Biomass to Biogas to Biochar

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1. Introduction

Before you meet the handsome prince, you have to kiss a lot of toads!

- The Stitchery of Wellesley Hills, 1975

The above may be the first of many variants of this same basic saying.

I write moderately detailed technical articles involving a number of subjects, and I read much material in trying to find leads to the articles. I spent much time researching several of these leads on emerging products recently, and afterwards I moved each of them into my "Not-posted but done" file due a major potential flaw in each product. Then I found my prince – the subject for this article. I was skeptical at first, but the more I dug the better this looked. As I start writing this, I can see I still have much research to do, but I am convinced.

2. The Convincer

Let's say you have a concept for a plant that turns trash into, not treasure, but useful and valuable products. It is reasonable that it might take a decade to completely flesh out the process behind this plant, as this one did. A possible dead-end to this effort would be some serious environmental issues with air-pollution, or other emissions, since this is intended to be a green-tech product.

So where would you work on initial pilots and your first full-scale plant? Since this company is in Southern California, the Mohave Desert sounds like a nice place, right? How about the middle of Los Angeles for the former. It gets better. The full-scale factory: *The nation's largest natural gas utility, SoCalGas, with the participation of the South Coast Air Quality Management District (AQMD), is supporting Kore's full-scale waste to biogas thermochemical-conversion system on a SoCalGas site in the heart of central Los Angeles, one of the most tightly regulated airsheds in the country. The pyrolysis system began processing feedstocks in August 2021, generating valuable data in support of commercialization.*[1]

Since I'm still a bit cautious when it comes to kissing toads, I wanted to make sure this was a real prince, so after a brief web search, I found a contract amendment for this project on the South Coast AQMD site, and this is linked below.

http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2021/2021-mar5-006.pdf?sfvrsn=2

3. The Process

When a pile of manure is left in a field, for instance, it naturally converts into methane and CO_2—two greenhouse gasses that warm the planet. But if the manure is fed into a pyrolysis machine, about half of its carbon is converted into solid carbon, also called

[1] Kore Website, Projects, https://koreinfrastructure.com/projects/

char. In this form, the carbon atoms can't be broken down by microbes and released as CO_2. The element is then sequestered as a solid, and its potential to warm the atmosphere is eliminated.[2]

Hydrogen accounts for roughly 70% of all matter in the universe—and these days, it seems that hydrogen power startups account for about the same share of emerging green-tech companies in California. But while the space is replete with big dreams using hydrogen to power planes, cars, buildings and more, most companies are still years away from finishing a prototype—let alone building a plant or going to market.

Not so for Kore Infrastructure. The energy startup is already online at its plant in Downtown Los Angeles, where it's converting tons of waste into hydrogen, biogas, renewable natural gas and carbon char every day.

Author's note: Note that the above char (a.k.a. biochar) has many industrial uses as described below. Not mentioned are its use in filtration and carbon for electronics (semiconductors and batteries). The above mentioned renewable natural gas is also known as biomethane. Burning biomethane in existing combined-cycles plants, capturing the CO_2 and sequestering it has the potential to be carbon-negative. See the paper from a few years ago, briefly described and linked below:

Zero-Emissions Combined Cycle and Beyond: This paper has a proposal that will keep combined cycle power plants running by converting them to (nearly) zero greenhouse gas (GHG) emission operation. Ultimately these can be converted to negative emissions technology to offset other GHG sources.

https://www.energycentral.com/c/cp/zero-emissions-combined-cycle-and-beyond

The idea behind Kore's technology is similar to that of other companies also deploying the process known as pyrolysis: You take organic waste like deadwood and brush, heat them in a low oxygen environment at a very high temperature, and collect the gasses and carbon char left over. When all goes well, this avenue of hydrogen production can be carbon negative, meaning that CO_2 is removed from the carbon cycle that usually sees it burned into the atmosphere.

Kore has a reasonable graphic for their process on their website (linked in reference 1, above), under the "Process" tab. This is below (next page). The descriptions below are from this page (minus the videos).

