Systems Design of a Petroleum Coke IGCC Power Plant: Technical, Economic, and Life Cycle Perspectives

Ikenna J. Okeke, Thomas A. Adams II
Department of Chemical Engineering, McMaster University, 1280 Main St. W, Hamilton, ON, Canada, L8S 4L7

1. Introduction – Petroleum Coke

Petroleum Coke (Petcoke)
- Undesired solid waste of crude oil refining
- Predominate in heavy oil processing
- Up to 30% of heavy oil feed

Table 1: Petcoke analysis [1]

Ultimate analysis (wt.% dry)	Value
Carbon	84.9
Hydrogen	3.9
Nitrogen	1.3
Sulfur	6
Ash	3.1
Oxygen	0.8
Proximate analysis (wt.%)	
Fixed carbon	83.3
Volatile matter	11.9
Ash	3
Moisture content	1.8

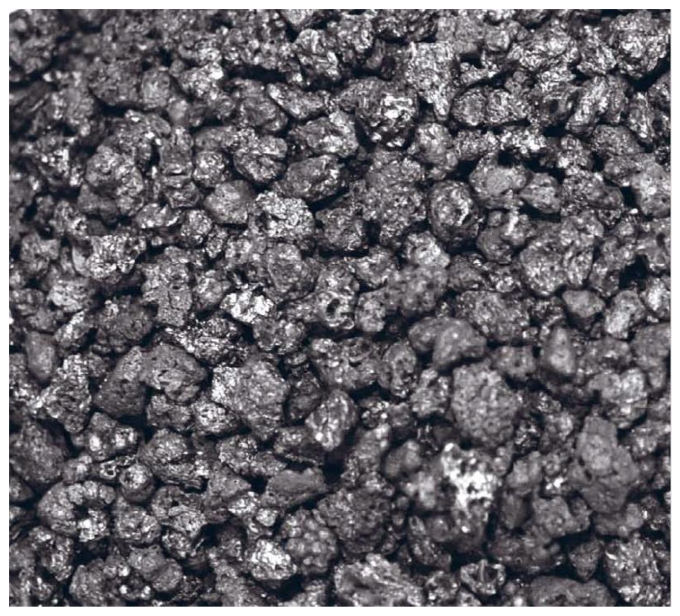

Fig 1: Delayed petcoke

Petcoke Challenges
- Up to 10% higher (energy basis) GHG emissions when combusted compared to coal [2]
- High sulfur content [1]

Traditional Petcoke disposal
- Calcination: use as anode
- Limited use as fuel in North America [2]
- Mostly stockpiled

Fig 2: Petcoke stockpile

2. Motivation

Petcoke is a high value fuel
- Low cost fuel compared to coal and biomass [3]
- High energy content [4]

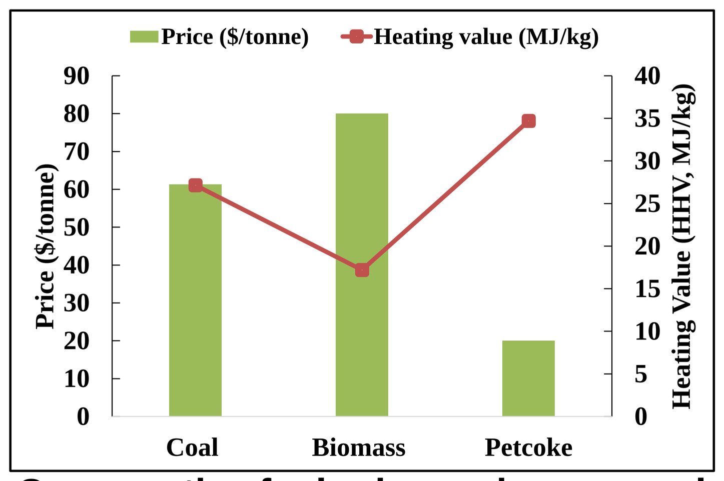

Fig 3: Comparative fuel price and energy values

Potential feed for power generation
- Convert petcoke to clean power
- Displace coal-fired power plants
- Reduce GHG emissions with aid of CCS technology

3. Objective

- Conduct a technical, economic, and life cycle assessment of a petcoke IGCC power plant

