COMPARISON BETWEEN FBC & PF TECHNOLOGY APPLICATION IN SOUTH AFRICA

Independent Power Generation in Southern Africa

17th March 2016

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BACKGROUND & OBJECTIVE

The South African Integrated Resource Plan (IRP) for Electricity 2010-2030, Update Report issued in 2013, tabled an allocation of 6 250 megawatts (MW) for Coal. The Coal allocation referenced to options of: Pulverised Fuel (PF); Fluidised Bed Combustion (FBC); Imports; and Own Build.

The presentation of the paper reviews previous comparisons between PF and FBC technologies within a South African context. The comparison focuses on financial, technical, and environmental performance. Referral is also made to previous studies and quantifications in the space of primary energy resources associated with the consumptions of the respective technologies – with a key referral to the South African Coal RoadMap (SARCM) 2013.

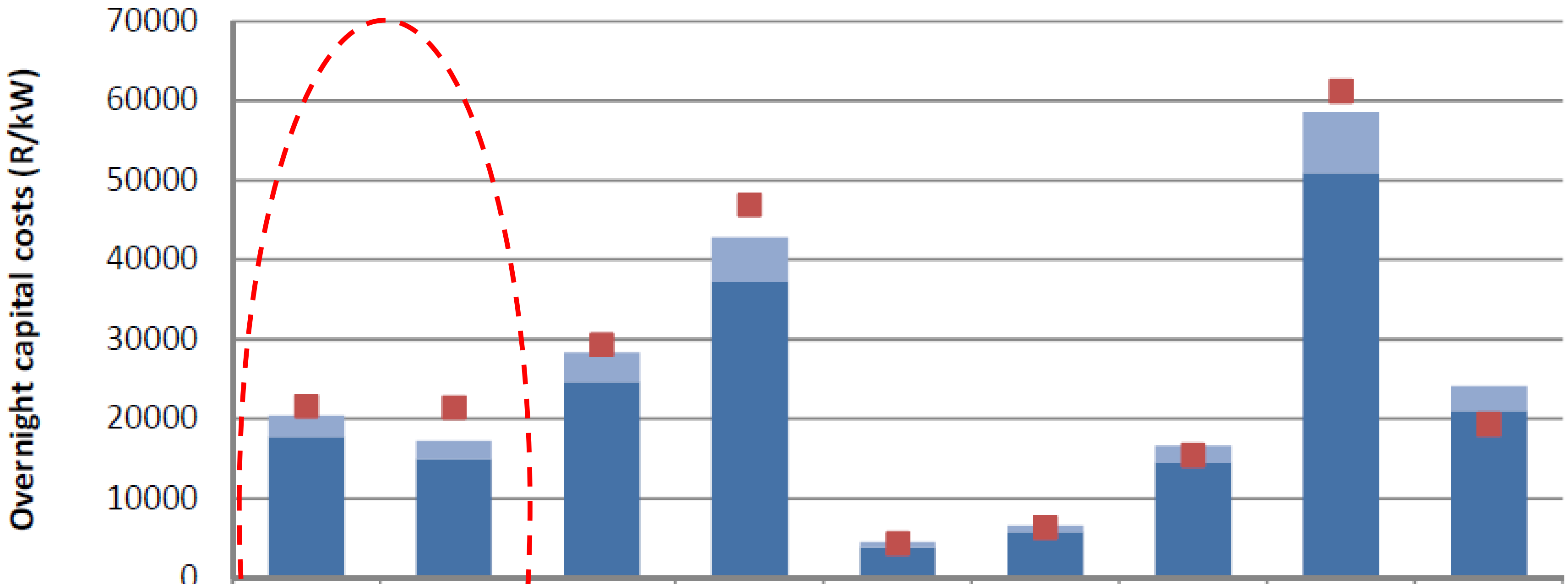
The comparison between both technologies and gap identification to advance them respectively within the South African context is the overall objective to position the technologies competitively.

MINISTERIAL DETERMINATIONS *(IRP 2013 UPDATE)*

	New build options								Committed					Non IRP
	Coal (PF, FBC, imports, own build)	Nuclear	Import hydro	Gas – CCGT	Peak – OCGT[1]	Wind	CSP	Solar PV	Coal	Other	DoE Peaker	Wind[2]	Other Renew.	Co-generation
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
2010	0	0	0	0	0	0	0	0	380	260	0	0	0	0
2011	0	0	0	0	0	0	0	0	679	130	0	0	0	0
2012	0	0	0	0	0	0	0	300	303	0	0	400	100	0
2013	0	0	0	0	0	0	0	300	823	333	1020	400	25	0
2014	500	0	0	0	0	400	0	300	722	999	0	0	100	0
2015	500	0	0	0	0	400	0	300	1444	0	0	0	100	200
2016	0	0	0	0	0	400	100	300	722	0	0	0	0	200
2017	0	0	0	0	0	400	100	300	2168	0	0	0	0	200
2018	0	0	0	0	0	400	100	300	723	0	0	0	0	200
2019	250	0	0	237	0	400	100	300	1446	0	0	0	0	0
2020	250	0	0	237	0	400	100	300	723	0	0	0	0	0
2021	250	0	0	237	0	400	100	300	0	0	0	0	0	0
2022	250	0	1 143	0	805	400	100	300	0	0	0	0	0	0
2023	250	1 600	1 183	0	805	400	100	300	0	0	0	0	0	0
2024	250	1 600	283	0	0	800	100	300	0	0	0	0	0	0
2025	250	1 600	0	0	805	1 600	100	1 000	0	0	0	0	0	0
2026	1 000	1 600	0	0	0	400	0	500	0	0	0	0	0	0
2027	250	0	0	0	0	1 600	0	500	0	0	0	0	0	0
2028	1 000	1 600	0	474	690	0	0	500	0	0	0	0	0	0
2029	250	1 600	0	237	805	0	0	1 000	0	0	0	0	0	0
2030	1 000	0	0	948	0	0	0	1 000	0	0	0	0	0	0
Total	6 250	9 600	2 609	2 370	3 910	8 400	1 000	8 400	10133	1722	1020	800	325	800

2011 Determinations — 2012 Determinations — Eskom commitments (pre IRP)

OVERNIGHT CAP-EX
(IRP 2013 UPDATE)



	PF Coal (with FGD)	FBC Coal (with FGD)	IGCC	Nuclear	OCGT	CCGT	Wind	CSP (Parabolic, 9 hrs)	PV crystalline (fixed tilt)
Inflation	2 655	2 234	3 682	5 554	590	863	2 156	7 599	3 130
IRP 2010	17785	14965	24670	37205	3955	5780	14445	50910	20971
IRP Update	21572	21440	29282	46841	4357	6406	15394	61176	19250

