BIOGAS UPGRADING USING BIOCATALYST TECHNOLOGY

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ABSTRACT

Akermin, Inc. has in collaboration with Novozymes A/S, developed a new biocatalyst-based technology to upgrade biogas and the system has successfully completed testing and demonstration, capturing CO_2 from power plant flue gas.

At the Biofos Wastewater Center in Copenhagen, Akermin, Inc. and HMN Gashandel A/S will demonstrate the new technology at full-scale by building and operating a biogas upgrading system, based on Akermin's biocatalyst technology. The project is funded by the Danish EUDP Programme.

Akermin's proprietary biocatalyst uses "nature's perfect catalyst" – the enzyme carbonic anhydrase - to accelerate CO_2 absorption into a non-volatile, environmentally-friendly solvent. The enzyme is immobilized in a polymer film which is coated on conventional mass transfer devices (packing) that are inserted in the CO_2 absorber column. These polymer films help to protect the enzyme from high pH, temperature and shear forces. This approach not only increases enzyme stability but improves operational performance.

The Akermin system will demonstrate the following benefits:

- CO_2 absorption at ambient pressure reduces capital cost and electrical power consumption for biogas compression.
- Combines an environmentally-friendly biocatalyst with a non-volatile, non-toxic solvent that is resistant to oxygen and impurities.
- Over 40% reduction in steam consumption for CO_2 regeneration at lower temperatures versus systems using amine solvents. The use of low grade reject heat at less than 105°C may reduce steam consumption and operating cost even further.
- High methane recovery (99.9%)
- High process flexibility, able to quickly respond to changes in biogas flow.
- Simple process with reduced requirements for solvent reclamation.

The project is fully in line with the social agenda for using domestic resources from farming and industry in biogas production and makes use of the natural gas grid for distribution and storage of renewable energy.

Lower cost for upgrading biogas will accelerate the use of renewable biogas in the gas grid.

INTRODUCTION

The growth of the world's population and ever increasing demands upon the global ecosystem raise the question of how to balance industrial output and agricultural production with other critical needs such as provision of clean drinking water, management of waste and pollution, and development of renewable energy sources. These issues of critical importance to the future health of our planet have become significant political priorities. Thus, it is not surprising that governmental efforts focus around development of sustainable solutions to produce renewable resources, while managing waste and pollution in an environmentally-friendly manner.

The sustainable management of organic waste has become a key issue. While uncontrolled dumping that results in soil, air and water pollution is now closely regulated in advanced economies, in developing countries the movement is only recently gaining the momentum. The processing of organic waste using anaerobic digestion (AD) to produce biogas is a sustainable and environmentally-friendly solution that reduces pollution while providing a base-load, renewable energy source that can be utilized by society in many ways.

AD is a process where organic waste is broken down, in the absence of oxygen, to produce biogas and digestate. AD occurs naturally in landfills or in manufactured units (digester units). The size of these units can range from small portable units used in developing countries by individual families to very large units that process millions of gallons of organic waste from agricultural residues (straw, manure, etc.), sewage sludge from waste-water treatment plants, separated household waste or other organic waste.

Biogas from an AD typically contains 50-60% methane (CH_4), 40-50% carbon dioxide (CO_2) and much smaller concentrations of other impurities that are dependent upon the waste input. The digestate is a decomposed residue that is rich in minerals. Therefore, subject to waste input and local/regional regulations, the digestate may be reused as a fertilizer by-product. In summary, AD provides an efficient and environmentally-friendly solution to process organic waste, while simultaneously producing a renewable fuel.

Because raw biogas contains a substantial concentration of methane which is a concentrated greenhouse gas (GHG), digestion units dedicated to organic waste reduction are required to flare the methane to minimize GHG emissions to the atmosphere. However, with minimal treatment of the raw biogas, it is possible to combust this methane on-site to produce electricity and heat. Most large digesters are equipped with technology to take advantage of this renewable energy source and offset electricity demand while producing waste heat used to improve digester operating efficiency. The remaining waste heat can be used for local or district heating.