Material Handling: *The raw materials for the Kore process are the hydrogen carbon and oxygen contained in the feedstocks, which can range from agricultural residue to deadwood and construction debris. Before entering the hopper, some feedstocks require drying as well as chopping or grinding, to attain the two to three inch size required by the process.*

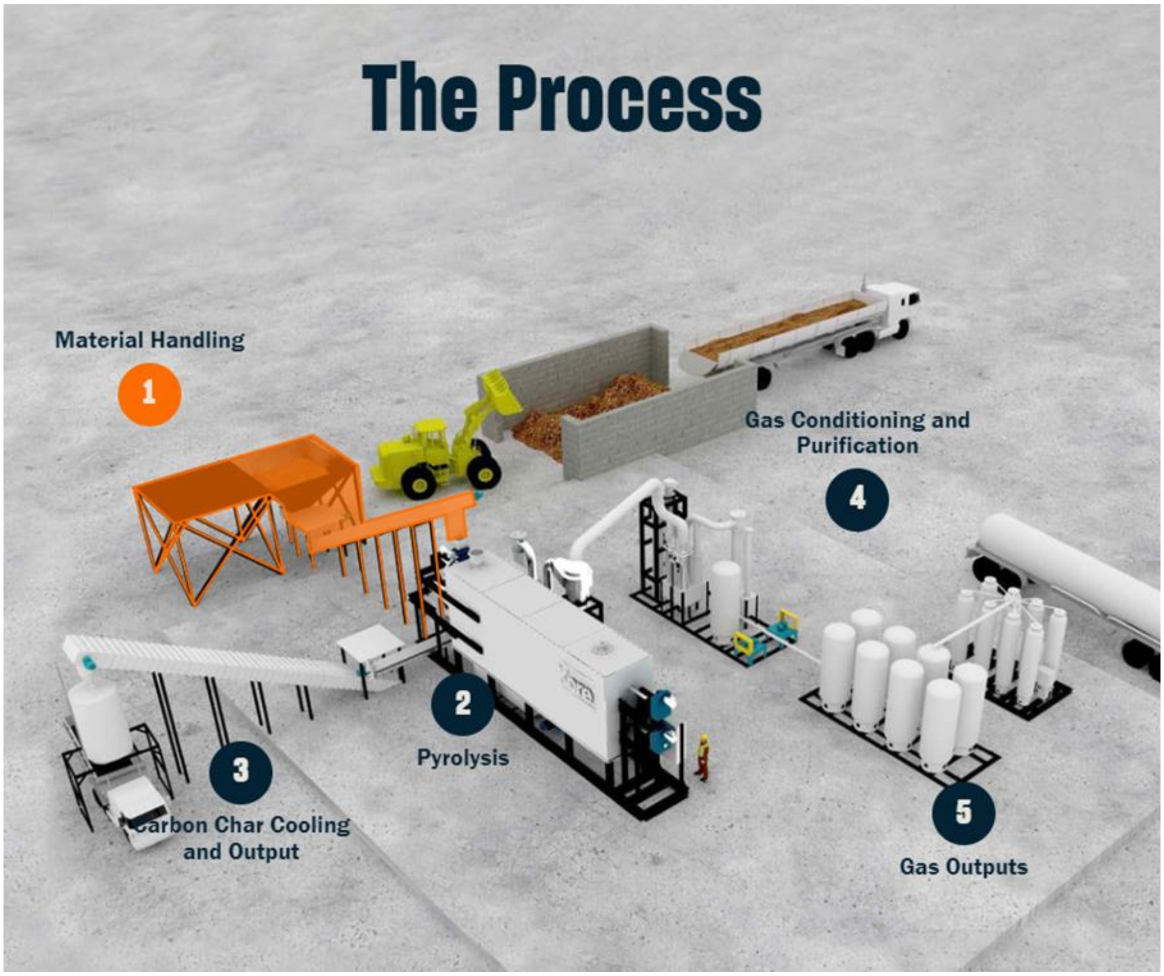
Pyrolysis: *The feedstock is continuously fed into the pyrolyzer and is indirectly heated to temperatures exceeding 1,000°F. The feedstock is converted to a gas consisting of hydrogen, methane, carbon dioxide and carbon monoxide. The fixed carbon becomes an elemental carbon char.*