PF & FBC FINANCIAL COMPARISON
(IRP 2013 UPDATE)

	Pulverised coal, with FGD	Pulverised coal, with CCS	Fluidised bed combustion (coal) with FGD	Fluidised bed combustion (coal) with CCS
Rated capacity, net (MW)	4500 (6 x 750)	4500 (6 x 750)	250	250
Life of programme	30	30	30	30
Typical load factor (%)	85%	85%	85%	85%
Overnight capital costs (R/kW)	21572	40845	21440	40165
Lead time	9	9	4	4
Phasing in capital spent (% per year) (* indicates commissioning year of 1st unit)	2%, 6%, 13%, 17%*, 17%, 16%, 15%, 11%, 3%	2%, 6%, 13%, 17%*, 17%, 16%, 15%, 11%, 3%	10%, 25%, 45%, 20%	10%, 25%, 45%, 20%
Adjusted overnight capital costs, accounting for capex phasing (R/kW) and discount rate	25772	48789	23661	44325
Fixed O&M (R/kW/a)	552	923	543	902
Variable O&M (R/MWh)	51.2	81.4	110.8	149.1
Variable Fuel costs (R/GJ)	17.5	17.5	8.75	8.75
Fuel Energy Content, HHV, kJ/kg	17850	17850	17850	17850
Heat Rate, kJ/kWh, avg	9812	14106	10081	15425
Equivalent Avail	91.7	91.7	90.4	90.4
Maintenance	4.8	4.8	5.7	5.7
Unplanned outages	3.7	3.7	4.1	4.1
Water usage, l/MWh	231	320	33	43
Sorbent usage, kg/MWh	15.8	22.8	38	59
CO2 emissions (kg/MWh)	947.3	136.2	978	150
SOx emissions (kg/MWh)	0.46	0.66	0.47	0.72
NOx emissions (kg/MWh)	1.94	0.42	1.39	2.13
Hg (kg/MWh)				
Particulates (kg/MWh)	0.13	0.18	0.13	0.2
Fly ash (kg/MWh)	168	241.5	172.6	264.1
Bottom ash (kg/MWh)	3.3	4.8	3.4	5.2
FGD solids (kg/MWh)	25.2	36.2	61.1	93.4
Levelised Cost				
Adjusted Capital (R/MWh)	287.10	543.51	263.58	493.78
O&M (R/MWh)	125.33	205.36	183.73	270.24
Fuel (R/MWh)	171.71	246.86	88.21	134.97
Total (R/MWh)	584.14	995.72	535.52	898.99