An even more advantageous biogas utilization approach involves 'biogas upgrading'. Under this approach, raw biogas is first treated to remove impurities like siloxanes, and H_2S. Then, in a second step, the CO_2 is removed leaving behind a renewable natural gas (referred hereafter as RNG or 'biomethane') that can be injected into the natural gas grid or compressed to produce a renewable compressed natural gas (CNG) or liquefied natural gas (LNG) for use as a vehicle fuel for cars or trucks. Because RNG offsets the use of a fossil fuel, there is a net reduction in GHG emissions to the atmosphere. In Europe and in some parts of North America, governments have started to subsidize the production of RNG because it is one of the most carbon neutral vehicle fuels available in the market. Estimates such as the one summarized in Figure 1 illustrate the magnitude of the net GHG reduction that is achieved when RNG is substituted for conventional fossil fuels.

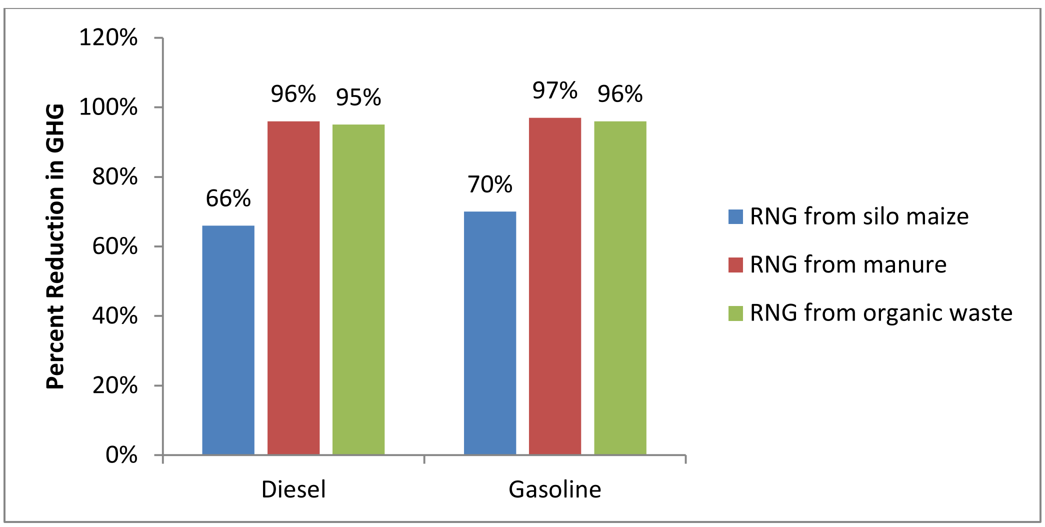

Figure 1. Estimated GHG Reduction for Renewable Natural Gas versus Conventional Fossil-Fuels (Source: Environment Agency Austria)

While exact statistics are not available, there are known to be over 50,000 medium to large size AD units producing biogas world-wide. Over the past 10 years, roughly 275 plants have been placed into operation to upgrade biogas to produce RNG; the vast majority in Germany.[1] However, if all biogas was upgraded to produce RNG, the estimated potential supply (based on today numbers) could exceed 1100 PJ with potential for further growth as new AD units are placed into service.[2] The

[1] IEA Global Database of Biogas Upgrading Units, Month, 2013.
[2] IEA Statistics

World Bioenergy Association estimates that the current RNG potential approaches 36,000 PJ.[3] Current natural gas consumption world-wide is 117 trillion cubic feet (2013)[4]; this is equivalent to around 130,000 PJ. Thus, the potential exists for RNG to replace over 25% of current natural gas consumption.