[2] David Shultz, dotLA, "Kore Infrastructure Is Turning Waste Into Clean Energy in Downtown LA," April 12, 2022, https://dot.la/kore-infrastructure-waste-clean-energy-2657143186.html

Carbon Char Cooling and Output: *The carbon char exits the reactor at around 1,400°F and falls onto a conveyer, where it cools in vacuum conditions. Every ton of feedstock produces around 400 pounds of carbon char, which can be used as a coal substitute and as a soil amendment that can reduce irrigation needs by up to 60 million gallons per year (based on a single 1 ton/hour Kore system).*

Gas Conditioning and Purification: *The gas exits the reactor and enters a cyclone separator, which removes dust and soot. Then a Venturi scrubber cools the gas and removes condensable liquids. The result is a moisture-free, impurity-free biogas.*

Gas Outputs: *Kore's biogas has a heating value of 500-600 BTU/ft^3, about half that of pipeline natural gas: it can be used to produce steam, electricity and heat. The gas can be upgraded on site to ultra-pure hydrogen, or it can undergo methanation to be converted to renewable natural gas with the same energy value as conventional natural gas. All gases can be pressurized and stored on site.*



The volume of the three gases produced are shown in the figure below. I believe that these are alternative output gases, not simultaneous output gases. Also note that the above says "*The feedstock is converted to a gas consisting of hydrogen, methane, carbon dioxide and carbon monoxide…*" It is assumed that either output is further processed to incorporate the CO_2 into "renewable biogas" (syngas, see sect. 6), or sequestered.

4. Economics

Any new product had better have good economics if it is to succeed. Fortunately I came across a good Forbes article on Kore, and it gave me some information that let me explore the economics of at least one of the gases produced.

…The end result of all Kore's hard work is a modular system that is safe, self-sufficient, easy to service and repair and which produces carbon-negative fuels and value additive biochar. The plant in Los Angeles has a daily capacity of 24 tons of construction wood waste, deadwood, and agricultural detritus, and will produce 1,000 kg of hydrogen (at a very low price point of around $2 / kg) or 10 million BTU of renewable biogas, and 6 tons of solid carbon char every day.[3]

Shields[4] *told me that the company has gone through many iterations of the basic design and learned a great deal with every iteration. Key components are built on skids that can be pulled out to make servicing the parts easier, the hopper can be modified to accept different feedstocks, each component is equipped with monitors to quickly inform an operator of current status, and the entire facility can be sited on an acre or less of ground.*

The upside of all this design and redesign work is that the Kore system works great. The downside is that working 14 years to build the first commercial version of its product is diametrically opposed to the Candy Crush Economy model favored by the venture capital (VC) community of building products and rolling them out quickly.

Hard asset investing is not something that comes easily to VCs, many of whom have made their fortunes in the world of software, where a new prototype can be pounded out in a long weekend fueled by pizza and Adderall.

Private equity investors, on the other hand, are generally good at hard asset investing. The problem is that innovation is not something with which they typically feel