FINANCIAL COMPARISON - SENSITIVITIES *(IRP UPDATE 2013)*

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	PF+FGD	PF+CCS	FBC+FGD	FBC+CCS
Overnight Cap-Ex (R/kW)	21 572	40 845	21 440	40 165
Variable Fuel Costs (R/GJ)	17.5	17.5	8.75	8.75
CV (HHV) (MJ/kg)	17.85	17.85	17.85	17.85
Water Usage (l/MWh)	231	320	33	43
Sorbent Usage (kg/MWh)	15.8	22.8	38	59
CO_2 Emissions (kg/MWh)	947.3	136.2	978	150
SO_X Emissions (kg/MWh)	0.46	0.66	0.47	0.72
NO_X Emissions (kg/MWh)	1.94	0.42	1.39	2.13
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FINANCIAL COMPARISON - SENSITIVITIES
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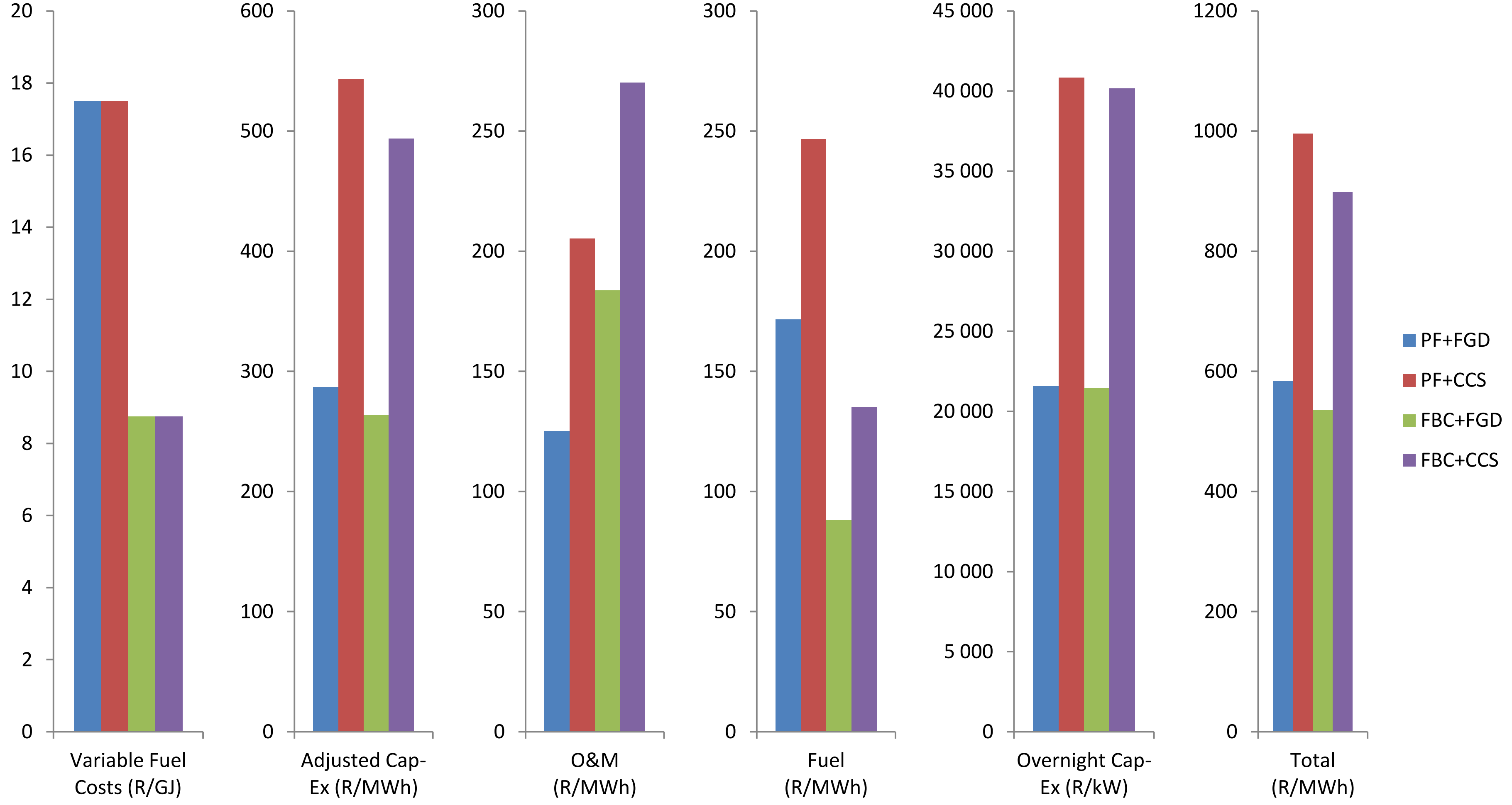
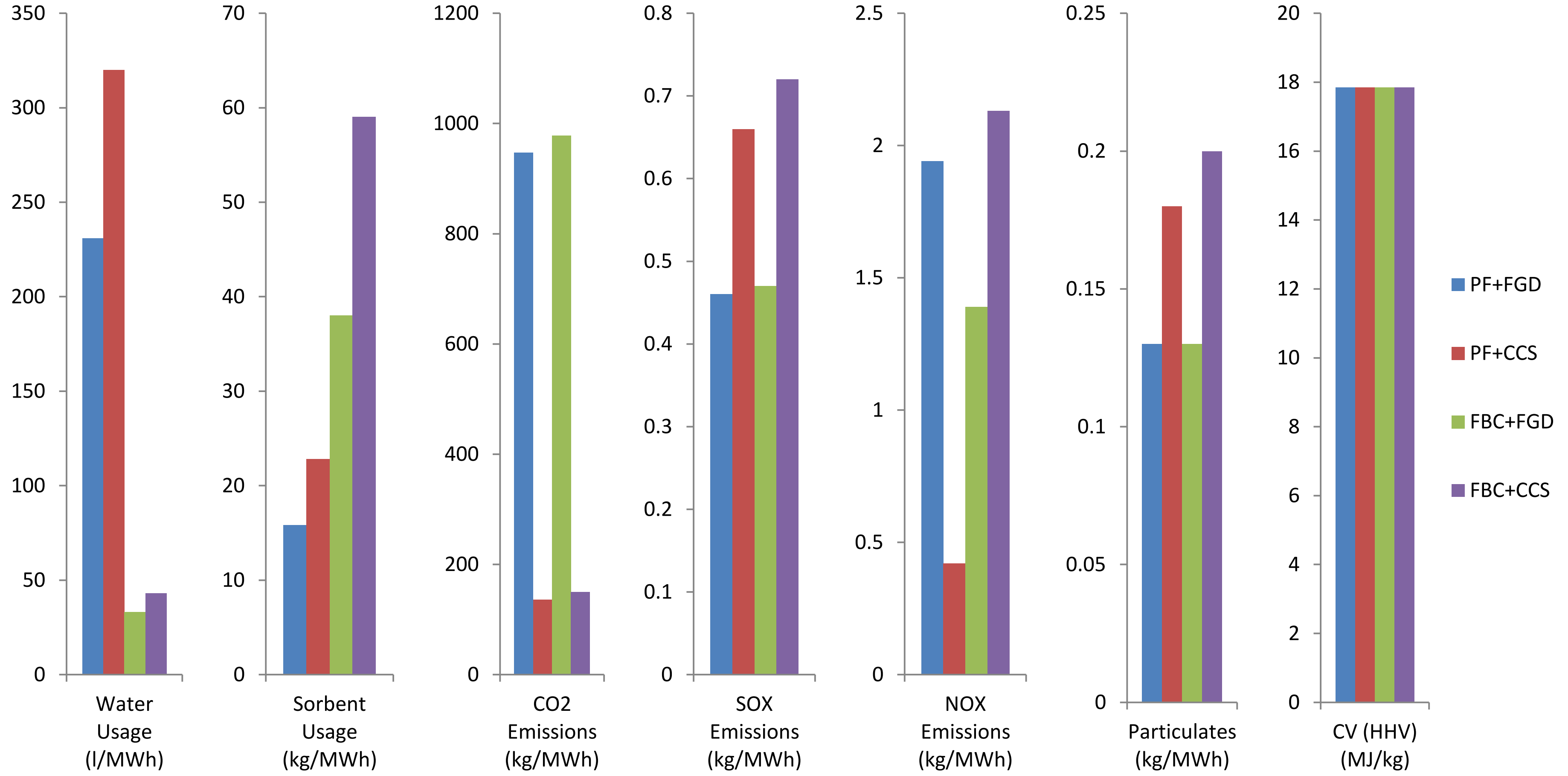


TECHNICAL COMPARISON - SENSITIVITIES
(CREATED FROM – IRP UPDATE 2013)



TECHNICAL & ENVIRONMENTAL ANALYSIS

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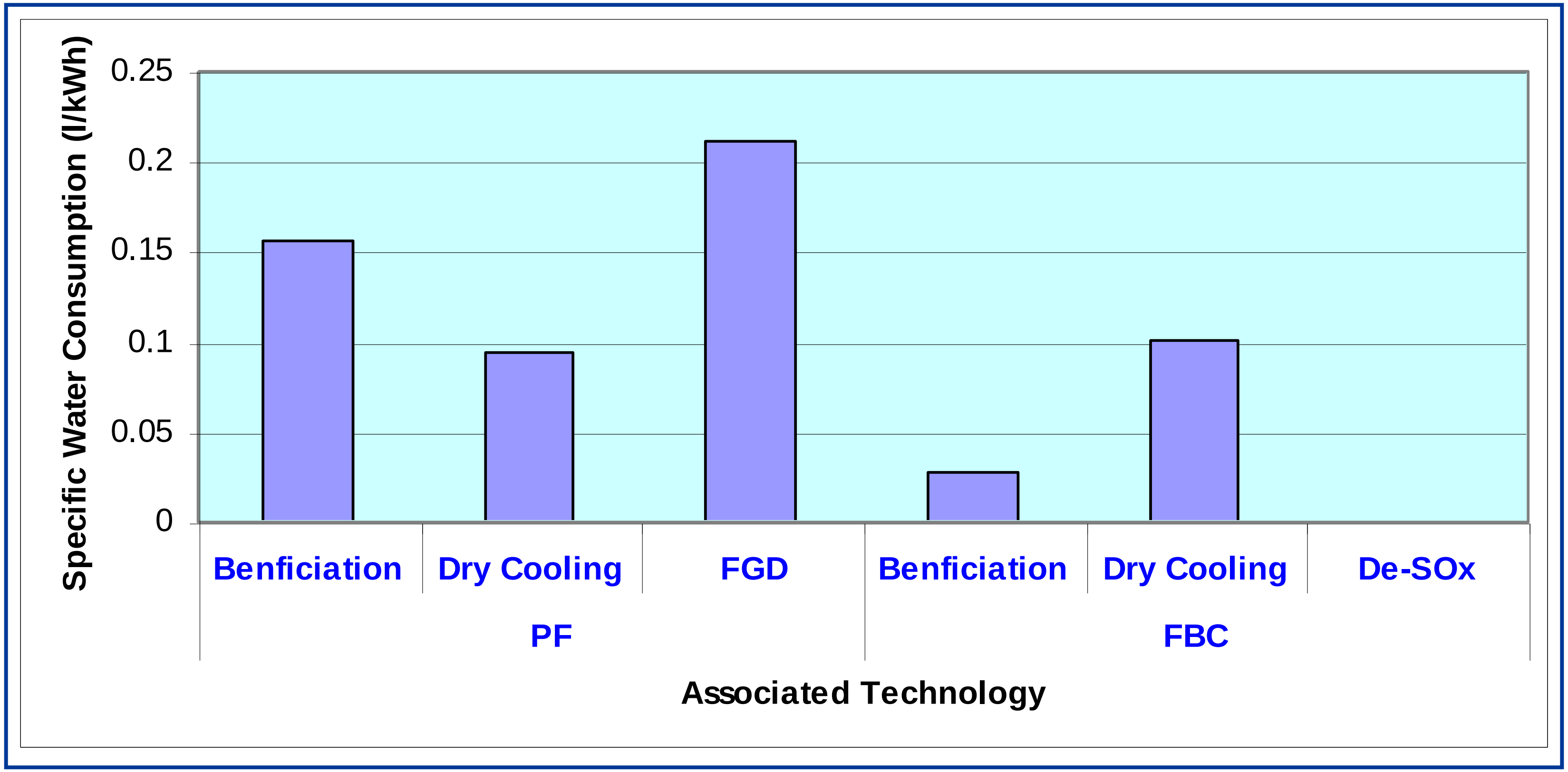
Assumptions:

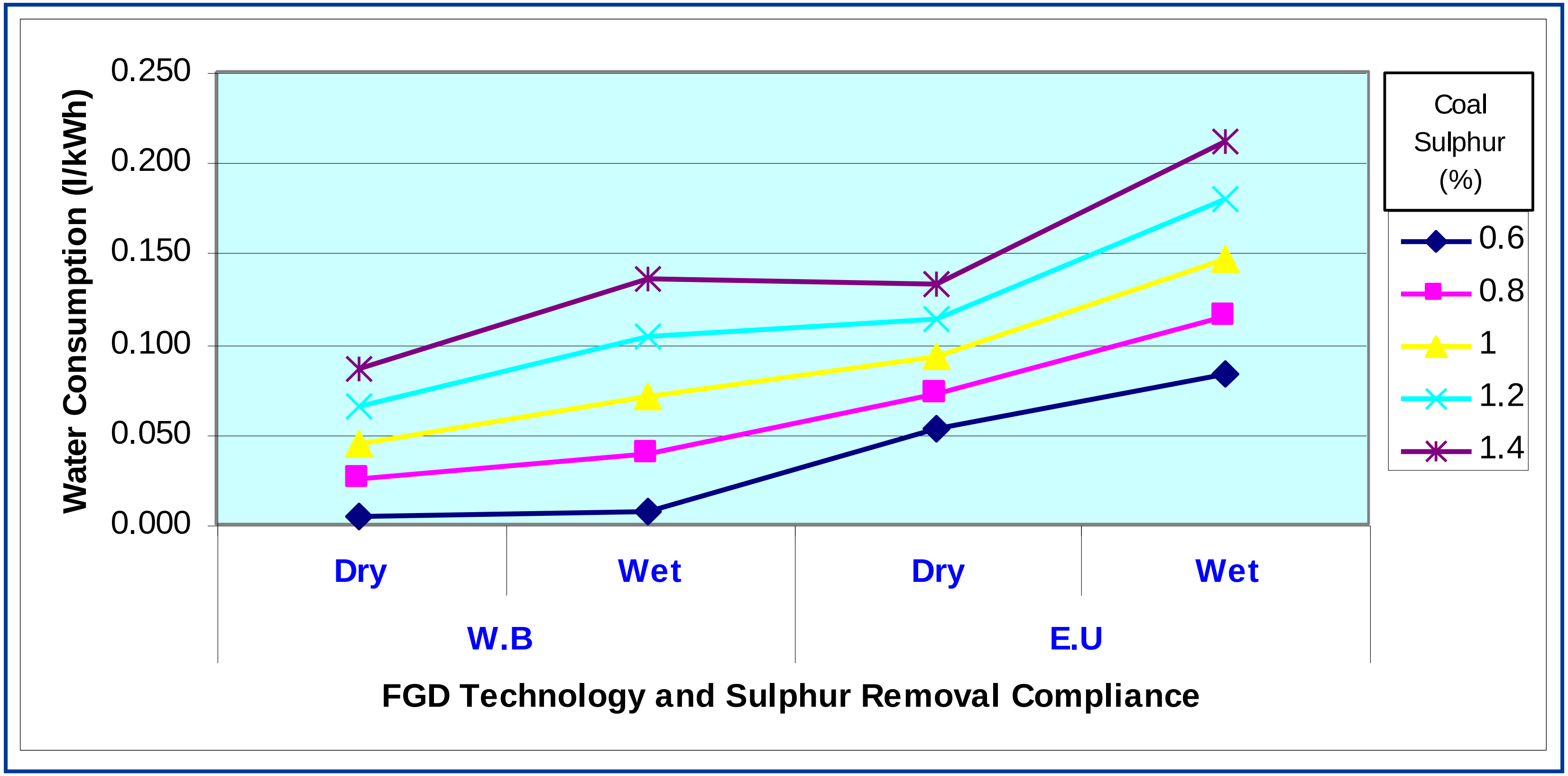
- Coal: PF = 20 MJ/kg; S = 1.4% & FBC = 16 MJ/kg; S = 1.6%,
- Sorbent: Wet-FGD = 90% & FBC = 70% ($CaCO_3$),
- SO_2 Compliance = 200 mg/Nm^3 Limit,
- Ca/S Molar ratio: WFGD = 1.03; DFGD = 1.25 & FBC = 2, and
- Base Plant: Efficiency = 40%; Capacity Factor = 81%.

TECHNOLOGY SPECIFIC WATER CONSUMPTION



The generation plant water consumption is 3 times higher for PF than for FBC. The overall energy complex, inclusive of mine, accounts for greater than 3.5 times for PF than FBC.

WET & DRY FGD WATER CONSUMPTIONS RELATIVE COAL SULPHUR CONTENT & SULPHUR REMOVAL COMPLIANCE



Wet is 1.6 more water intensive than dry.

