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

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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)

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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

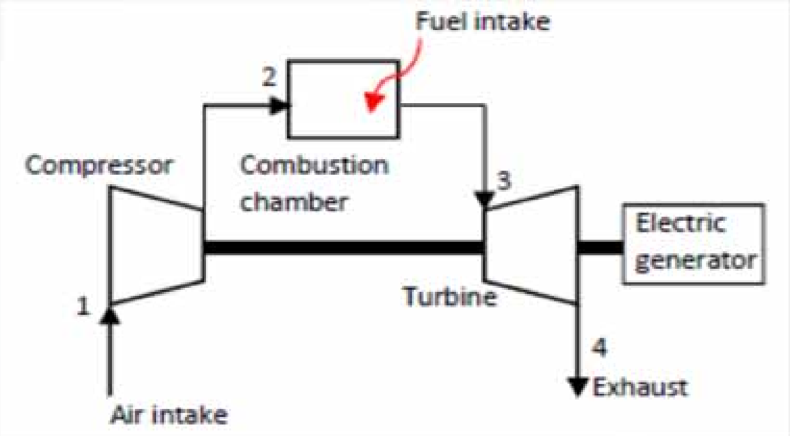

Fig 1 Sketch of simple GT cycle

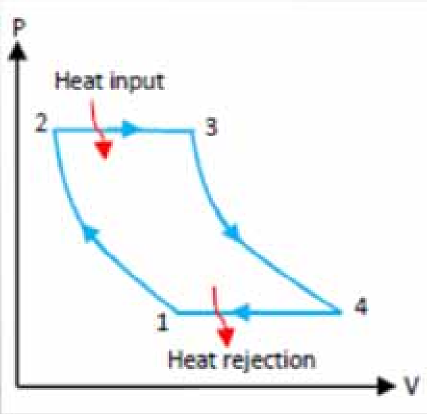

Fig 2
PV diagram of a Brayton cycle

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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

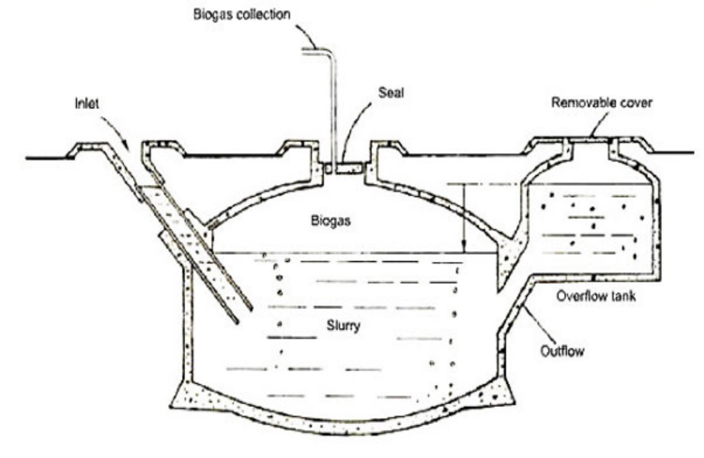

Fig.4 biogas supply

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Energy production/consumption in SA

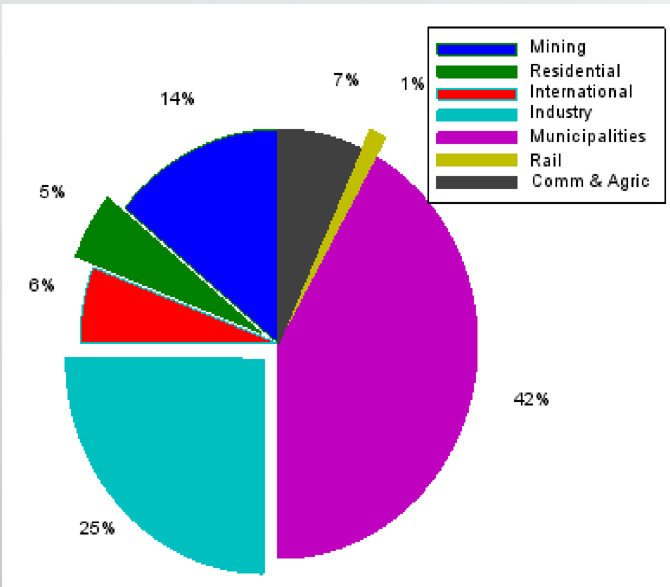

Fig.5 Sectoral electricity consumption in South Africa by March 2014 (data adapted from [Eskom (2014, Jul)].