China has an ambitious target to develop over 16,000 new agricultural and industrial biogas projects by 2020 producing an additional 50 billion m^3 of biogas that is equivalent to 30 billion m^3 (110 PJ) of RNG.[5] As more countries in Europe, North America and Asia create subsidies to incentivize the development of biogas upgrading, the forecasted production of RNG is expected to continue a rapid growth in the medium-term. However, a massive capital investment would be required to develop hundreds of thousands of AD and upgrading units world-wide. To support this level of growth, the industry requires reductions in the capital and operating cost of producing RNG. There are a number of areas where costs can be reduced (e.g., standardization of grid monitoring and injection requirements, aggregation of organic waste materials to leverage economies of scale, improved digestion efficiency, etc.) However, one of the largest costs in the supply chain is the upgrading step where the CO_2 is separated from the treated biogas; this step can comprise roughly 20-30% of the total cost. So, with an obvious focus on sustainability, the market needs new technologies that create energy-efficient and environmentally-friendly solutions to reduce the cost to upgrade biogas to RNG.

PROJECT ENZUP

Project ENZUP (www.enzup.com) is a DKK 42 million ($7 million US), three-year demonstration project for biogas upgrading that is roughly 50% funded through a grant from the Danish Energy Agency (EUDP). The partners for this project include:

- **Akermin**, a company based in St. Louis, Missouri, USA that is using a multi-discipline approach to produce an Industrial Biocatalyst that can be incorporated into conventional processes for CO_2 removal. Akermin is responsible for providing the upgrading unit process design, production and supply of the Industrial Biocatalyst and technical support to the Project.
- **Ammongas A/S**, a Danish engineering company with significant experience in the design of process technology for gas separation will design and supply the upgrading system. Ammongas will provide technical support during project construction and commissioning.
- **Biofos A/S**, a municipal owner/operator of three waste-water treatment plants that service the City of Copenhagen and surrounding areas; the project will be located at their Avedore plant.
- **The Dansk Gasteknisk Center A/S (DGC)** will be responsible for coordinating site testing and developing the subsequent technical and economic analyses to establish commercial viability.
- **HMN Gashandel A/S (HMN)**, the commercial part of HMN Naturgas I/S, is Denmark's biggest operator of natural gas distribution. HMN will lead the Project and oversee the construction and operation of the facility.
- **Novozymes** is a world leader in bio innovation and production of commercial enzyme products for use across a wide variety of applications. Novozymes is responsible for development and scale-up of enzyme used in the production of Akermin's Industrial Biocatalyst.

The goal of the project is to demonstrate the benefits of Akermin's biocatalyst technology for biogas upgrading and support Denmark's objective to develop new technology to produce a sustainable, cost-effective, grid-quality RNG that will offset combustion of fossil fuels and reduce GHG emissions to the atmosphere. This facility will produce grid-quality, RNG that will be injected into HMN's distribution network. The unit is scheduled to operate for two years as a demonstration project and hereafter on commercial basis.

The project will be constructed at the Biofos waste-water treatment plant which cleans roughly one-third of the waste from the city of Copenhagen, Denmark (Figure 2). The organic waste is processed in an environmentally-friendly manner using large digesters to produce biogas and a digestate product that is easily disposed. The biogas, which is comprised primarily of methane and CO_2, is presently combusted to produce electrical power and heat used in the digesters and buildings. This

[3] World Biogas Fact Sheet, World Bioenergy Association, 2014
[4] US Energy Information Administration, International Energy Outlook, 2013
[5] 8. B.Raninger etal..Biogas to grid in China: challenges and opportunities of a new market from industrial large scale biogas plants" in "Biogas Engineering and Application, volume 2. Bejing 2011.

project will produce up to 2.6 million cubic meters per year (250,000 cubic feet per day) of grid quality RNG. When this facility commences operations in the 2nd quarter of 2015, this is expected to be the largest demonstration of a biocatalyst used to remove CO_2 from an industrial gas stream anywhere in the world.

Figure 2. Biofos Waste-Water Treatment Plant Located in Copenhagen, DK (the anaerobic digester units are located in the center of the photo)

BIOGAS UPGRADING USING AKERMIN'S INDUSTRIAL BIOCATALYST

Akermin's technology uses enzymes to produce a proprietary Industrial Biocatalyst that can be readily incorporated into conventional chemical absorption processes for CO_2 removal. By addressing the key issue of enzyme stability in harsh industrial environments, Akermin's environmentally-friendly approach to CO_2 removal significantly reduces capital and operating costs for owners and operators of industrial facilities.