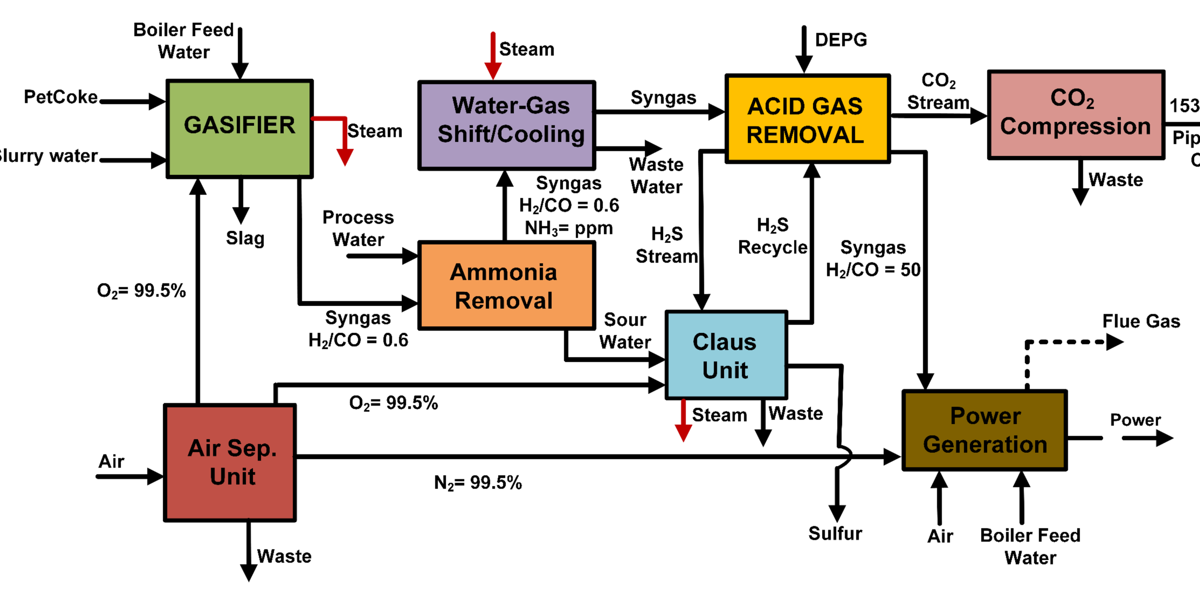

Fig 4: Petcoke IGCC process flow diagram [4]

4. Methodology

- **Modeling approach**
  - Power plant size: 550 MWe (Net)
  - Tool: Aspen Plus® v10
- **Economic assumptions**

Table 2: Cost estimation parameters [4]

Parameters	Values	Parameters	Values
Plant life (yrs)	30	Tax rate (%)	40
Plant avail. (%)	85	Rate of return (%)	12
Plant loan (yrs)	30	Depreciation method	MACRS
Loan interest (%)	9.5	Working capital (%)	5%
Debit/Equity (%)	50	Operating hours (hrs)	8000

- **LCA Approach (ISO 14000)**
  - Goal: Evaluate and analyze the environmental impacts of petcoke IGCC power plant
  - Scope: Cradle to Gate (CTG)
  - Functional unit: 1 MWh of electricity
  - Life cycle inventory: Mass & Energy balance [4], GREET model, US LCI
  - Reference: 1 MWh of supercritical pulverized coal (SCPC) and coal-IGCC plants