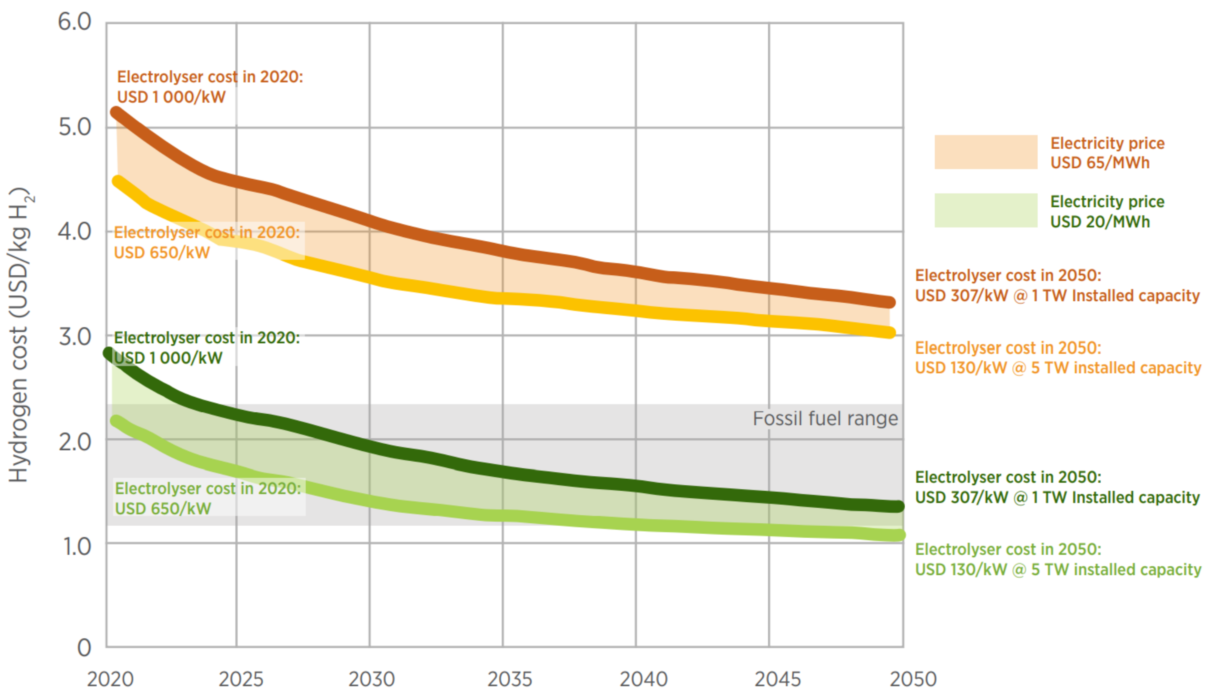
[3] Erik Kobayashi-Solomon, Forbes, "A Backbone For The Circular Economy, Kore Infrastructure Turns Trash Into Treasure," May 2, 2020, https://www.forbes.com/sites/erikkobayashisolomon/2022/05/02/a-backbone-for-the-circular-economy-kore-infrastructure-turns-trash-into-treasure/?sh=41a0a89c2bd5
[4] Kore's founder and CEO, Cornelius Shields

comfortable. PE folks are the ones who make a living analyzing hard asset businesses with long operating histories and relatively predictable cash flow profiles then figuring out how to structure transactions that will pay off for themselves and their investors.

Show a private equity person a hard asset business with no operating history and a wide range of possible future cash flow scenarios and they'll look at you as a Labrador Retriever might if commanded to solve a calculus problem.

In the end, Shields, a serial entrepreneur and private investor, has spent a great deal of his own fortune on the development of Kore, and he believes that strategic investors (i.e., corporations whose own businesses might benefit from a given start-up's innovation) are really the most suitable partner for a business like his.

Note the price of Kore's hydrogen is $2 / kg. Also note that this is neither green hydrogen (made from the electrolysis of water using renewable / zero-carbon electricity) nor blue hydrogen (made from geologically-sourced natural gas with the resulting CO_2 captured and sequestered), but something else. Since it's made from biomass process I have assumed that has no net greenhouse gas emissions, so it could probably be considered equivalent to green hydrogen. Fortunately I just posted a paper on green hydrogen economics (as I'm writing this in late May), which is referenced here,[5] and the chart below is referenced here.[6]



As you can see $2/kg compares very favorably with the current cost of green hydrogen given a very low price of renewable power. See the referenced papers for other details.

[5] The Economics of Green Hydrogen, https://energycentral.com/c/cp/economics-green-hydrogen
[6] IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi, 2020, https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

5. Use Cases

The cases below originally came from the Kore site, but have been heavily edited by me.

