Commentary
Alternative carbon-based fuels

Hein Neomagus[1*], **John Bunt**[1] **and Nthabiseng Leokaoke**[1]
[1]Centre of Excellence in Carbon-Based Fuels, North-West University, Potchefstroom Campus, Private Bag X6001, Potchefstroom 2520, South Africa
*Corresponding author: hein.heomagus@nwu.ac.za

https://doi.org/10.17159/caj/2023/33/2.17302

The need for alternate carbon-based fuels

The pressing global challenge of climate change has intensified the search for sustainable and environmentally friendly energy sources. Among the potential solutions, the need for alternate carbon-based fuels has gained prominence as a critical avenue for reducing greenhouse gas emissions and mitigating the impact of fossil fuel consumption. Traditional carbon-based fuels, such as coal, oil, and natural gas, have long been the primary drivers of economic development and industrialization. However, their combustion releases vast amounts of carbon dioxide (CO_2) into the atmosphere, contributing significantly to the greenhouse effect and global warming.

To address this issue, scientists, researchers, and policymakers are exploring alternative carbon-based fuels that offer a more sustainable energy future. One promising category of alternate carbon-based fuels includes biofuels derived from organic materials, such as plant biomass or algae. Unlike fossil fuels, biofuels can be considered carbon-neutral because the plants used in their production absorb CO_2 from the atmosphere during their growth. This closed carbon cycle helps offset the emissions released when the biofuels are burned for energy. Another avenue involves developing synthetic fuels, often referred to as e-fuels or electrofuels, which are produced by using renewable energy to convert CO_2 and water into hydrocarbons or other fuel molecules. These synthetic fuels can be used in existing combustion engines or fuel cells, providing a potential bridge between current infrastructure and a more sustainable energy system.

The need for alternate carbon-based fuels is underscored by the limitations and challenges associated with widespread adoption of renewable energy sources like solar and wind. These sources are intermittent and dependent on weather conditions, making energy storage and distribution challenging. Carbon-based fuels, whether derived from biomass or synthesized through renewable processes, offer a more reliable and flexible energy solution that can complement intermittent renewables. Moreover, transitioning to alternate carbon-based fuels can help reduce dependence on geopolitically sensitive regions for traditional fossil fuel sources. This diversification enhances energy security and reduces the geopolitical tensions associated with access to conventional energy resources. This commentary provides some insight into our focus on alternate carbon-based fuels development at the North-West University.

Green coal

A new formulation of 'green coal' has been developed, and its application has been tested at the coal research laboratories of North-West University. Bio-oil and biomass char were produced from sweet sorghum bagasse using hydrothermal liquefaction (HTL) at temperatures between 280 and 300°C. The resulting char was mixed with medium-rank C bituminous discard coal fines and calcium carbonate ($CaCO_3$) in different ratios, and the mixtures were pelletized and gasified using CO_2 at temperatures up to 1000°C. The experimental data revealed that the reaction rate of the biochar was significantly higher than that of raw coal.

To further examine the impact of temperature and catalyst on elemental sulphur retention during pellet combustion, a combustion setup was used, showing low sulphur retention for raw coal and biochar blends. However, the addition of a metal catalyst/sorbent increased sulphur retention to 56-86%, decreasing with rising temperature. A simulation using FactSage™ predicted that operating the fixed-bed gasifier in catalytic gasification mode at 800°C would remove over 50% of the pyritic sulphur as insoluble $CaSO_4$ from the gaseous phase. This aligns with the experimental results, and six international patents have been filed for this innovative process.

Fine discard coal briquetting

South Africa produces approximately 30 million tonnes of coal fines annually, which can lead to dust release, acid mine drainage and spontaneous combustion. Agglomeration technologies present a unique solution, allowing for fine coal use in conjunction with other waste materials. The North-West University has evaluated briquetting and extrusion as possible agglomeration techniques, looking at co-utilisation, waste valorisation and binder optimisation. Binder costs are often the cause for cost impracticality in agglomeration, hence binders derived from waste plastics along with low concentration binders (poly-acrylic materials) have been tested.