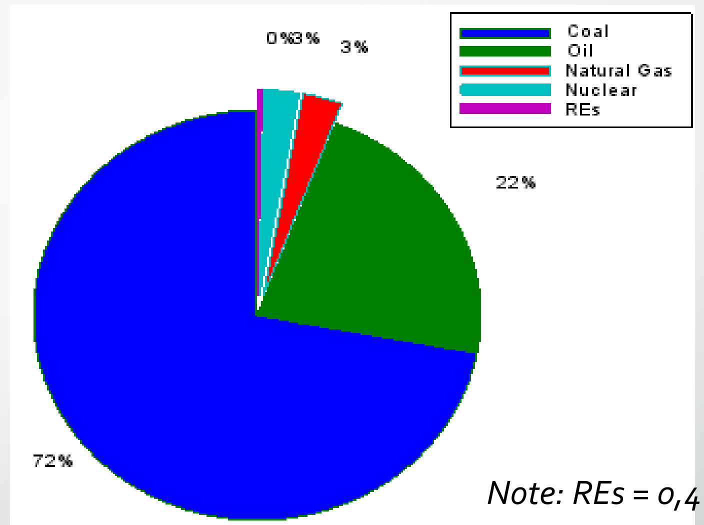

Fig. 6. Primary energy consumption in South Africa in 2013 [BP Statistical Review of World Energy, (2014)].

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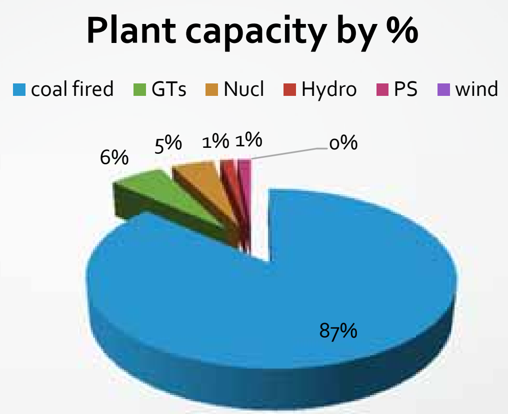
Energy production/consumption in SA

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**



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

Hence the need evaluation of hybrid potentials

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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.

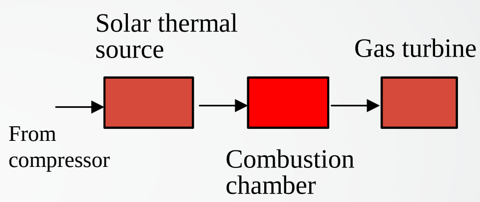

Fig. 7 Serial mode

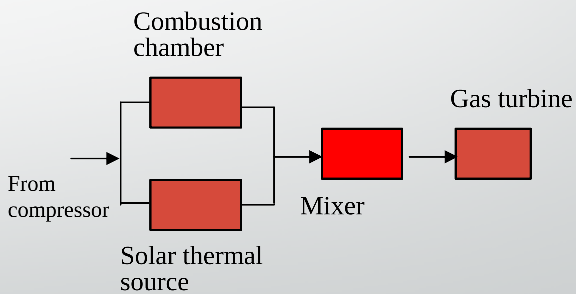

Fig. 8 Parallel mode

Note: Optimization/simulation necessary in each case

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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 MJ m^{-3}) and biogas (24.57 MJ m^{-3}) , computed from literature

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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)

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*

For solar – biofuel hybrid system,

$$E_{o,sb} = \eta_{GT}(E_{i,s} + E_{0,b}) \quad 5$$

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

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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;

  850×10^3 m^3/yr as at 2013 (Modise, 2013)

  Feedstock (WVO, canola, soybean)

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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

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- MSW - = $4.2x10^7$ m^3 (Ogolo et al 2011)

  = 0,7kg per capita or 37 100 tons per day (@53 million popn.)