5.1. Waste Management

Organic waste, where I live (Livermore, CA), is collected from residents in a separate (green) container. According to Livermore Sanitation, it sorted, .shredded, composted and then sold to be used in farming, gardening and landscaping. However Kore proposes to use this waste to produce alternative products, including those described below. In either case the product is recycled rather than dumped into a land-fill.

Livermore Sanitation offers separate organic service as described above for commercial customers. I would guess that that the opportunity for Kore would come from communities that do not have organics service / processing like Livermore. Also, (even in Livermore) there is a separate service for “construction and demolition debris (mixed)”, “solid waste, or “wood.” These would all need to be processed to remove non-organics (perhaps less for “wood”).

A list on the Kore site defined the following process input materials:

- *Agricultural residues (nut shells, fruit pits, and more)*
- *Green waste (grass and tree clippings, chipped trees, and more)*
- *Construction and demolition wood*
- *Municipal refuse-derived fuel (RDF)*
- *Municipal materials-recovery facilities (MRF) waste*
- *Pallets, packaging, and other fulfillment center refuse*
- *Deadwood from wildfire-prone areas*
- *Animal manure*
- *Biosolids from municipal wastewater*
- *Food waste*
- *Compost*
- *Plastics*

I find the last item interesting. Although most plastics are chemically organic materials, they generally rely on petroleum (mainly made from geologically derived natural gas). Even with processing, most waste will probably have some plastics in it. It is good this process can handle this, and as long as the amount remains small, it shouldn’t hurt the “green” credibility of their output biochar and fuel-gasses too badly.

Other items in the above list will have small amounts of metals, glass and other non-organic materials in them. Metals can be removed after shredding by electro-magnetic processing to the extent this is necessary to maintain the quality of the process outputs. Most other non-organic materials (glass, ceramic, and other non-metals) will hopefully pass through the process enact.

5.2. Energy Products

The energy products consist of three fuel-gasses. These are mostly from the Kore Site, but I modified the first two slightly (non-italics text)[7]

Renewable Biogas: *This can be used as a substitute for natural gas,* (but generally will require modified or specialized combustion hardware)*.* (With such modification,) *biogas is a sustainable replacement for operations that require steam, heat, and power generated by non-renewable natural gas.*

Renewable Natural Gas (RNG): *This can be injected into existing natural gas pipelines and directly replace conventional natural gas* (with no modifications required)*. Sustainable natural gas replacement for vehicles, heating, and other applications.*

Ultra-Green Hydrogen™*: This can be used as a carbon negative, 100% renewable alternative to hydrogen produced non-sustainably from natural gas. The Kore process produces 99.999% pure hydrogen for fuel-cell electric vehicles, including buses, trucks, trains, and cars.*

5.3. Biochar

Biochar can be used as a greenhouse gas (GHG) neutral energy source to help companies transition from coal, keeping future CO_2 emissions permanently locked in the ground. With CO_2 capture and sequestration combustion of biochar becomes carbon-negative.

Biochar also can be used for:

- *A soil amendment to improve nutrient retention and reduce irrigation needs by up to 60 million gallons per year (based on the capacity of a single Kore system)*
- *Filtration of various gas and liquids*
- *Carbon for electronics (semiconductors and batteries)*

6. Syngas

Since it’s an element, hydrogen is hydrogen. Assuming it’s purified to pipeline standards, the same thing be said of “natural gas,” whether it’s renewable natural gas (RNG, a.k.a. biomethane) or geologically derived. Thus there is little question that either will function like the any other hydrogen or natural gas.

I wanted to find out how easy it is to operate a generator from what Kore calls “renewable biogas.” The biomass industry and major companies that make electric generators (like GE and Siemens) tend to call this syngas or biomass syngas.