5. System Boundary

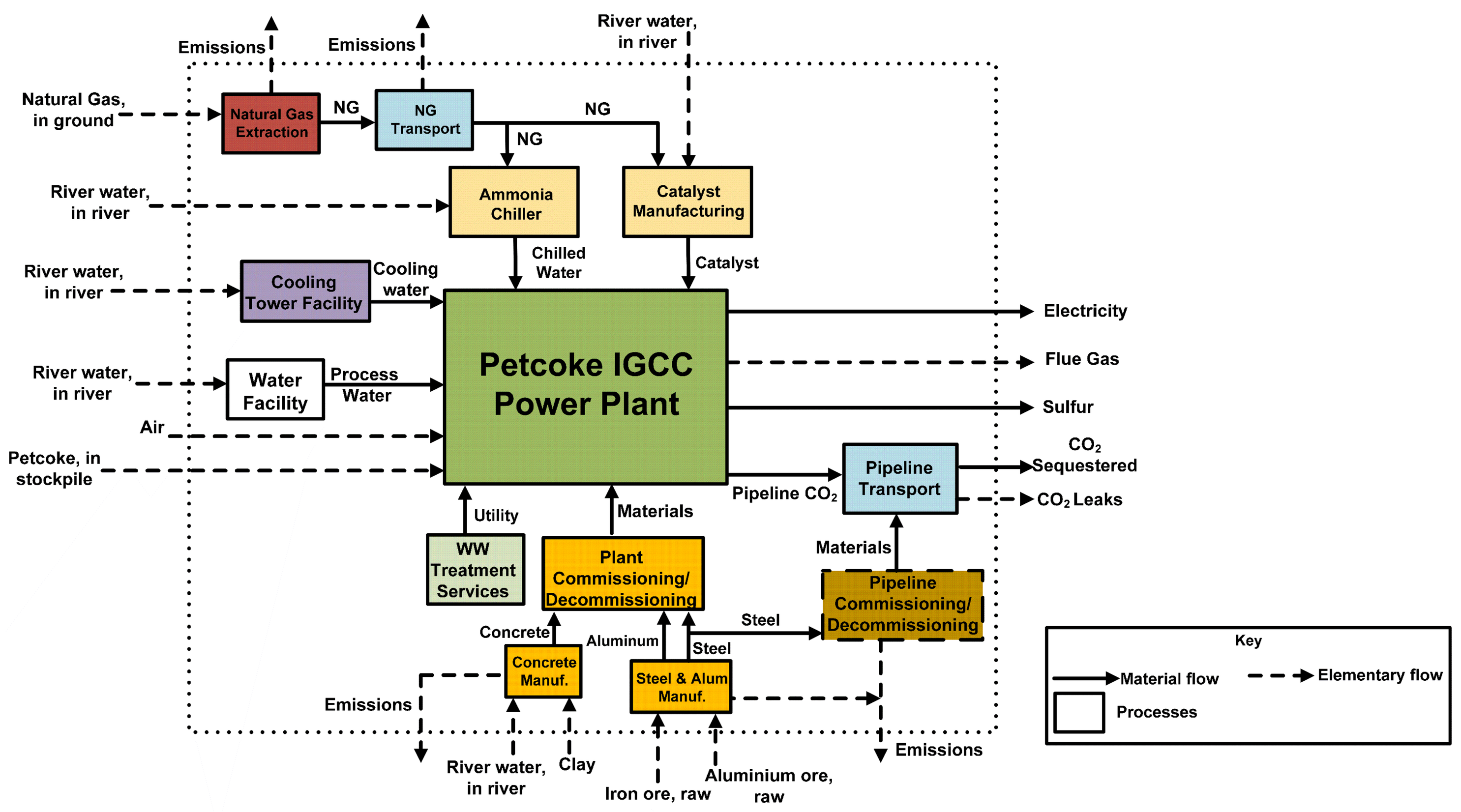

Fig 5: CTG system boundary of the pecoke IGCC power plant

6. Life Cycle Inventory

Table 3: CTG life cycle inventory of petcoke IGCC power plant [4]

Inventory	Petcoke-IGCC
Input flows (kg unless otherwise specified)	
Petcoke	367
Natural gas, in ground	1.25
River water, in river (m^3)	2.1
Iron ore, raw	0.11
Aluminium ore, raw	1.65×10^{-3}
Output flows	
Products flow	
Electricity (MWh)	1
Sulfur (kg)	21.5
Sequestered CO_2 (kg)	964
Emissions flow to air (kg)	
Ammonia	4.84×10^{-6}
Carbon dioxide	202.45
Carbon monoxide	0.07
Dinitrogen monoxide	2.43×10^{-4}
Methane	0.24
Nitrogen dioxide	1.64×10^{-6}
Nitrogen oxides	0.01
NMVOC, Non-methane volatile organic compounds	2.69×10^{-4}
Particulates < 10 µm	1.16×10^{-3}
Particulates < 2.5 µm	4.04×10^{-4}
Sulfur oxides	1.57×10^{-2}
Sulfur dioxide	0.39
VOC, volatile organic compounds	0.01