IMPACT OF DE-SOx TECHNOLOGIES ON EFFICIENCY & ASSOCIATED CO_2 EMISSIONS

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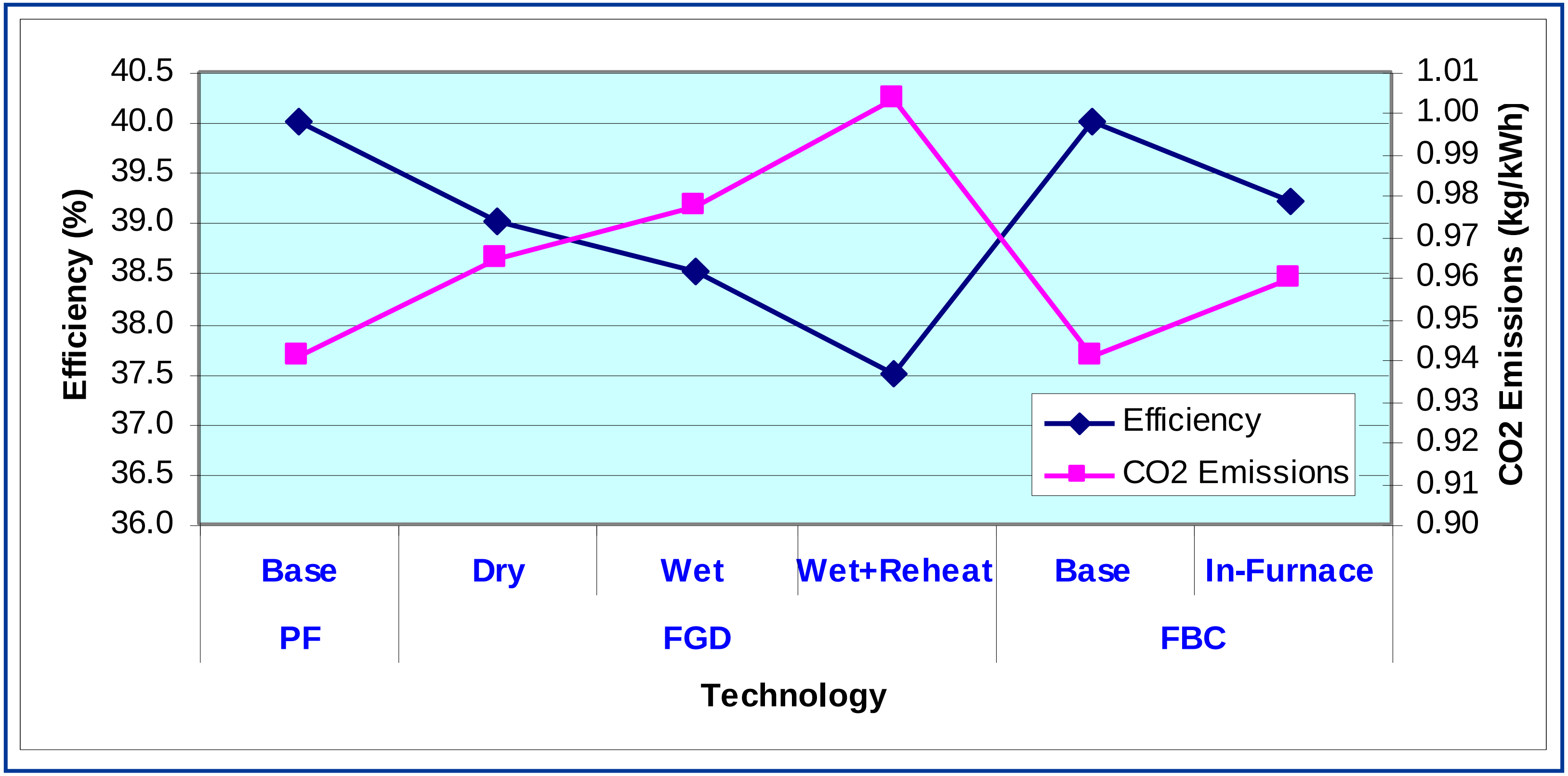
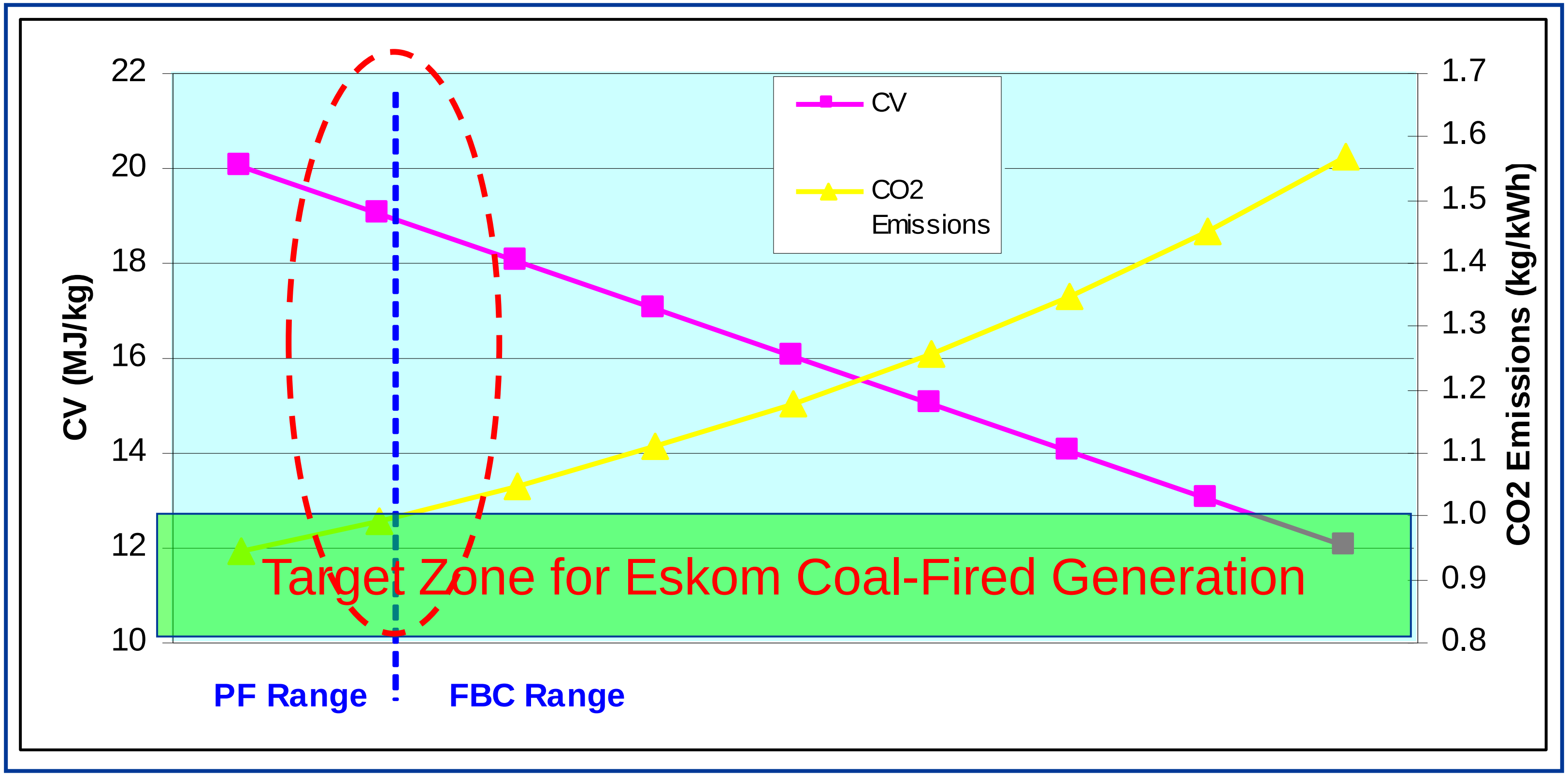