  = $442m^3$/ton of landfill gas (Pitchel 2005)

  = $16,4x10^6$ m^3 /yr
- Waste water – = 450×10^6 m^3 /day (WEC 2014)

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CSP

- High SLA of approximately 194 000 km^2 (Pegels 2010) identified
- if only 1% used = 64GW (Pegels 2010) (@ 30,2MW/km^2)

  = 400GW solar resource (@ 16% S2E eff)

  = 80GW_{th} (20% collector eff)

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b) RE-based electricity generation potential

Single source of energy

Table 4: Electricity generation potential of each RE resource

Technology	Potential (x 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 x 10^6 MWh/yr

10.55 x 10^6MWh/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 10^6 MWh/yr

10.55 x 10^6MWh/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

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Thank you for listening

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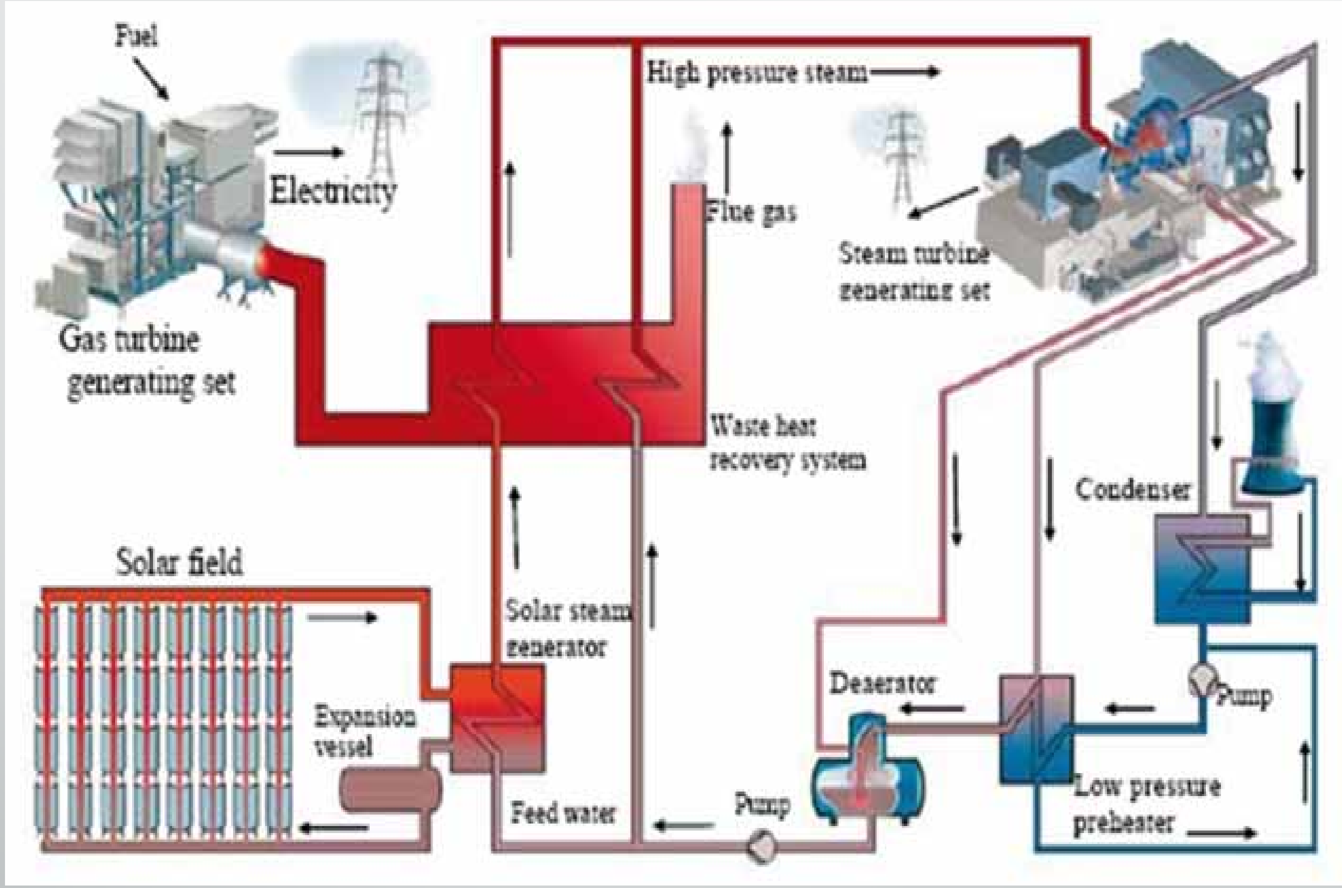