7. Results

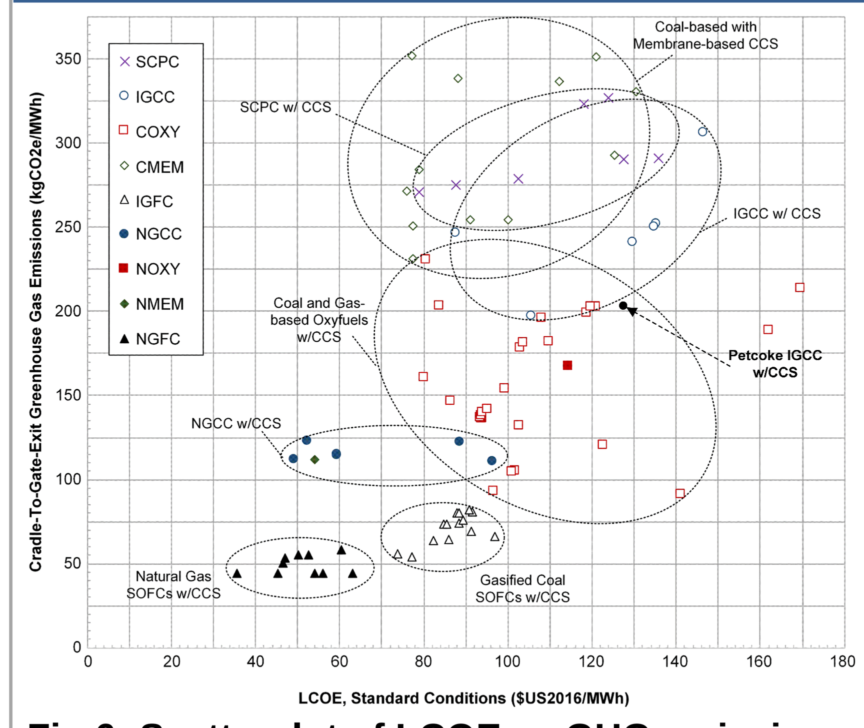

Fig 6: Scatterplot of LCOE vs GHG emissions for coal and gas technologies [5] compared to petcoke-IGCC

Table 4: Summary of performances

Parameters	IGCC	IGCC[a]	SCPC[a]
Feed type	Petcoke	Coal	Coal
Feed rate (tonne/h)	201	235	225
Total power (MW)	756	753	642
Net power (MW)	550	550	550
Thermal eff. (HHV%)	26	31	33
Heat rate (MJ/MWh)	12,737	11,607	11,007
Unit fuel cost ($/GJ)	0.00	2.5	2.5
TCI ($M)	1780	1753	1784
LCOE ($/MWh)	123.51	140.5	132.6
GHG emissions (tonneCO_2eq/kWh)	0.196	0.251	0.286