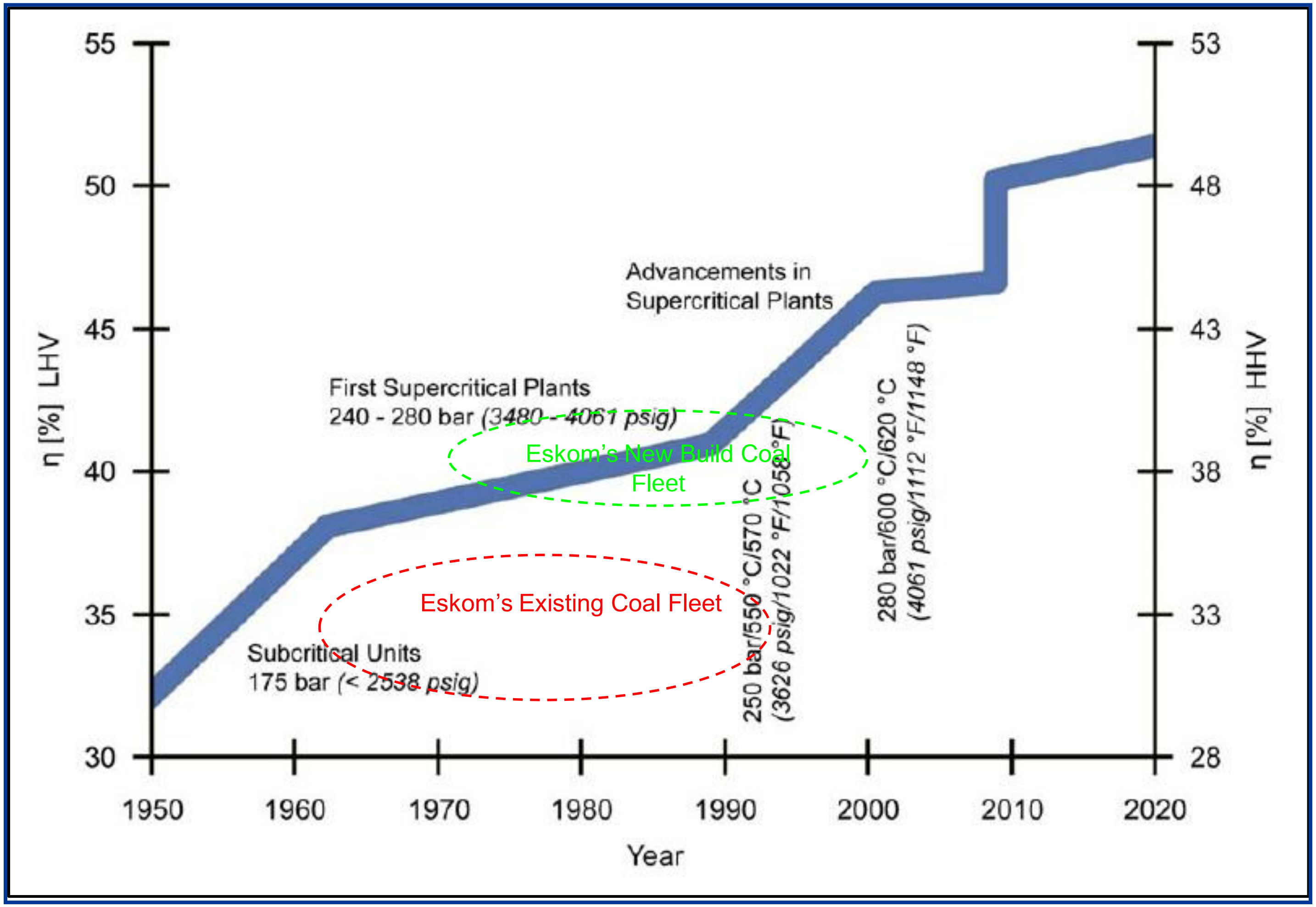
As an approximate, for every percentage lost in efficiency, around 2.5% additional CO_2 is emitted.

CV & ASSOCIATED CO_2 EMISSIONS



Within the PF CV range, the impacting increase in specific CO_2 emissions is approximately 0.55% for a 1 MJ/kg drop, whilst within the FBC CV range, the impacting increase in specific CO_2 emission ranges from 6 – 8% for every drop in a MJ/kg.

EVOLUTION OF STEAM POWER STATION EFFICIENCY WORLDWIDE *(Alstom)*



What about FBC? Where can it evolve to and by when?

SACRM SCENARIOS
(SACRM 2013)

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MAIN DETERMINANTS

LAGS BEHIND

The world decarbonises, but coal remains a significant energy source in South Africa and other developing countries. Coal-based power generation still dominates local electricity supply, but with clean coal technologies such as ultra-supercritical power stations, carbon capture and storage and underground coal gasification as they become available.

A new coal-to-liquids plant is built in 2027 to meet local liquid fuels demand.

LOW CARBON WORLD

The world decarbonises and moves towards use of nuclear and renewables for electricity supply. Funding is available for South Africa to follow suit, with no new coal-fired power stations built beyond Medupi and Kusile.

Carbon capture and storage is pursued and no more coal-to-liquids plants are built in South Africa.

MORE OF THE SAME

Coal use continues globally and locally. Coal-based power generation using existing supercritical technologies dominates the electricity mix, and the life of existing power stations is extended.

