COALGAE®

INSTITUTE FOR CHEMICAL TECHNOLOGY AT THE NELSON MANDELA METROPOLITAN UNIVERSITY (INNOVENTON)

WHAT IS COALGAE®?

Coalgae® is a composite material formed through the biological modification of coal by live microalgae, followed by the agglomeration of the coal-microalgae mixture into pellets, briquettes or extrudates.

THE COALGAE® OPPORTUNITY

The opportunities and value of Coalgae® include:

- Utilisation and monetisation of discard coal.
- Providing a solution to the environmental management of waste coal fines, which can reduce the costs compared to alternative methods.
- Upgrading of the quality of the discard coal by reducing the ash content and hence increasing the calorific value and quality of the final product.
- Extending the life of coal mines by depleting reserves at a lower rate.
- Adds a biomass fraction to coal that avoids the challenges associated with co-feeding of 100% biomass pellets with coal.
- Incorporate renewable energy into the energy mix of a company and improve sustainability ratings, as well as compliance with increasingly strict environmental legislation.
- Opportunity to reduce carbon taxes or purchase of carbon emission reduction credits.

Coalgae® is a direct substitute for coal in the vast majority of its applications and can be further processed to yield a wide variety of products, including liquid fuels.

COALGAE® IN MORE DETAIL

Work at the NMMU's research entity, InnoVenton, has shown that concentrated microalgae slurries can be adsorbed onto the surface of carbonaceous materials, such as coal and charcoal, and act as an excellent binder for fine coal at microalgae loadings of 5% biomass (dry weight basis) without the need for any other additional binding material. Higher biomass loadings are possible and the choice of loading will depend on the product application and customer requirements. The product, called Coalgae®, may be prepared in various solid forms, e.g. granules, briquettes, pellets or extrudates. Coalgae® exhibits excellent mechanical and water resistance properties.

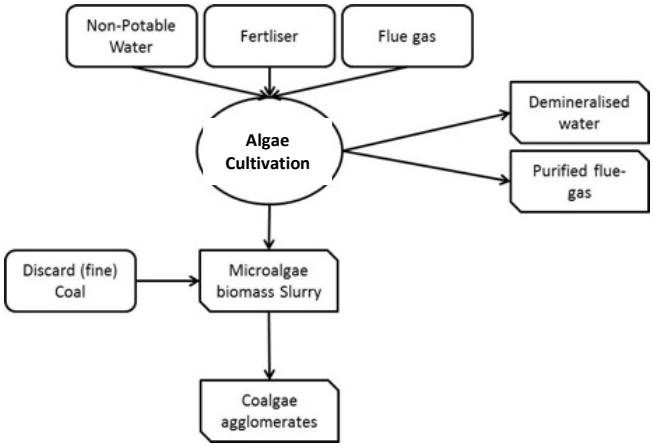
Apart from the potential to recover discard or fine coal through agglomeration with microalgae biomass, the adsorption of microalgae onto coal fines also offers the potential to upgrade discard coal through a process that appears to be a combination of biological modification of the coal together with selective demineralisation of the waste coal. The result is a high quality substitute for coal. In addition, Coalgae® may be further processed by technologies such as pyrolysis, direct liquefaction and gasification to liquid fuels with a bio-derived fraction, as well as other high-value compounds.

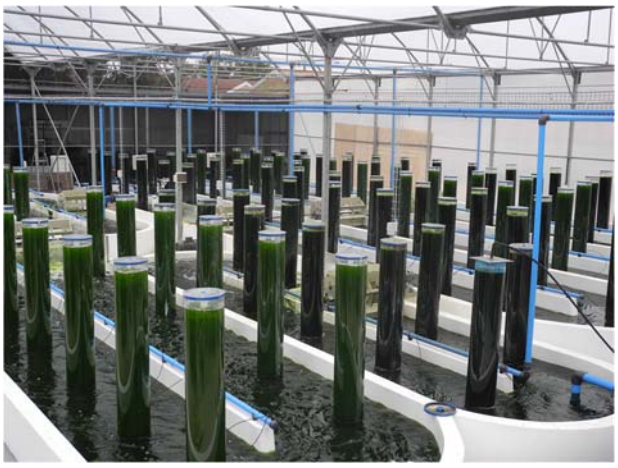
In summary, Coalgae® is a direct substitute for coal in the vast majority of its applications and adds a renewable energy fraction to the customer's operations. Its use requires no process or equipment changes. Moreover, the ability of Coalgae® to demineralise poor quality discard coal selectively is an important competitive advantage of the process that allows recovery of significant value from waste and poor quality coals.

