

Evaluation of the Potentials for Hybridization of Gas Turbine Power Plants with Renewable Energy in South Africa

By

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Outline of presentation

- Introduction
- Methodology
- Findings/Discussion
- Conclusion

Introduction

- Fossil fuel issues
 - Emissions , SA contribution (Winkler, et al 2011)
 - Rain water contamination
 - Scarcity/unevenly distribution
 - Prices
- Solution
 - RE tech
 - Low emission
 - Available
 - Improves existing power source
 - GT hybrid (from coal driven to RE driven)
 - RE resources in SA (Amigun et al 2011, Pradhan & Mbowha 2014, DME 2007)

GT fundamentals

- Cycles

- OCGT

- minimal output (30 – 40 % fuel energy) mech. work, electrical efficiency low, (Poullikkas, 2005)

- Low electrical eff

- Atm heating – exhaust gas

- Heat can be used to heat compressed air

- CCGT

- GT + Steam Turbine

- Increased efficiency (up to 50 %)

- Firing

- DFGTs

- EFGTs

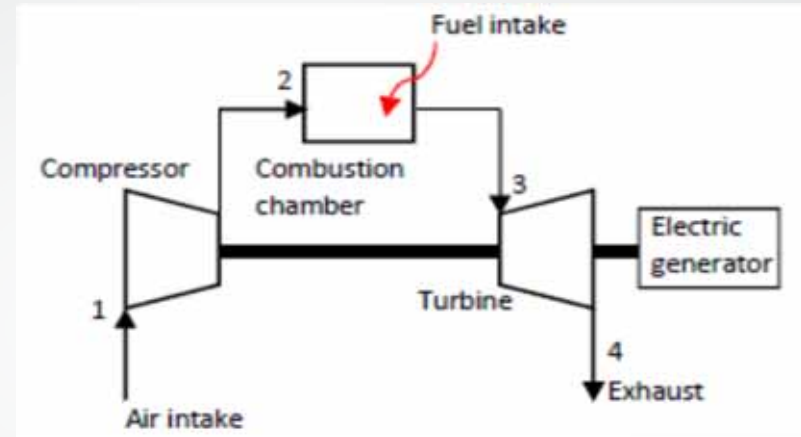


Fig 1 Sketch of simple GT cycle

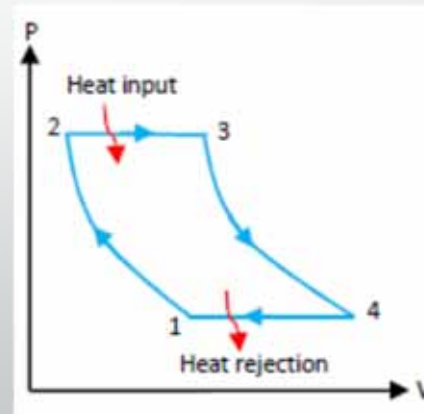


Fig 2
PV diagram of a Brayton cycle

GT fuels

- Heavy duty GT fuel flexibility
- Gaseous
 - NG, syngas, biogas
 - heavy oils,
 - LPG,
 - petrochemicals (propene, butane, propane)
 - hydrogen-rich refinery by-products such as naphtha, ethanol,
- Liquid
 - Diesel, aromatic gasoline
 - biofuels