Two new coal-to-liquids plants are built between 2027 and 2040 to meet local liquid fuels demand.

AT THE FOREFRONT

Coal use continues globally, but South Africa aims to diversify its energy mix to include renewables and more nuclear generation. New coal-fired power plants after Medupi and Kusile use ultra-supercritical technologies, with smaller power stations (including FBC stations) being built.

No more coal-to-liquids plants are built.

BUILD PLAN FOR POWER STATIONS UNDER IRP 2013 UPDATE, EXTRAPOLATED TO 2040 *(SACRM 2013)*

Technology	Coal Fired Power Stations
IRP 2010 Policy Adjusted	Six small fluidised bed combustion (FBC) units. Medupi, Kusile and one further PF coal-fired power station online from 2027.
Extrapolation 2030 - 2040	Three large-scale PF stations of 4,500 MW each (or a number of smaller FBC stations)

COAL RESOURCES *(BULLETIN 113)*

Coalfield	Coalfield Area (km^2)	In-Situ Resources (Mt)	Mineable Reserves (Mt)	Recoverable Reserves (Mt)
1. Witbank	**5,645**	17,730	13,160	12,460
2. Highveld	**11,104**	16,909	10,979	10,979
3. Eastern Transvaal	**11,523**	8,000	5,000	4,698
4. Klip River	**3,209**	1,695	1,135	655
5. Utrecht	**3,015**	950	658	649
6. Vryheid	**1,587**	222	170	204
7. Nongoma	**1,440**	257	173	98
8. SWA-Zulu	**5,403**	1,599	499	147
9. South Rand	**4,976**	2,721	591	730
10. Sasolburg	**2,085**	4,757	2,233	2,233
11. Free State	**20,879**	16,250	4,920	4,919
12. Springbok Flats	**5,327**	6,500	3,250	1,700
13. Waterberg	**2,237**	114,875	14,977	15,594
14. Mabelebele	**2,091**	1,450	349	267
15. Mutamba	**971**	n/a	n/a	n/a
16. Venda-Pafuri	**1,872**	n/a	n/a	n/a
17. Mapangubwe	**852**	256	202	n/a
18. Moteno-Indwe	**7,200**	261	50	n/a
19. Kruger-Lebombo	**6,000**	n/a	n/a	n/a
Total	**97,413**	**196,031**	**58,845**	**55,480**

COAL – DISCARDS

Table 1: Discard Weighted Average of Proximate Analysis

CV (MJ/kg)	Volatiles (%)	Ash (%)	Sulphur (%)	Fixed Carbon (%)
14.6	18.5	46.1	2.7	32.0

Table 2: Slurry Weighted Average of Proximate Analysis

CV (MJ/kg)	Volatiles (%)	Ash (%)	Sulphur (%)	Fixed Carbon (%)
21.9	21.8	26.8	1.3	47.0

- Production ~ 60 Mt/a;
- Accumulation ≥ 1 Bt.

WATER RESOURCES

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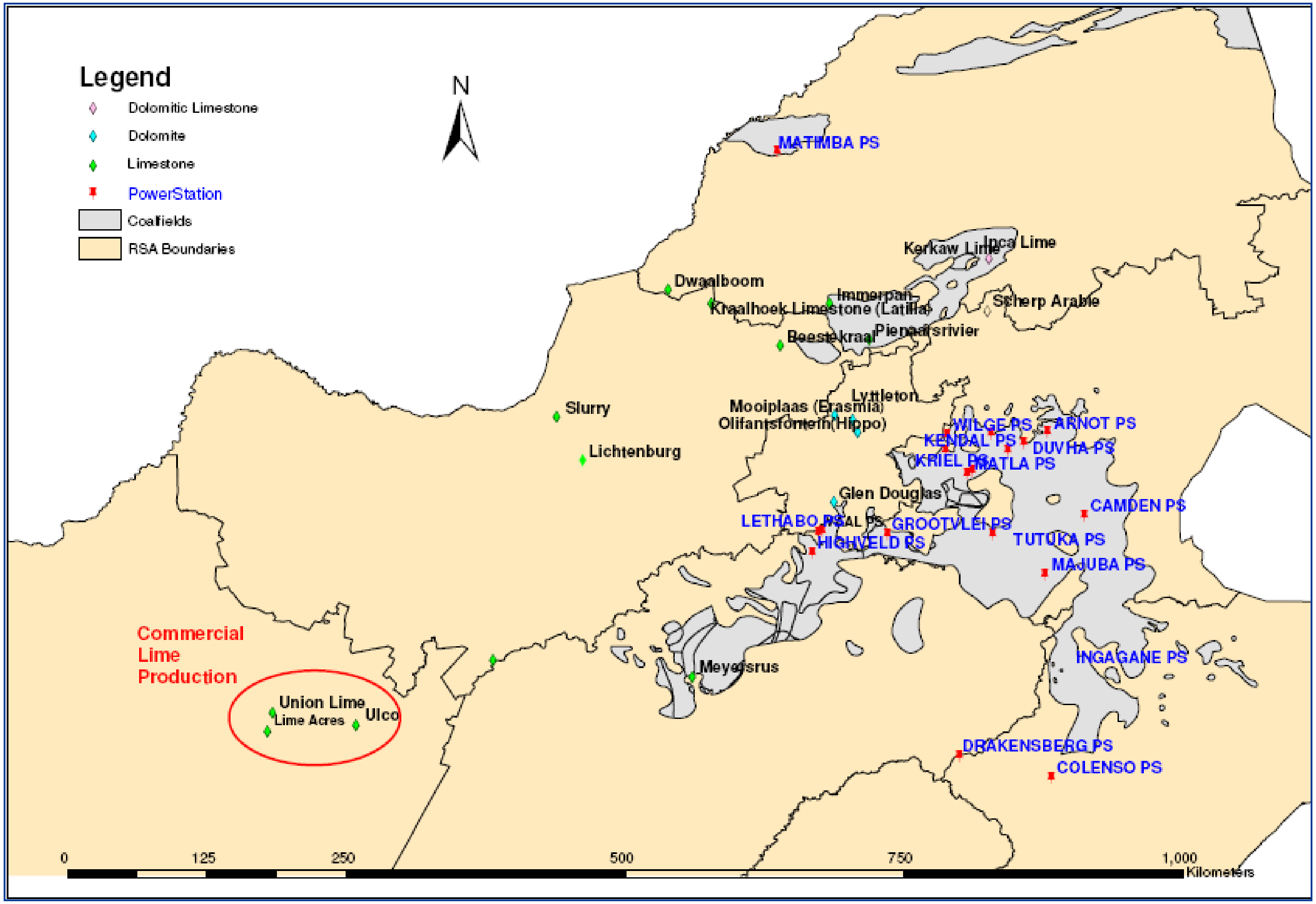
Table 3: Reconciliation of Requirements for and Availability of Water for the Year 2025
Based on a 4% GDP Growth Scenario *(Created from NWRS)*