Agglomerates produced were found to have compressive strengths double that of the binderless briquettes, and in some cases surpassing the compressive strength of run-of-mine coal (14 MPa). These agglomerates can potentially be used in fixed-bed gasification or chain grate stoker fired boiler combustion applications. Over the course of the years, the testing facilities at the university have grown enough to allow for the continuous production (25 – 200 kg/hr) and testing (mechanical as well as thermal) of the manufactured agglomerates.

Waste valorisation

The green coal initiative has opened avenues for innovative fuel formulations. One promising approach involves extruding coal fines with recycled low-density polyethylene (LDPE) and polypropylene (PP) as binders. The binder content varied from 5 to 100 wt%, and the mixtures were processed in a co-rotating twin-screw extruder at 220°C. This novel method, not explored previously, resulted in extrudates with varying mechanical strength. Those containing 10% or more binder content exhibited strength and homogeneity, while a 5% binder proved insufficient. Under load, the extrudates with 10% LDPE and 10% PP displayed compressive strengths of 17.3 and 5.9 MPa, respectively, before breaking. The extrudates, regardless of binder content, showed consistent compressive strength after exposure to water. Moreover, they absorbed less than 5% water after 24 hours of submersion. As the binder concentration increased, the calorific value of the extrudates significantly rose due to the higher calorific values of LDPE and PP compared to coal fines. Additionally, higher binder content led to a decrease in sulphur content. Thermogravimetric analysis (TGA) revealed synergy between plastics and coal fines during pyrolysis. The study suggests that co-extrusion of recycled plastic with coal fines can yield carbonaceous fuels with enhanced hydrophobicity, heating value, and strength compared to using coal fines alone. This approach not only addresses environmental concerns but also utilizes waste coal fines and plastics for industrial applications.

In a related study, the slow co-pyrolysis behaviour of extrudates from South African Highveld coalfield coal fines and recycled LDPE and PP was investigated. Plastic fraction varied from 10 to 100% during extrusion. Slow pyrolysis yielded up to 83% char from coal fines and over 90% condensable products from plastics. The slow heating rate favoured condensable product production, increasing with plastic concentration. Equations were developed to predict pyrolysis yields and characteristics based on coal and plastic composition. The results indicate potential applications in stand-alone pyrolysis plants for downstream chemicals production and char gasification, marking a step forward in alternate fuel technology.

Cook-stove emission reduction

The use of coal as a domestic fuel source still occurs and is linked to poor health due to exposure to household air pollution. Alternative carbon-based fuels have been considered for use in a newly designed cook-stove, with the aim of increasing the air quality in households where electricity driven equipment is not always feasible. Coal-biomass pellets and lump coal were combusted in this newly designed semi-continuous cook-stove at the North-West University. Biomass addition generally leads to lower sulphur emissions and ash generation, and at low concentrations (up to 25 wt%), a reduction in particulate matter emissions was also observed. The use of torrefied wood was shown to increase the potential energy content of the fuel, approaching the calorific value of low-grade coal. To improve handleability, binders such as starch and PVA were utilised, and were found to have no significant influence on the NO_x or SO_x emissions of the pellets. Finally, it was found that all the fuel batches in combination with the improved semi-continuous coal stove delivered significantly lower NO_x, SO_x, and CO emission levels than when compared to conventional coal stoves using lump coal. A roll out of 50 coal stoves in a low-income settlement has been concluded, and the improvement of air quality is now being evaluated. This stove can also be fed with blended coal/biomass pellets, which can potentially make the process more sustainable. Modifications to the stove design are currently underway.

Conclusion

The imperative need for alternative carbon-based fuels arises from the urgency to address climate change, reduce greenhouse gas emissions, and transition towards a more sustainable energy landscape. Biofuels and synthetic fuels represent promising pathways that align with the goals of mitigating environmental impact, fostering energy security, and promoting technological innovation for a cleaner, more resilient future. This commentary has provided some insight into our focus on alternative carbon-based fuels at the North-West University with the view to lower emissions and improve process efficiency and sustainability.