Fig.3 Natural gas supply

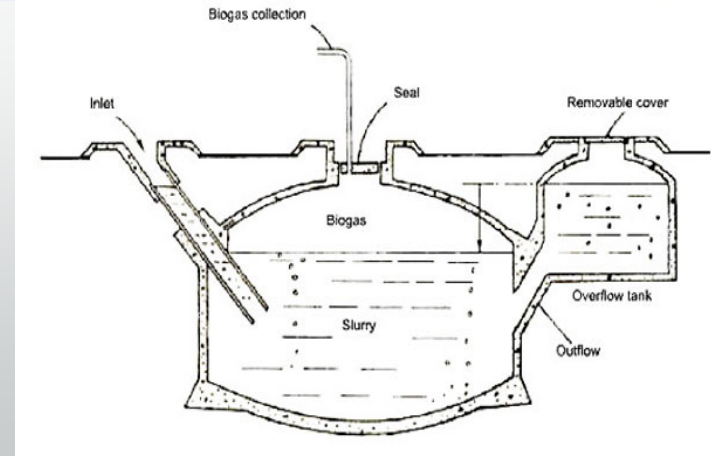


Fig.4 biogas supply

Energy production/consumption in SA

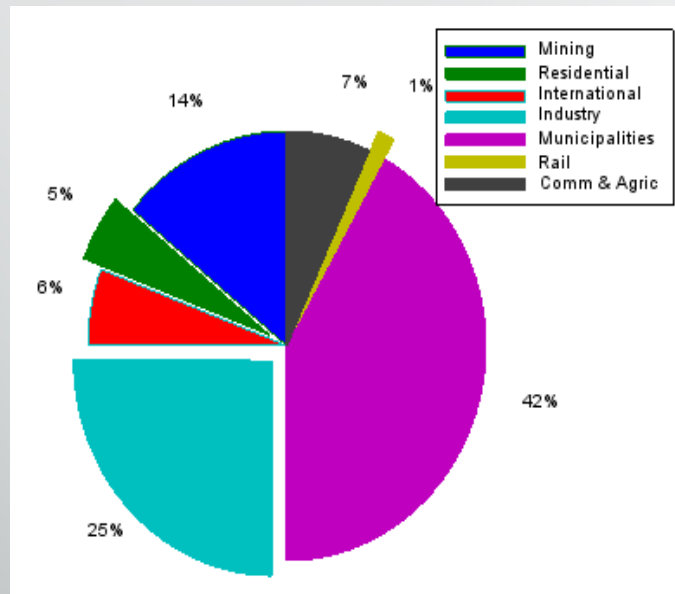


Fig.5 Sectoral electricity consumption in South Africa by March 2014 (data adapted from [Eskom (2014, Jul)].

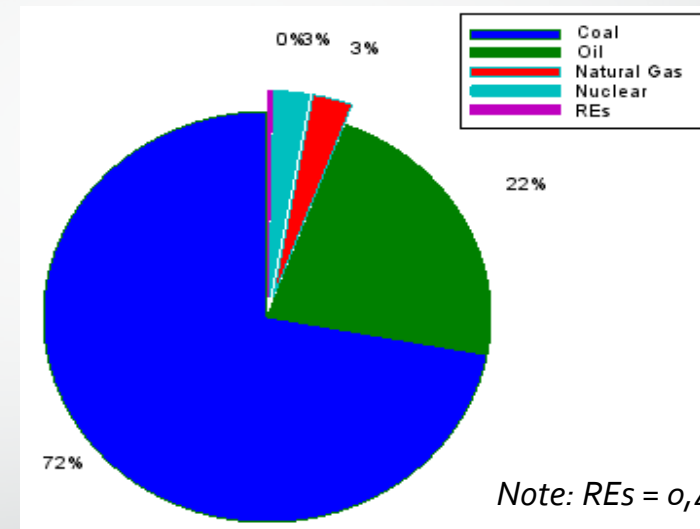


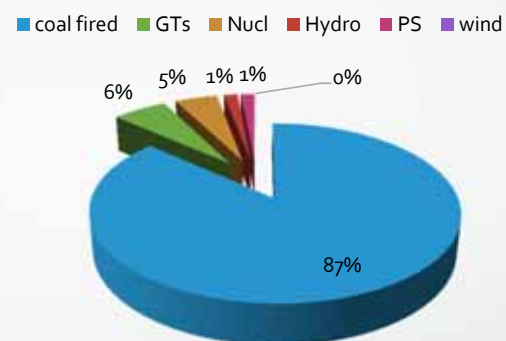
Fig. 6. Primary energy consumption in South Africa in 2013 [BP Statistical Review of World Energy, (2014)].

Energy production/consumption in SA

Table 1: Eskom's power stations by plant mix [Eskom (2014, Jul)].

Type	No of stations	Total nominal capacity (MW)
Coal fired	13	35726
Gas/liquid fuel GT	4	2409
Hydro	6	600
Pumped storage	2	600
Nuclear	1	1880
Wind	1	3
Total	27	41995

Plant capacity by %



- GTs , driven by diesel, kerosene and natural gas (DEIAR, 2009; Savannah Environ., 2009)
- OCGT, no hybrids

Hence the need evaluation of hybrid potentials

Hybridization with RE

Combination of two or more different fuel inputs to produce base load.

- Single RE fuel power generation is expensive, eg
- STEP cost is high (Olivenza-Leon et al 2015)
- Fossil only, issues more than cost
- By 1) retrofitting existing system
2) brand new system
- Latter is more promising.

Note: Optimization/simulation necessary in each case

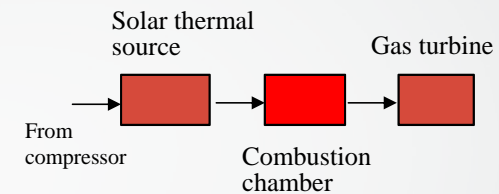


Fig. 7 Serial mode

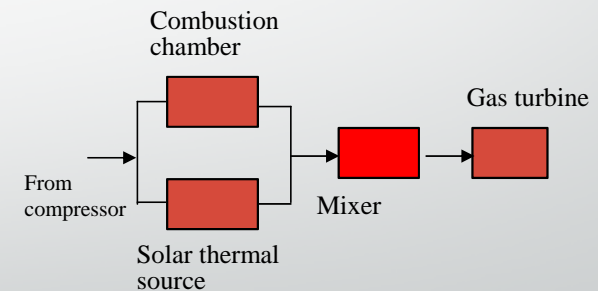


Fig. 8 Parallel mode

Methodology

Data collection

- Desktop method
- Reports , journal articles, other published works

Data analysis

- To obtain annual energy output from resources (MWh/yr)
- $E_o = \eta E_i$ 1
- E_i = input energy from fuel type (resource)