[a]Source data from [6] and scaled to 550 MWe

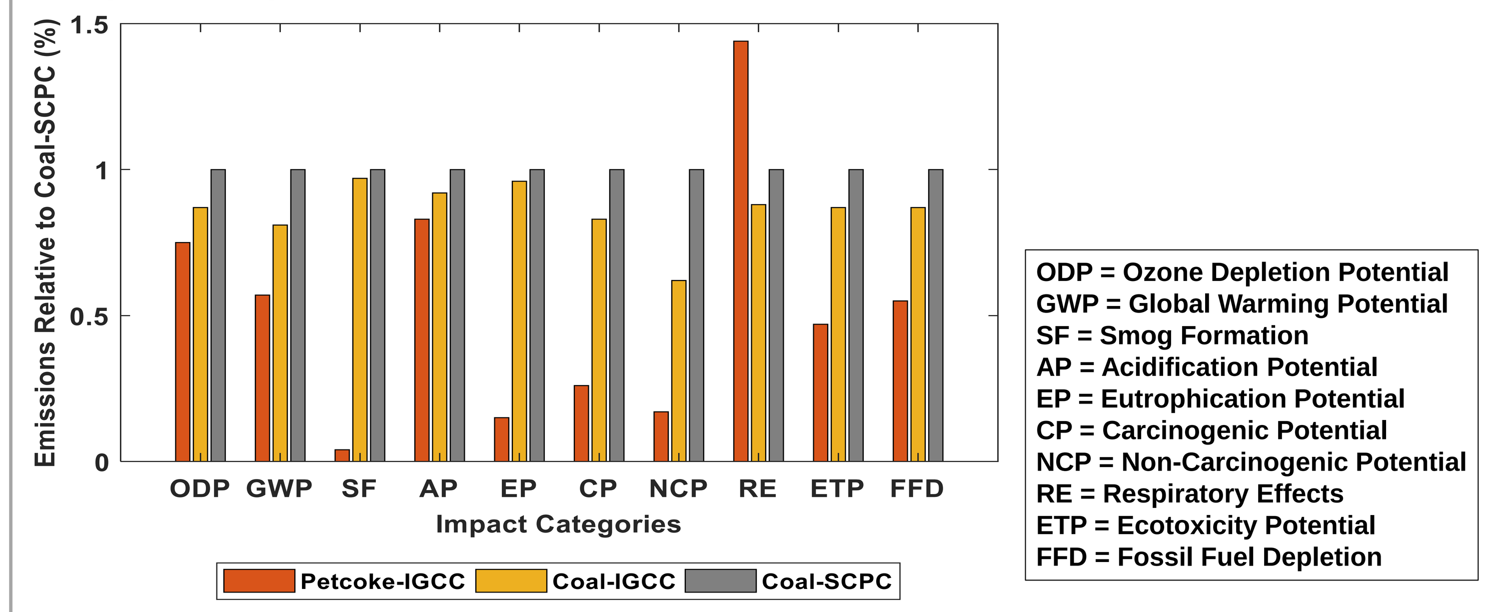

Fig 7: CTG impact categories comparison relative to Coal-SCPC

8. Results – Sensitivity Analysis

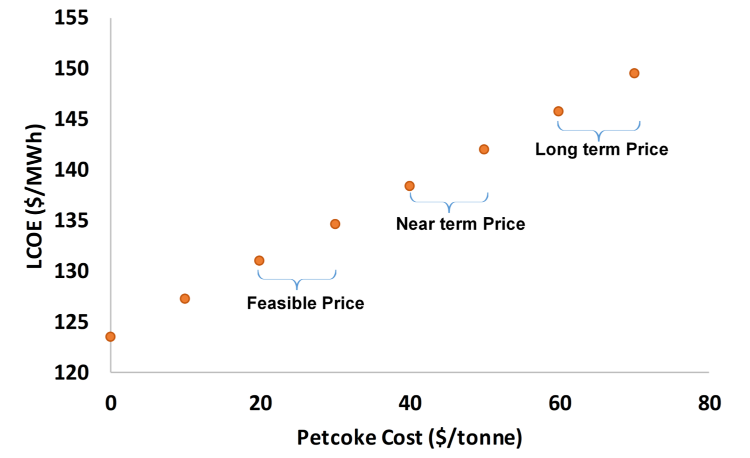

Fig 8: Sensitivity analysis of the effect of petcoke price on LCOE

9. Conclusions & Future work

- **Conclusion**
  - Petcoke IGCC showed to be a viable approach to dispose the ever-growing petcoke stockpile.
  - Life cycle GHG emissions of the petcoke IGCC is 209 kgCO_2eq/MWh which is 43% lower than the status quo coal-fired power plant.
  - Reduction in fossil fuel depletion of 45% compared to SCPC was also achieved.
- **Future work**
  - Compare the petcoke IGCC environmental impacts to that of stockpiling petcoke in a location such as Alberta, Canada.
  - Explore the synergy of design configurations which can combine petcoke and natural gas into a single power plant.

10. References

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[6] Fout, T., A. Zoelle, D. Keairns, M. Turner, M. Woods, N. Kuehn, V. Shah, V. Chou, L. Pinkerton, and J. Black. "Cost and Performance Baseline for Fossil Energy Plants Volume 1b: Bituminous Coal (IGCC) to Electricity Revision 2b—Year Dollar Update." *United States Departmeant of Energy: Washington, DC, USA* (2015).

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