ADVANTAGES OF COALGAE

- *High mechanical strength (enables normal handling and transport of agglomerated product).*
- *High weather resistance (can be stockpiled without need for weather protection).*
- *Direct replacement of coal by biomass reduces fossil fuel-derived greenhouse gas emissions.*
- *At worst, microalgae biomass does not reduce the energy value of fine coal due to the high energy value of the microalgae biomass. At best, a significant increase in energy value may be brought about by selectively removing mineral components as microalgae selectively bind to carbon.*
- *At 5 to 10% mass loadings, microalgae biomass has no significant impact on the ultimate properties of coal.*
- *Inherent oxygen content of microalgae biomass results in a significantly cleaner burning product due to the internal supply of oxygen for combustion.*

THE PROCESS





There are two major process sections: microalgae cultivation and coal/microalgae processing. The major input requirements for microalgae cultivation are non-potable water, nutrients (fertiliser) and a source of CO_2, such as flue gas. The microalgae are harvested from the cultivation system by means of settling and the concentrated microalgae slurry is mixed with coal fines. The resultant coal-microalgae slurry is dewatered and formed into agglomerates. The latter is a proven technology that is used worldwide, albeit using different binding agents.

STATE OF THE TECHNOLOGY

Microalgae cultivation has been demonstrated in a pilot plant facility (approximately 400 m^2) at InnoVenton in Port Elizabeth, South Africa, for about four years now. The system has proved robust and a number of iterations of the photo-bioreactor design and cultivation system have been introduced to optimise the design and efficacy of the process. The system runs continuously between the various technical development campaigns, with concentrated microalgae solution harvested periodically (this can range from daily to weekly depending on environmental conditions). The microalgae biomass is removed from solution by gravity settling followed by adsorption on coal fines in a batchwise manner and further processed to Coalgae® agglomerates.

Hatch Goba was appointed to provide a full basic engineering package of the demonstration plant and a cost estimate of a commercial-scale plant (100 ha or greater) in 2014. Since then various improvements have been made to the algae cultivation section to improve the biomass yield and reduce the capital investment. The engineering study is currently being updated to incorporate the new design.

The technology is protected by a number of patents filed in the top six coal-producing countries and countries that are large users of coal, such as South Africa, China, India, the US, the EU and Australia. The product name, Coalgae, is trademarked.

FEASIBILITY ANALYSIS

The main customers for Coalgae® product are companies that use coal for some purpose, e.g. electricity and heat generation (utility companies, mining companies, cement and paper manufacturers, etc.) or liquid fuels. There are also smaller household applications.

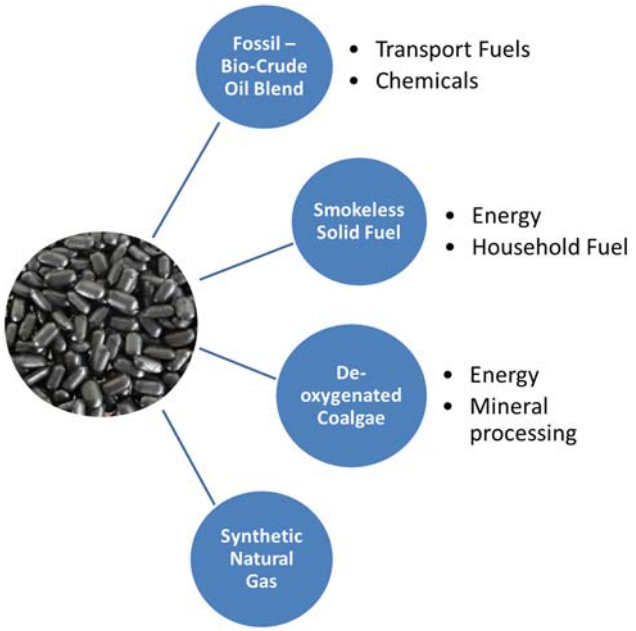
We believe the production and sale of Coalgae® is a viable business proposition on a commercial scale, i.e. algae cultivation area of at least 100 ha. Techno-economic studies of the Coalgae® process have been performed to evaluate the economic viability of a technology that involves the cultivation of microalgae, upgrading fine (discard) coal, and then selling the Coalgae® product as a thermal coal. The techno-economic studies indicate that, at an appropriate scale and based on assumptions drawn from the pilot plant and engineering study, the process is financially viable and can generate an internal rate of return (IRR) in excess of 15%. The analysis is dependent on the specific circumstances under which the plant is constructed and operated. The results of the techno-economic study for a 100 ha facility under the base assumptions and on a stand-alone basis are shown the in table. The ultimate business of the commercialisation entity is likely to be licensing the suite of technologies and higher returns are expected from the licensing business.

