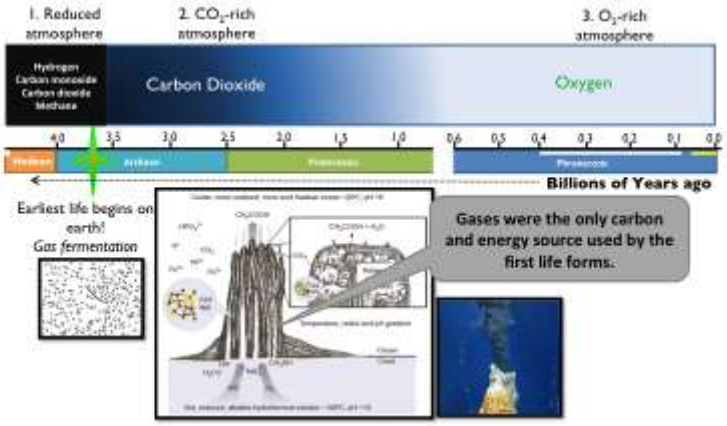
Technical background on the LanzaTech Process

Introduction

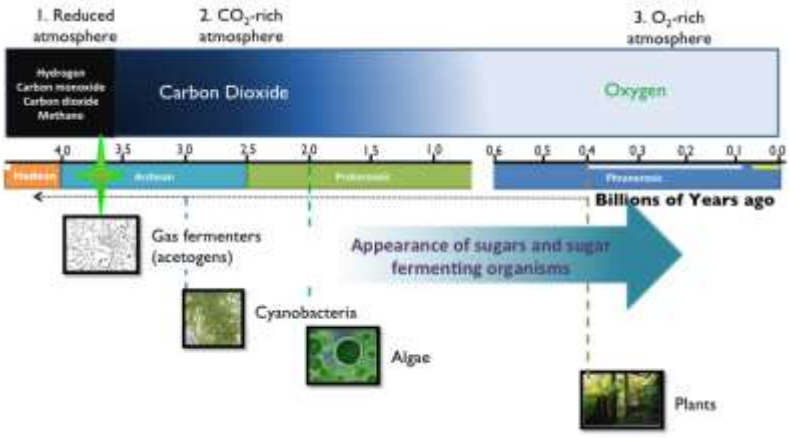
LanzaTech's gas fermentation process is a new approach to reduce CO_2 emissions while producing low carbon liquid fuels and chemicals. The technology to utilize CO-rich gases derived from wastes and residues from heavy industry is ready for immediate implementation across the USA at commercial scale; the first commercial unit is in development in China, to be completed in 2014.

The Origins of Microbial Fermentation

The LanzaTech microbe is a naturally-occurring organism in the family of acetogens, or gas-fermenting organisms. They represent one of the earliest life forms and utilize only gases for their entire life cycle. LanzaTech was founded to take advantage of these organisms to reduce carbon emissions and produce sustainable biofuels.



As can be seen in the timeline below, the biology used by acetogens is ancient, predating that of cyanobacteria or algae.



The natural biology of these microbes allows them to grow using the gas emissions from hydrothermal vents. The process involved is hypothesized to be one of the oldest biological reactions on earth. Ethanol is produced naturally as a part of this process.

Emissions from many industries, including steel manufacturing, are very similar to the gases produced by hydrothermal vents that acetogens grow on in nature.

Gas from both hydrothermal vents and steel manufacture include:

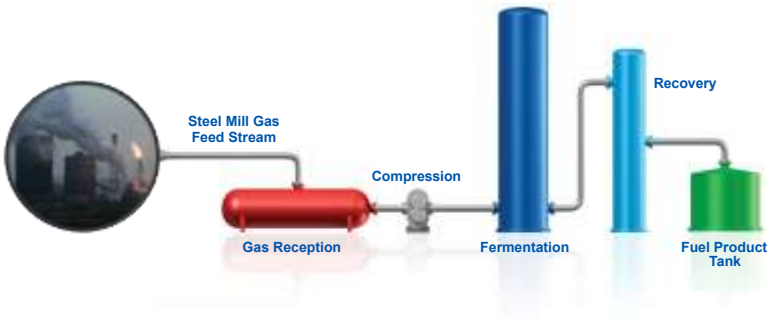
Carbon monoxide (CO)
Hydrogen (H_2)
Carbon dioxide (CO_2)
Hydrogen sulphide (H2S)
Methane (CH_4)

In 2005, LanzaTech's cofounder and Chief Scientific Officer, Dr. Sean Simpson, set out to identify acetogens that could grow on steel mill gas residues and produce useful products.

He identified a promising microbe that had been isolated from rabbit gut and brought it to LanzaTech's laboratories in New Zealand. After an extended period of accelerated natural selection, during which the microbes were repeatedly grown and those that produced the highest levels of ethanol were isolated, a strain was identified that produced sufficient ethanol to be economically sound while still being robust enough to grown on industrial gases. The resulting microbe is not a GMO, rather a natural strain selected to perform optimally with steel mill residues.

Commercial Gas Fermentation

The core of the LanzaTech technology is *gas fermentation* -- that same microbial process that evolved so long ago. LanzaTech microbes grow on gases (rather than sugars, as in traditional fermentation). During gas fermentation, carbon-rich industrial gases such as residues produced during steel manufacture, are transformed into commodity fuel and chemical products in a continuous process, providing a novel approach to carbon capture and reuse.