First, an explanation from the biomass industry:

The technologies for transforming biomass into energy, fuels, chemicals or other value-added products come in one of two varieties. One is founded on the natural biological processes carried out by microbes, or they're dependent on the calibrations of heat, pressure and/or oxygen that define various thermochemical reactions generally referred to as gasification. At the moment, the former is the glitzy star at the center of the

[7] https://koreinfrastructure.com/uses/

renewable fuels stage, while the latter-the understudy to these microbial wonders-is gaining a reputation for robust consistency and efficiency.[8]

"Syngas production is sort of an orphan," says Alexander Koukoulas, senior technology consultant for ANL Consultants LLC, which services the pulp and paper, packaging, chemicals and bioenergy industries. "It hasn't really seen much in the way of publicity even though it's a much more mature technology that has been used at commercial scale for quite some time."

To harness the energy stored in the chemical bonds of agricultural waste, forest residues or any other of the profusion of carbohydrate-containing leftovers that can serve as renewable energy feedstocks, engineers tinker with the deforming powers of heat and pressure with the aim of breaking the linkages that hold these molecules together and capturing the chemical energy released in the process. This chemical energy is contained in a mixture of molecules collectively called synthesis gas (or syngas) because it's suitable for the synthesis of various fuels and chemicals. The principal components of syngas are carbon monoxide and hydrogen but the concentrations of these and the presence of other minor molecules can be tailored by using different thermochemical reaction conditions.

6.1. General Electric

Did you know that you can easily burn non-standard fuels in your aero-derivative gas turbines? In addition to low BTU fuels like biomass syngas, landfill gas, and digester gas, our turbines can also burn various types of high-H_2 fuels, including but not limited to: refinery process gases, coke-oven gas, and blends of H_2 with methane.[9]

6.2. Siemens

First of all Siemens was your author's former employer (I'm a Siemens retiree, but I also worked for GE early in my career), and I frequently lean on them for specialized power generation information.

The SGT6-5000F is able to burn a wide range of fuels including natural gas, LNG, syngas, ethane, propane….[10]

The engine offers dual fuel capability and tolerates fuels within a wide Wobbe range.

There were several combustion turbines that had the above text in their description, but these are all heavy duty turbines like might be used in a utility-scale combined cycle plant. Siemens also offers internal combustion engines (IC or "gas engines") that appear to be what they recommend for syngas:

Gas engines can run on very low heating value (LHV) fuels like syngas (4.5 MJ/Nm³).[11]

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[8] Jessica Ebert, Biomass Magazine, "Syngas 101," http://biomassmagazine.com/articles/1399/syngas-101/

[9] GE, "Alternative fuel gas turbine retrofits," https://www.ge.com/gas-power/services/gas-turbines/upgrades/alternative-fuel-retrofit

[10] Siemens Energy, "SGT6-5000F," https://www.siemens-energy.com/global/en/offerings/power-generation/gas-turbines/sgt6-5000f.html

[11] Siemens Energy. "Gas turbines or gas engines," https://www.siemens-energy.com/global/en/offerings/power-generation/rice.html

However, there may be a problem with IC engines, they tend to emit large amounts of pollution, both of the greenhouse kind, and of other kinds.

6.3. Hydrogen and Methane

Methane (natural gas) is the normal fuel for combustion turbines, and there will be greenhouse gas (GHG) emissions whether the methane is biomethane or not. The key with biomethane is that the net GHG emissions should be lower due to it being offset by CO_2 in the organic material used in making it absorbed when growing. However there are secondary emissions from transportation, manufacturing, etc. which make the net emissions non-zero. Although it is not a mature technology, using carbon-capture and sequestration for the exhaust of the turbine has the potential to drive the emissions negative. Also secondary emissions are becoming lower over time,

Using hydrogen in combustion turbines is already possible to a limited extent. See the earlier post described and linked below for details.

A modern combined cycle plant fueled with geologically sourced natural gas can evolve to very low GHG emissions in the future. See section 2 of the paper linked below for details.

https://energycentral.com/c/gn/reasonable-transition

6.4. Microturbines

I researched microturbines ability to burn syngas or hydrogen, and didn't find much, really nothing on syngas. Regarding hydrogen see the link below from a Capstone site. Capstone is (by far) the largest producer of microturbines in the U.S.

https://www.capstonegreenenergy.com/info/news/press-releases/detail/3860/