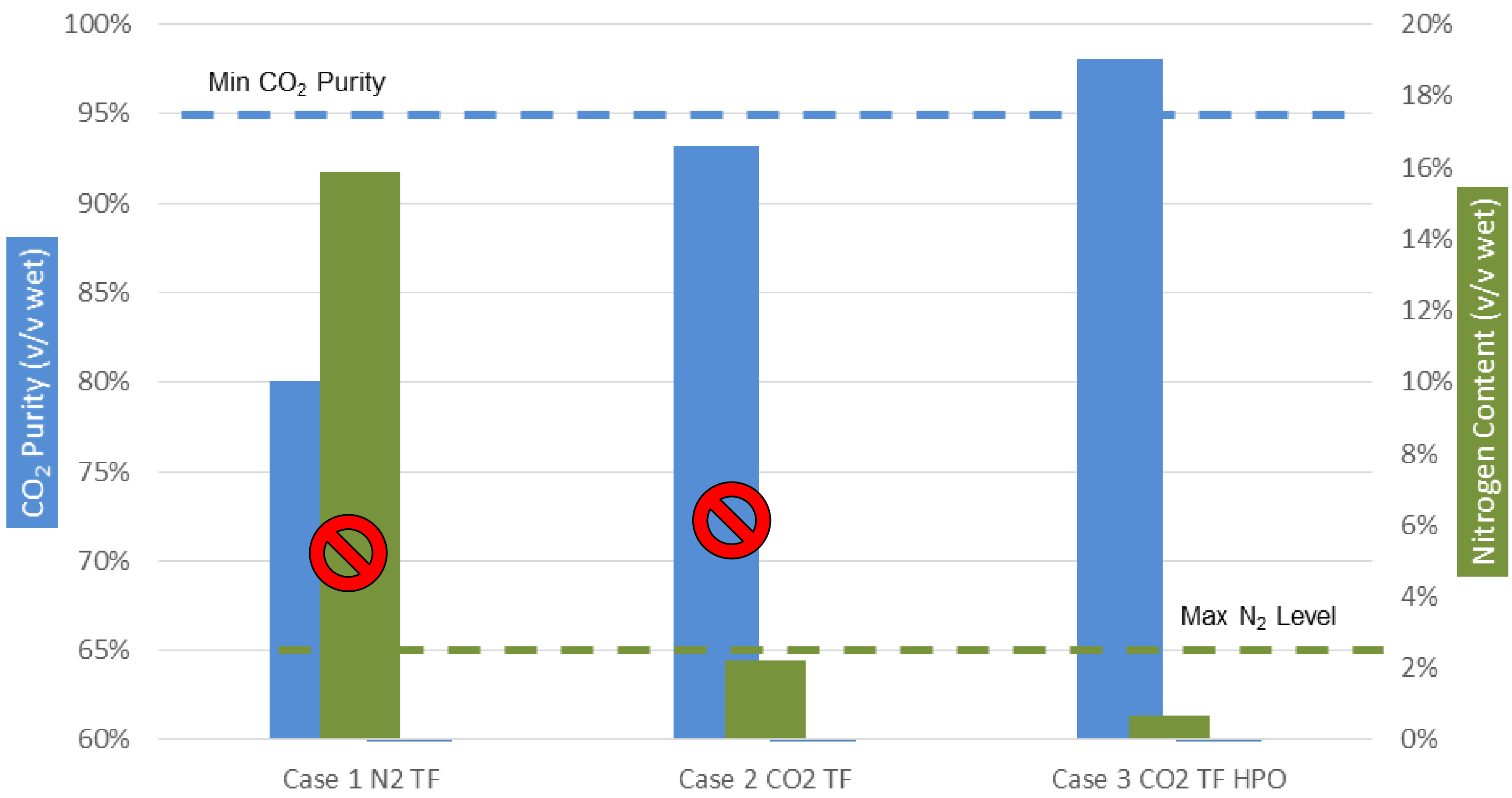
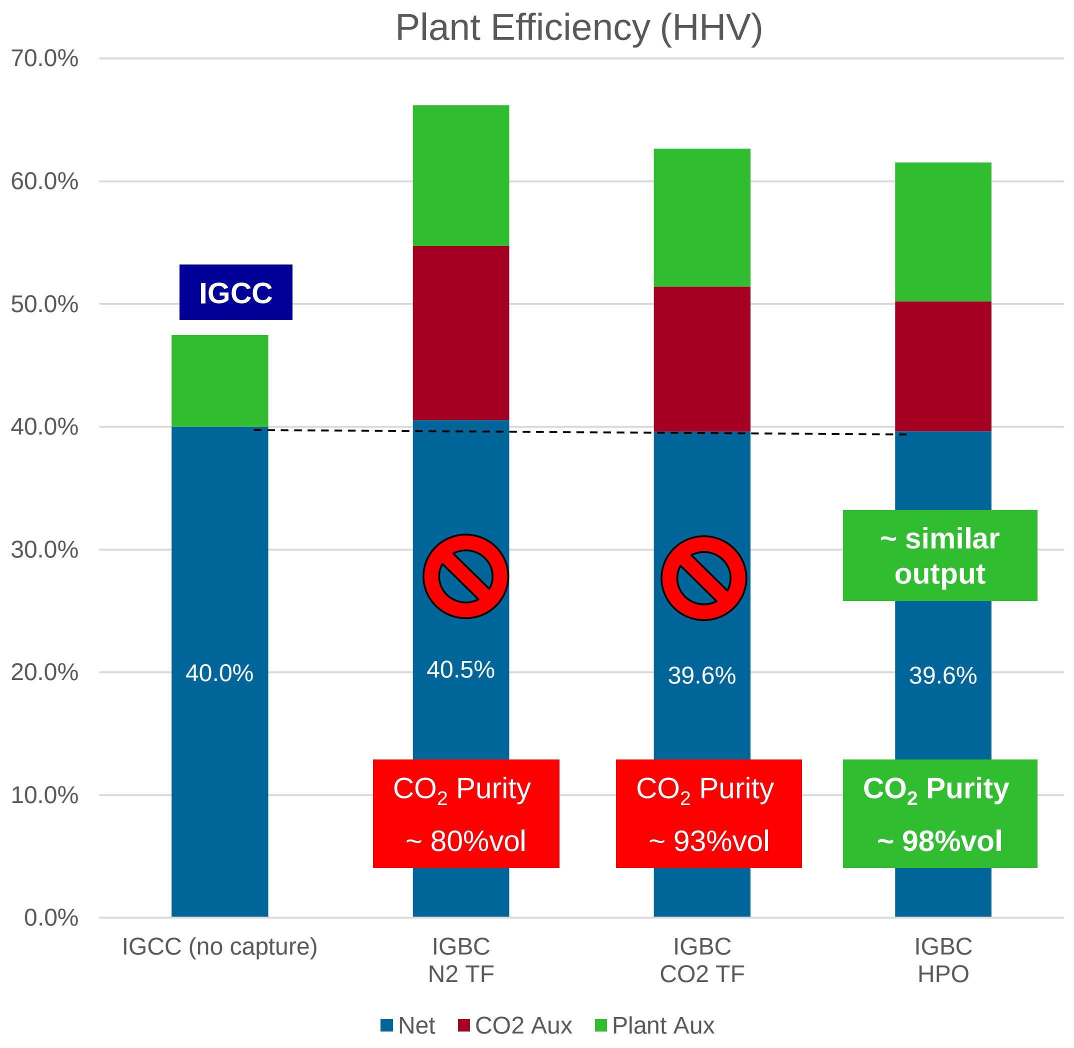
Performance Results - Product Purity