In the steel industry, carbon is used primarily as a chemical reactant to reduce iron oxide to metallic iron. This is an important distinction from the typical industrial use of carbon as a fuel. While alternative energy sources such as wind and solar can replace fossil fuels, they cannot replace carbon in steelmaking. Thus, the resulting steel-mill waste gases are unavoidable residues of industrial production.

The residual gases produced through this reaction represent the biodegradable fraction of industrial waste and are an inevitable consequence of the chemistry of steel making. They contribute to 5-7% of global CO_2 emissions.

When gas fermentation is deployed in the steel mill, instead of sending a residual gas stream to a flare or power generation unit, it is cooled, cleaned and injected into a fermentation vessel containing proprietary microbes and liquid media. The microbes grow and increase their biomass by consuming $CO/CO_2/H_2$. As a byproduct of this growth, they make ethanol and chemicals that can be recovered from the fermentation broth, similar to the way that yeast make ethanol or other products. The desired fermentation products are separated from the fermentation media and purified for sale as a fuel grade gasoline component and as chemical intermediates.

A unique aspect of the process is the ability to utilize gas streams with a range of CO and H_2 compositions to produce fuels such as ethanol and chemicals such as 2,3-butanediol at high selectivities and yields. While both CO/CO_2 and H_2 are utilized in the LanzaTech process, LanzaTech's proprietary microbes are also able to consume hydrogen-free CO-only gas streams, due to the operation of a highly efficient biological water gas shift reaction occurring within the microbe. This reaction allows the bacteria to compensate for any deficiency in H_2 in the input gas stream by catalyzing the release of hydrogen from water using the energy in CO.

The low temperature, low pressure gas fermentation route benefits from tolerance to a wide variety of impurities and pollutants, eliminating the need for extensive gas clean-up or conditioning. The microbes used in the gas fermentation process convert carbon to ethanol at very high selectivities compared to the conventional chemical synthesis routes. The result is higher overall fuel and thermal efficiency.

Environmental Impact

LanzaTech's bioethanol produced by industrial gas fermentation will contribute to United States goals and the RFS by producing Advanced Biofuels to be blended for transportation sector. Production of bioethanol from US steel mill residues alone could amount to over 15% of the RFS's target of 2.75 billion gallons of advanced biofuels in transport by 2013 without compromising food security or creating direct or indirect land use change. Future platform chemical products represent a form of carbon sequestration, in which carbon is captured and stored in end products such as plastics that are derived from these chemicals. The process at LanzaTech's demonstration facility in China has earned a world-first sustainability certification from the Roundtable on Sustainable Biomaterials (RSB) Services Foundation.

• ***GHG Emissions***	• Up to 70% GHG emissions reduction compared to petroleum fuels on a well-to-wheel basis • Globally, up to 150 M tonnes of CO_2 emissions could be avoided by re-using steel mill gas residues alone
• ***Air Pollutants***	• LanzaTech allows a >85% reduction in particulate matter and NOx compared to CHP
• ***Land Use***	• No use of land beyond plant installation at industrial site
• ***Water Use***	• Process water can be treated and recycled.
• ***Energy Efficiency***	• ~60% superior energy conversion efficiency • In addition, off-gas carbon is captured in useful liquid fuels, rather than used for electrical energy, which could be provided by other means, such as solar, hydro or wind
• ***Sustainability Assessment***	• Roundtable on Sustainable Biomaterials (RSB), Tsinghua University in China and Michigan Tech University in the USA to assess and quantify the environmental impacts, including GHG emissions associated with all stages of the process. • E4Tech, a London based environmental assessment group that has been at the forefront of methodology development, will be maintaining an independent, rigorous approach to LanzaTech's sustainability assessment

Commercialization Status

LanzaTech's process has been demonstrated at pilot-scale since 2008 using waste flue gas streams from the BlueScope Steel mill in Glenbrook, NZ. The first 100,000 gallon /year pre-commercial facility with leading steel producer, Baosteel in Shanghai met and exceeded all production targets in 2012. LanzaTech's second pre-commercial facility using steel mill waste gases is in operation near Beijing with Capital Steel.

The first full scale (>30 million gallon per annum) commercial production facility operating on steel mill gases is expected to be completed by the end of 2014. The projected cost of production is competitive with the lowest-cost bioethanol available today.

In the United States, LanzaTech is also developing a biomass project that will produce the same products using syngas derived from forestry residues.

Products

The current LanzaTech process makes fuel grade ethanol, certified by the American Society for Testing and Materials (ASTM) according to standard D4806-98. Through partner technology, LanzaTech ethanol can be converted to low carbon aviation fuel. Samples of the resulting synthetic jet fuel has been delivered to the US Federal Aviation Administration and the US Air Force Research Laboratory, where it has been demonstrated to meet the specifications of ASTM D7566, the standard specification for Aviation Turbine Fuel containing synthesized hydrocarbons.

LanzaTech is also developing processes that target increased production of chemical co-products such as 2,3-butanediol, which can be converted to butadiene, an important chemical intermediate in production of nylon and synthetic rubber, as well as to other major bulk commodity chemicals such as MEK (methyl ethyl ketone) or in direct use as a specialty chemical.