Process Economics	
IRR	18.5%
NPV @ 15%	ZAR 181 million
Payback Period	5 years

CURRENT STATUS AND FURTHER DEVELOPMENT

The Coalgae® technology is currently being demonstrated in a micro-scale technical demonstration facility at the NMMU. The purpose of the current demonstration is to integrate the various unit operations of the technology, to produce several tons of Coalgae® product, to carry out independent external product testing, to provide marketing samples to interested parties, and to carry out further technical development work using Coalgae® as feedstock. These technologies include:

- Partial de-oxygenation of the Coalgae®.
- Pyrolytic topping of the Coalgae® to produce a fossil-bio-crude oil blend.
- Pyrolytic topping of the Coalgae® to produce a partially devolatilised solid fuel.



Initial tests indicate high yields of “bio-crude oil” and partially devolatilised coal (char), and the process appears to have significant advantages relative to conventional biomass pyrolysis or coal liquefaction. InnoVenton is in the process of acquiring a larger pyrolysis plant that will enable further process development and product characterisation. The bio-crude oil can be utilised in standard refinery processes and yields final petroleum products that contain a fraction of biofuel without the need for additional blending. The char is a smokeless, clean fuel suitable for households and emergency relief situations. It may also have high-value industrial applications.

NEXT STEPS AND WAY FORWARD

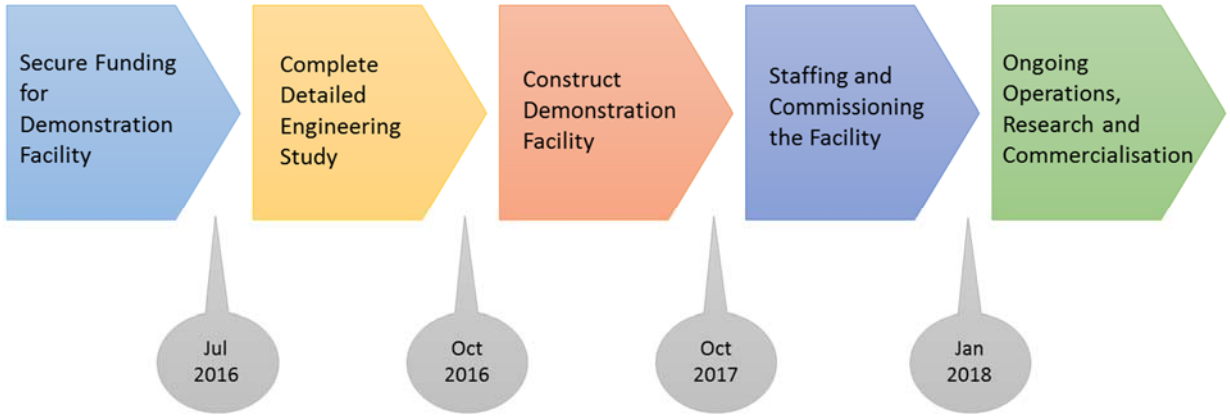
InnoVenton intends to construct and operate a Coalgae® demonstration plant (1 to 5 ha cultivation area) in order to demonstrate this novel and innovative technology under real world conditions on a larger scale, and in an integrated and continuous manner. The aim is to prove the process is buildable, scalable, operable and maintainable. The demonstration plant will also:

- Enable continuous improvement of the integrated technology package to further enhance its commercial attractiveness.
- Serve as a marketing tool to potential licensees and customers.
- Allow further research, development and demonstration of downstream technologies and assist in developing new product applications.
- Provide larger quantities of final product than are possible on the existing pilot plant, which will enable additional testing of market acceptability and more rigorous application testing.
- Allow optimisation of critical technical operating parameters, which cannot be done on the current pilot plant because of technical/equipment limitations.

Ultimately, the demonstration plant will enable the development of a complete technology package for licensing to customers.

The total cost of the next phase is estimated at approximately ZAR 120 million/USD 7.5 million/EUR 6.5 million. The funding will cover the capital investment in the demonstration microalgae cultivation facility and processing plant for microalgae-coal composites (Coalgae®), facility operating costs and development of the pyrolysis technology (liquid fuels and clean coal). The demonstration plant will not be a financially viable stand-alone entity because the scale is too small, but it is a critical step for commercialisation. **We are seeking investment partners for the demonstration plant, which will be housed in a separate legal entity. The new company will undertake the necessary commercialisation and business activities, and be responsible for licensing the suite of technologies globally.**

The project will follow a stage-gate approach with an approximate timeline as set out below.



For further information, please contact:

Brian Tait

brian@infinergy.za.com

+27 82 920 9382

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