Biofuels

$$E_{i,b} = D_b C_b \quad 2$$

$$E_{o,b} = \frac{\eta_b f_{c,b} E_{i,b}}{3600} \quad 3$$

D_b = energy density of fuel (MJm^{-3})

C_b = annual prod. Capacity (m^3/yr)

η_b = system efficiency

$f_{c,b}$ = capacity factor of the system

D_b for biodiesel (33998 MJ m^{-3}), bioethanol ($23\,496 \text{ MJ m}^{-3}$) and biogas (24.57 MJ m^{-3}), computed from literature

Data analysis

Concentrating solar power (CSP)

$$E_{i,s} = n \eta_s f_{c,s} P_{i,sp} \quad 4$$

$E_{i,s}$ = annual thermal energy from solar

n = total number of hours in a yr

η_s = solar collector efficiency

$f_{c,s}$ = capacity factor of the CSP plant

$P_{i,sp}$ = total solar resource potential (MW)

For solar – biofuel hybrid system,

$$E_{o,sb} = \eta_{GT}(E_{i,s} + E_{o,b}) \quad 5$$

where, η_{GT} = gas turbine efficiency,

$E_{o,sb}$ = energy output of the hybrid system,

$E_{i,s}$ = energy input from the solar field,

$E_{o,b}$ = energy input from biofuel combustion processes

Table 2: Data on efficiency and capacity factors of OCGT and CCGT [DEIAR, 2009].

Technology	Fuel type	Efficiency (%)	Capacity factor (%)
OCGT	Biofuel	34	10
CCGT	Biofuel	50	50
OCGT	Solar	20*	30*
CCGT	Solar	50*	50*

Findings / Discussion

a) Resource potential

Biodiesel

- Industry still young (Pradhan & Mbowha 2014), resources to expand the industry are available. Implementation of biofuel policy (2%) important.
- Existing industry;

850 x 10³ m³/yr as at 2013 (Modise, 2013)

Feedstock (WVO, canola, soybean)

Biogas

Table 3: Biogas production potential from animal wastes

Animal	Average Population (10 ⁶)/yr	Average waste (kg/animal/day)	Total waste (kg/yr)	Biogas yield (m ³ /kg dung)	Total biogas (x 10 ⁶) (m ³ /yr)
Cattle	13.80 ^{*a}	10.0 ^b	5.037x10 ¹⁰	0.04 ^b	2014.8
Sheep	0.022 ^{*a}	2.0 ^b	16.060x10 ⁶	0.05 ^b	0.8030
Goat	0.0021 ^{*a}	2.0 ^b	1.533 x10 ⁶	0.05 ^b	0.0767
Piggery	0.0016 ^{*a}	1.2 ^b	0.701 x10 ⁶	0.07 ^b	0.0491
Poultry	999.75 ^{*c}	0.1 ^b	3.649x10 ¹⁰	0.06 ^b	2189.5
Human	≈ 53 ^d	1.2 ^b	2.321 x10 ¹⁰	0.07 ^e	1624.98
TOTAL					7088,08



- MSW -
 - = $4.2 \times 10^7 \text{ m}^3$ (Ogolo et al 2011)
 - = 0,7kg per capita or 37 100 tons per day (@53 million popn.)
 - = $442 \text{ m}^3/\text{ton}$ of landfill gas (Pitchel 2005)
 - = $16,4 \times 10^6 \text{ m}^3/\text{yr}$
- Waste water – = $450 \times 10^6 \text{ m}^3/\text{day}$ (WEC 2014)

CSP

- High SLA of approximately 194 000 km² (Pegels 2010) identified
- if only 1% used = 64GW (Pegels 2010)(@ 30,2MW/km²)
 - = 400GW solar resource (@ 16% S2E eff)
 - = 80GW_{th} (20% collector eff)

b) RE-based electricity generation potential

Single source of energy

Table 4: Electricity generation potential of each RE resource

Technology	Potential ($\times 10^6$ MWh/yr)		
	Biodiesel	Biogas	Solar
OCGT	0,27	1,64	210,24
CCGT	2,01	12,09	876,00