Performance Results - Power



- Low purity CO_2 working fluid delivers more power but not within product specification
- Case 3 (HPO) meets specification and achieves near 100% capture with similar power output

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Performance Results

Case		IGCC w/o Capture	sCO_2 Case 1	sCO_2 Case 2	sCO_2 Case 3
Transfer Fluid		N_2	N_2	CO_2	CO_2
Oxygen Purity	v%	95	95	95	99.5
Fuel Input	MWth	1470	1470	1470	1470
GT/Expander Power	MWe	464	922	864	846
Steam Turbine Power	MWe	235	52.3	58.4	59.3
CO_2 Compression	MWe	-	95.0	86.3	83.2
CO_2 Pumps	MWe	-	113.6	87.2	72.4
Fuel Compression	MWe	-	46.6	43.4	42.7
Oxygen Supply (ASU/Comp)	MWe	74.4	91.1	90.7	92.5
Gasifier Auxiliary	MWe	16.2	16.2	16.2	16.2
Plant Auxiliary	MWe	19.3	14.7	14.9	14.8
Net Power Exported*	MWe	587.9	596.0	582.4	582.6
Overall Plant Efficiency	% HHV	40.0	40.5	39.6	39.6
Capture Rate	%	0	99.5	99.3	99.2
CO_2 Emission	lb/MWh	1770	11.6	12.9	13.6
CO_2 Emission	g/kWh	803	5.3	5.9	6.2
CO_2 Product Flow	lb/h	-	1,211,335	1,092,124	1,046,597
CO_2 Product Flow	kg/h	-	549,483	495,407	474,755
CO_2 Product Purity	v% wet	-	80.1	93.2	98.1

…with near 100% capture, performance close to IGCC without capture!

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Technical Risks

- Higher Pressure Gasification
- Exchanger and Piping
- Combustor Design – ultra low oxygen
- Expander Design
  - Integrally cooled HP blades
  - High temperature materials
- High & low temperature corrosion
- CO_2 Product Purity (oxygen)
- Ultra high pressure CO_2 Safety

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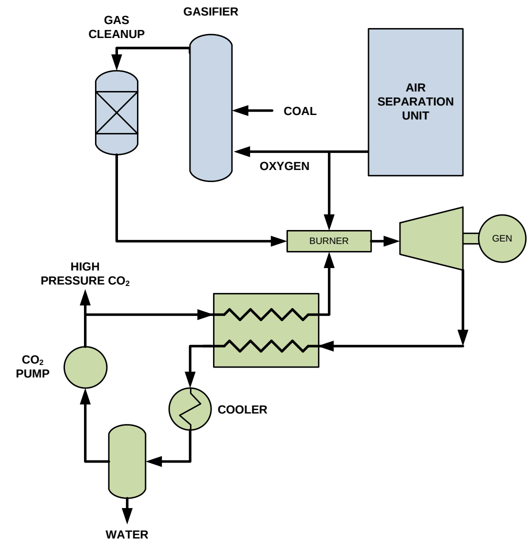
Conclusions and Recommendations

- Superior low carbon performance
- Proven gasification technology
- Near 100% capture
- Opportunities to improve efficiency



Future areas of investigation

- sCO_2 turbine development
- Combustion performance
- Heat exchanger cost reduction
- Economic cycle optimization
- Product gas purity improvement

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