An ISCCS Plant schematic diagram (courtesy: Siemens)

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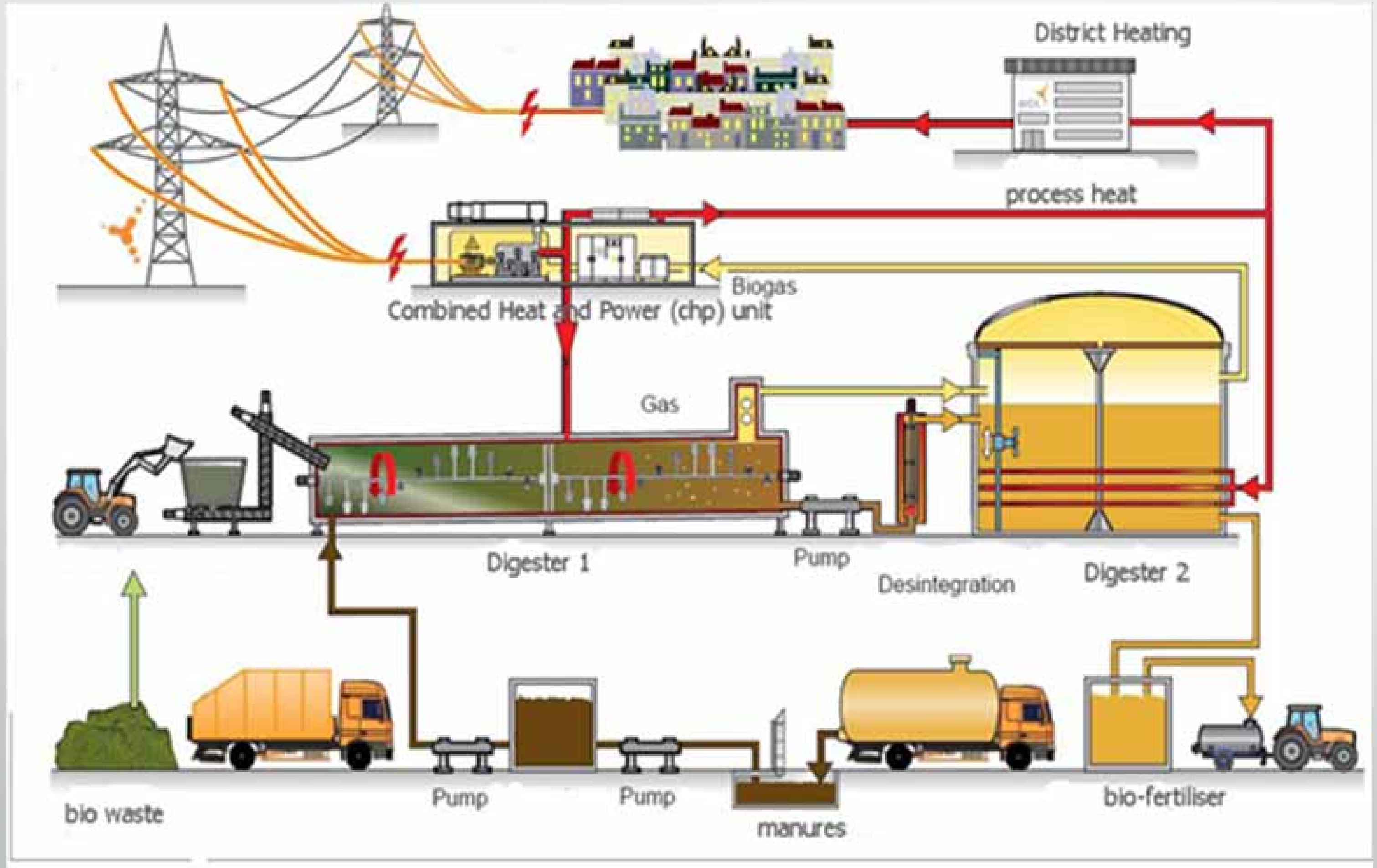

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