Existing GT capacity

$2,11 \times 10^6$ MWh/yr

10.55×10^6 MWh/yr

Hybrid sources of electrical energy

Table 5: Solar – biofuel hybrid

Biofuel	Potential power (x10 ⁶ MWh)	
	OCGT	CCGT
Biodiesel	210,51	878,01
Biogas	211,88	888,09

Existing GT capacity

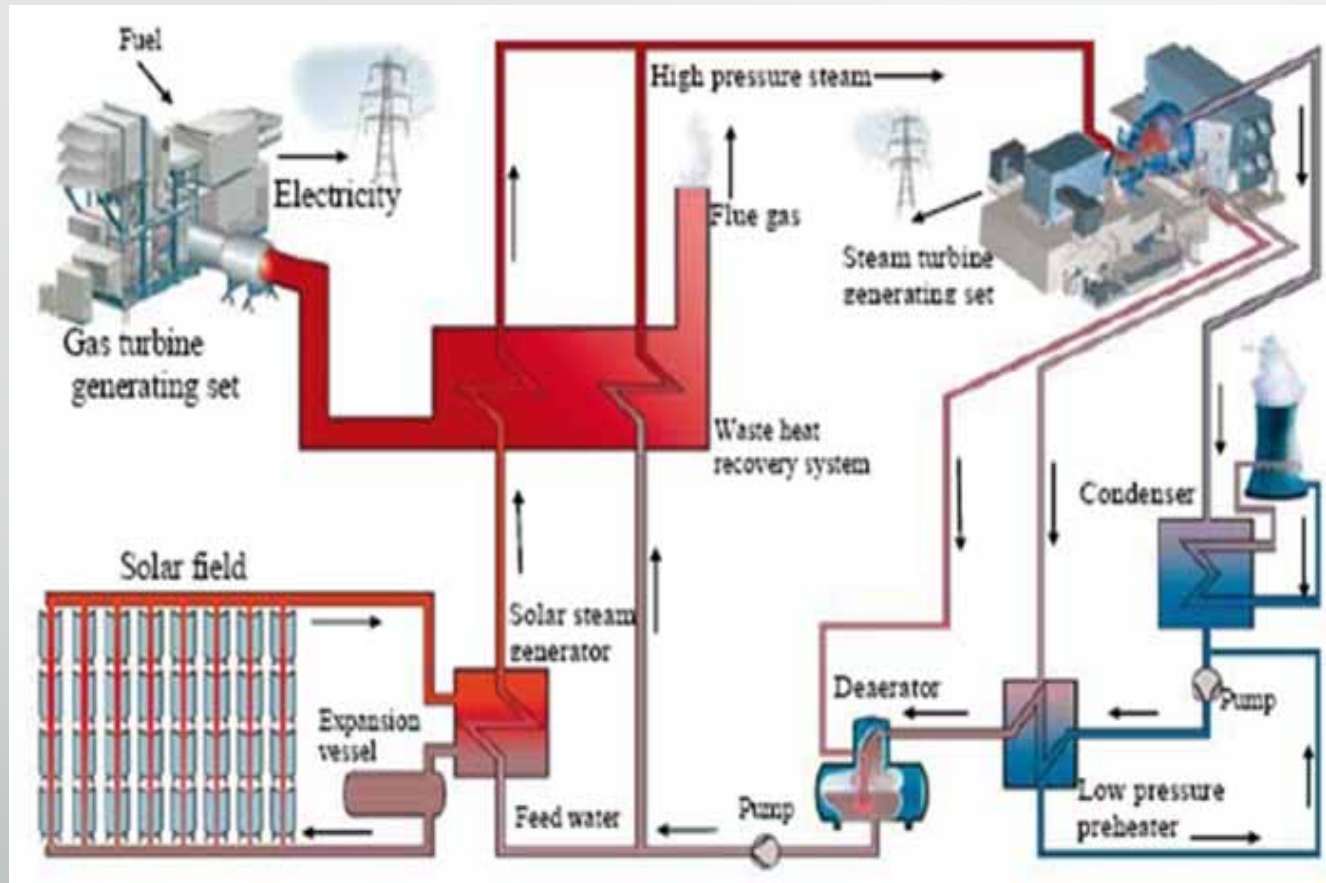
2,11 x 10⁶ MWh/yr

10.55 x 10⁶ MWh/yr

Conclusion

- The study is based on OCGT/CCGT/serial hybridization
- Only $2,01 \times 10^6$ MWh of electricity from biodiesel (CCGT)
- About $12,09 \times 10^6$ MWh of electricity from biogas (animal wastes) (CCGT)
- About $888,09 \times 10^6$ MWh of electricity from solar-biogas
- About $878,01 \times 10^6$ MWh of electricity from solar-biodiesel
- There is potential for solar-biofuel hybridization in SA
- Optimization studies necessary

Thank you for
listening



An ISCCS Plant schematic diagram (courtesy: Siemens)