Water Management Area (WMA)	Reliable Local Yield	Transfers In	Local Requirements	Transfers Out	Balance	Potential for Development
	(Mm^3/yr)					
1. Limpopo	295	23	379	0	-61	8
2. Luvuvhu/Letaba	405	0	351	13	41	102
3. Crocodile West and Marico	1,084	1,159	1,898	10	335	0
4. Olifants	665	210	1,143	13	-281	239
5. Inkomati	1,036	0	957	311	-232	104
6. Usutu to Mhlathuze	1,124	40	812	114	238	110
7. Thukela	776	0	420	506	-150	598
8. Upper Vaal	1,486	1,630	1,742	2,138	-764	50
9. Middle Vaal	67	911	415	557	6	0
10.Lower Vaal	127	646	703	0	70	0
11.Mvoti to Umzimkulu	614	34	1,436	0	-788	1,018
12.Mzimvubu to Keiskamma	886	0	449	0	437	1,500
13.Upper Orange	4,755	2	1,122	3,678	-43	900
14.Lower Orange	-956	2,100	1,102	54	-12	150
15.Fish to Tsitsikamma	452	653	1,053	0	52	85
16.Gouritz	288	0	444	1	-157	110
17.Olifants/Doring	337	3	380	0	-40	185
18.Breede	897	1	704	196	-2	124
19.Berg	602	194	1,304	0	-508	127
Total for Country	**14,940**	**7,606**	**16,814**	**7,591**	**-1,859**	**5,410**

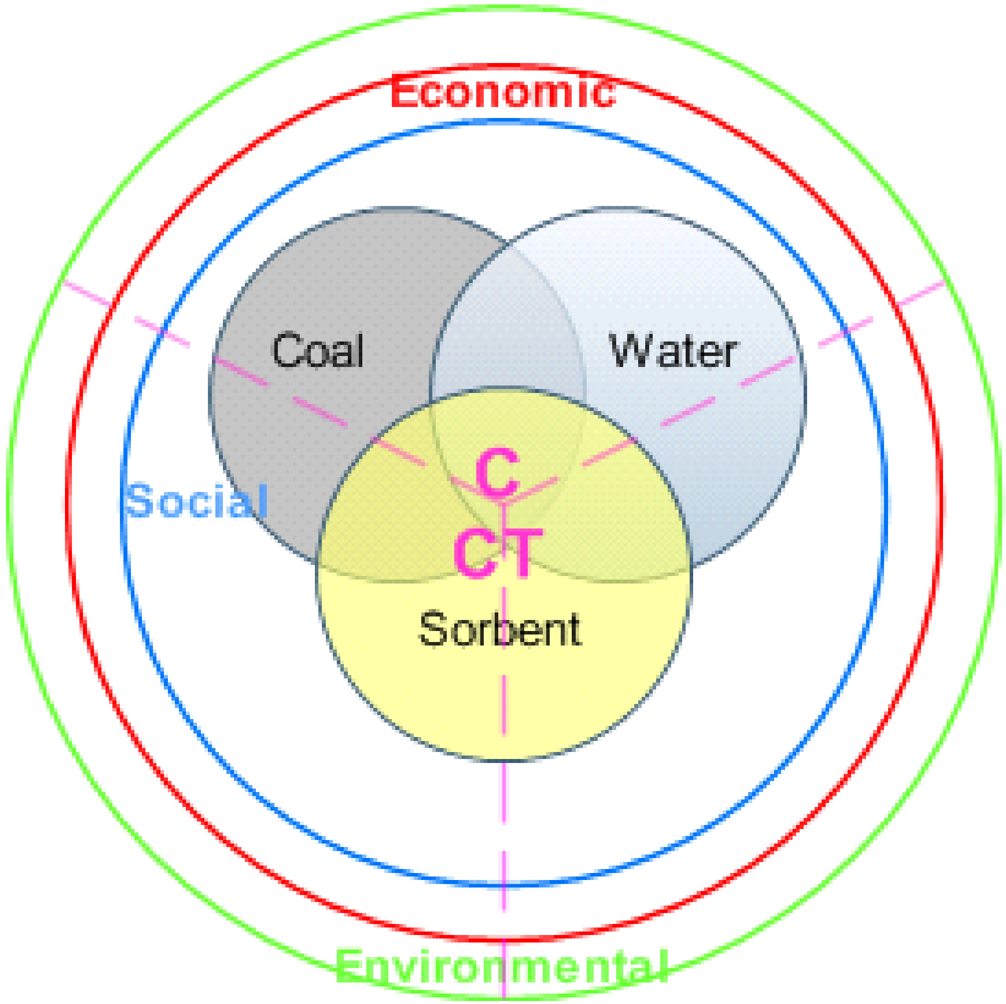
SORBENT RESOURCES

- Approximately 14 Bt Sorbent Resources in RSA,
- High quality proven Reserves of which 2.17 Bt,
- About 100 – 150 Mt available for FGD application only,
- The majority of resources are dolomitic and more suitable for FBC application.

LOCATION OF SORBENTS RELATIVE TO THE COAL DEPOSITS



RESOURCE OPTIMISATION MODEL



CONCLUSION

- It is likely that regardless of the decision taken on base load power, the use of FBC will grow in South Africa.
- FBC is suited to smaller modular applications, thus has good potential for being taken up by IPPs.
- Future advances, such as advanced supercritical FBC, will likely make this a very competitive technology, with high thermal efficiencies possible with very low quality coals.
- FBC offers the in-situ capture of SO_2, which avoids additional water consumption associated with post combustion FGD technology.
- Primary resource identification for application on the respective PF and FBC technologies provides the opportunity for design enhancements, process optimisation and reduction of levelised generation costs accordingly.
- Both PF and FBC technologies have a complimentary role to play in delivering the country's electricity generation requirements – present and future, however the planning of this has to be done in factoring the Resource Optimisation Model.

RECOMMENDATIONS

- The need to characterise fuel and sorbent sources is essential to evaluate against the PF and FBC application, as this enables fuel and sorbent technology matching. Subsequently, potential fuel and sorbent sources can prioritised for further characterisation and development. Primary resource identification for application on the respective PF and FBC technologies provides the opportunity for design enhancements, process optimisation and reduction of life-cycle costing accordingly.

- The opportunity to establish a national FBC fuel characterisation testing facility must be pursued given aforementioned recommendation.

- Biomass evaluation within FBC is essential and must be pursued through a research program from a CO_2 emission performance enhancement perspective.

Thank you

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