

Process Philosophy Adopted by Sustainable Clean Fuels, LLC

Goals

The goal in developing the process that is the subject of the patent application “Systems and methods of producing synthesis gas and bio-oil” was to produce fuels for transportation in a sustainable manner, using only carbon dioxide present in the atmosphere and water as feedstock to produce the fuel.

The intention was to maximize the use of existing, established commercial technologies and thus minimize the commercial uncertainties in implementing these complimentary process technologies.

One of the commercial challenges of converting biomass to transportation fuels on an industrial scale is the low energy density of the biomass, which requires large-volume transportation of the biomass. The biomass must be collected over a large radius far from the processing facility to meet commercial scale requirements, which significantly impacts biomass collection and transportation costs and carbon intensity (CI). Another issue with biomass collection is the need for storage, as biomass from agriculture (as an example) is seasonal. A commercial-scale operation is required throughout the year.

These challenges are addressed by selecting the most prolific biomass which will allow sufficient availability of biomass to be cultivated near the processing facility. This eliminates the need for pickup and transport by vehicles and uses instead a pipe connection between the cultivated biomass and the processing facility.

Azolla

One candidate for highly productive biomass is the Azolla fern. This plant doubles its mass within 3 days under ideal conditions. We can maintain ideal conditions 24/7 by cultivating it in a large, climate-controlled building using hydroponics and vertical growing methods that have already been commercialized for growing food. We can further increase this growth rate by introducing sufficient cooled exhaust from the power plant to increase the carbon dioxide (CO₂) concentration in the building from a nominal 400 ppm to 800 or 900 ppm. This doubling of CO₂ concentration has been shown to result in an additional 30% growth output.

Another benefit of growing vertically in a controlled building environment is the capture and reuse of water vapor lost through transpiration (evaporated) from the Azolla plant. The Azolla plant fixes its own nitrogen from the air, eliminating the need to add fertilizer (at a cost) to the growing medium.

Algae

An even more productive biomass is *Chlorella Sorokiniana*, a potential algal strain that can double its mass in 2.57 hours under ideal conditions. We can grow and harvest a large amount of biomass in a very short time, in close proximity to where it will be processed. One of the goals of our company is to develop the selected algae so that it can grow without sunlight.

The need for sunlight is a major contributor to the need for a large open area for algae growth. This, in turn, makes the area susceptible to undesirable organisms competing for the sustenance used to grow the desired algae. In addition, the depth of sunlight penetration is a limitation to the productivity of algae cultivation in mass production. Our disclosure in the patent-pending application identifies the methodology for producing the algae in the dark, in large continuously stirred tank reactors (CSTRs) in order to scale algae growth to commercial quantities. This work will be initiated as soon as resources are freed up to tackle this option.

One of the unique challenges in commercially processing fast-growing algae is drying it (or concentrating it) sufficiently to make it economically viable as a sustainable fuel. The removal of water is associated with a large energy deficit that cancels out the available energy from biomass-produced fuel.

Instead of drying the algae, we will process the algae into a crude bio-oil using hydrothermal liquefaction (HTL). Exposure of the biomass to high pressure and temperature, maintained for a reasonable period, separates the crude bio-oil from the biomass. The inclusion of water in the HTL process further enhances the recovery of crude bio-oil.

A typical difficulty in processing algae in the HTL process is the low concentration in water and the associated difficulties in algae concentration, which makes the economics of concentrating biomass an energy challenge. Methods evaluated to date include filtration, flotation, centrifugation, and various other techniques. All these methods are associated with a large energy deficit, which diminishes the utility of biomass as a source of a sustainable fuel that can compete economically with fossil fuels.

Our solution to the low concentration of algal biomass is novel. We do not intend to remove water but instead to add more biomass. In our case, it is *Azolla*, which does not grow as fast as algae but can be easily harvested without water. This *Azolla* can then be combined with the algae to produce a slurry biomass with a possible concentration of about 5% to about 40% solids (or more if needed). Our program is looking for an optimal solid concentration, which is probably between 20% and 35%. The limitation of concentration is due to pumping challenges and rheology, which leads to difficulties in heat transfer in the HTL process.

One of the other products leaving the HTL process is unused water that was not taken up by the biomass during its growth. The water after the HTL process contains both

organic carbon products and inorganic compounds that are soluble. Both types of compounds are in a state that can be reused in the biomass growth medium and are therefore recycled to the nearby cultivation section of the process. This minimizes the cost associated with adding additional compounds needed for optimal biomass growth.

Repurposed Coal gasification

At this stage, we have identified a process combination that delivers the biomass near the processing plant with an energy deficit that is not too large. The HTL process produces not only crude bio-oil but also a solid of fixed carbon and ash called “hydro char”. This solid residual product can either be used as a soil amendment to produce, for example, a “terra preta” that promotes the growth of agricultural crops while removing carbon dioxide from the atmosphere for about 1,000 years, or the hydro char can be used as a substitute for coal in a high-pressure coal gasifier. High-pressure coal gasifiers have been used for decades in commercial operation, and can convert biomass-derived coal-like material (either biochar produced by pyrolysis of biomass or hydro char produced by the HTL process).

The result of a gasifier fueled with a carbonaceous material (either fossil or biomass) and oxygen is a syngas. This syngas consists mostly of carbon monoxide (CO), hydrogen (H₂), and carbon dioxide (CO₂), with small amounts of methane (CH₄), nitrogen (N₂), argon (Ar), and other trace impurities. The syngas leaves the gasifier at high pressure and high temperature. The high temperature is cooled in heat exchange with the biomass being processed in the HTL process, while the syngas is then further cooled to the point where they can be then processed in conventional commercial processes to produce chemical commodities on a commercial scale.

Of particular interest in the use of syngas is the production of more transportation fuels. Because the source of syngas is biomass, the fuels produced are considered sustainable transportation fuels, all of which are subsidized by the government. Potential alternative commodity production outcomes are discussed in more detail in the “Process Options” section. These include gasoline produced via the methanol intermediate pathway or Fischer-Tropsch hydrocarbons, which combine with the crude bio-oil and are used as feedstock to a conventional refinery.

Process Flexibility

Our combination process is self-contained and generates sufficient energy and steam to power all processing equipment, including compressors and the air separation unit. All the carbon extracted from the atmospheric air is converted to either renewable fuels (or other desirable commodities) or a soil additive. The power island equipment discharges the exhaust gases into the atmosphere, a portion of which is diverted to the Azolla plant’s cultivation building, as previously described.

This is a highly integrated system of processes designed to produce sustainable fuels, cost-effectively on a large scale. At the same time, the licensee of the process can benefit from several opportunities for government subsidies, including for sustainable fuels, sequestration, or use of captured CO₂, and for the possible production of green hydrogen (H₂).

Which combination of feedstocks to invest in is a site-specific question, involving projections of supply and demand, and specific locational advantages. For example, a facility near the ocean could process macroalgae (Sargassum seaweed, kelp, etc.) rather than a combination of Azolla and algae. Away from the ocean, marine biomass processing would not necessarily be a good application.

Local agricultural waste or other readily available biomass nearby may also be of advantage for a given site. The key to this process is the flexibility of the biomass source and the flexibility of the commercial commodity products that can be produced. Flexibility also depends on the location of the facility. From regions with low solar radiation to desert locations, the process can be adapted to different sites. In addition, it is possible to locate the plant near a refinery, which typically serves metropolitan areas with high population density and high local demand for transportation fuels.