Enzymes as Biological Catalysts in Industrial Processes

Enzymes are proteins that catalyze chemical reactions. They work by lowering the reaction activation energy, thereby increasing the rate often by many orders of magnitude. Enzymes are remarkably fast, selective and environmentally-benign biocatalysts used in a variety of industries including the chemical, pharmaceutical, food, and textile sectors to increase process efficiency and lower production costs.

Akermin has focused its research efforts on developing efficient and economic enzyme-based alternatives to conventional formulated solvents that incorporate chemical promoters (typically primary and secondary amines). The promoters, while improving the efficiency of capturing CO_2, also increase capital requirements and operating and maintenance costs.

One class of enzymes particularly useful in biogas upgrading is carbonic anhydrases (CAs), which convert CO_2 and water to bicarbonate:.

$$CO_2 + H_2O \xrightleftharpoons{\text{Carbonic Anhydrase}} H^+ + HCO_3^-$$

Akermin is using developmental versions of recombinant, highly active, and thermostable CAs available from major enzyme suppliers. The enzymes have good expression and are manufactured using conventional fermentation processes.

Enzyme Immobilization and Stabilization

Carbonic anhydrases are fast acting catalysts with k_{cat} values up to 10^6 s^{-1}. However, despite their appeal, the high temperature of the stripping column has presented major challenges in utilizing soluble enzyme in a typical absorber/stripper configuration. To overcome the problem of the protein inactivation in the stripper there have been several efforts to immobilize CA on the absorber side of the reactor, thereby preventing the enzyme from being exposed to the high temperature stripping process. These efforts have included covalent immobilization onto solid supports, as well as entrapment and cross-linking within polymer coatings, Such approaches have suffered from poor enzyme retention, loss of enzymatic activity upon immobilization, and increased diffusional barriers. Akermin has developed an immobilization strategy that overcomes the aforementioned limitations.

A key component of Akermin's solution is immobilization and stabilization techniques that deliver the biocatalyst to the immediate vicinity of the gas-liquid interface in the absorber column. By concentrating the biocatalyst at the critical point in the CO_2 absorption process, Akermin takes full advantage of the enzyme's ability to accelerate CO_2 capture.

Benefits of the Industrial Biocatalyst

Akermin's Industrial Biocatalyst enables the use of non-volatile, carbonate-forming solvents which, without an enzyme, absorb CO_2 at a rate that is far too slow to have any practical use, but otherwise have outstanding physical properties. By addressing this key limitation, the Industrial Biocatalyst enables an environmentally-friendly solution for removing CO_2 from biogas with the following benefits:

- Combines an environmentally-friendly biocatalyst with a non-volatile, non-toxic solvent that is resistant to oxygen and impurities.
- CO_2 absorption at ambient pressure reduces capital cost and electrical power consumption for biogas compression.
- Over 40% reduction in steam consumption for CO_2 regeneration at lower temperatures versus systems using amine solvents; allows low grade reject heat at less than 105^{o}C to be used to further reduce steam consumption and operating cost.
- High methane recovery (99.9%)
- High process flexibility, able to quickly respond to changes in biogas flow.
- Simple process with reduced requirements for solvent reclamation.

Akermin has conducted extensive research and development (R&D) over the past several years to continuously improve the performance of the Industrial Biocatalyst to achieve high rate enhancement factors working with different solvents that have kinetic limitations but exhibit many other positive attributes. These research and development activities have focused on establishing and demonstrating extended biocatalyst performance, tolerance to impurities (including H_2S) and the technology to successfully and reliably deploy the Biocatalyst within a chemical absorption process. Studies performed with third-party engineering firms have demonstrated the benefits of using a biocatalyst-enhanced process across different applications.

Akermin has successfully developed two approaches to deploy the Biocatalyst in chemical absorption systems:

- In the first generation design, the Biocatalyst was coated on the packing material in the CO_2 absorber column. This allowed the Biocatalyst to accelerate CO_2 absorption while using a conventional approach for CO_2 desorption.
- In Akermin's second generation design, the Biocatalyst is deployed as microparticles suspended into the solvent. The benefits of the second generation design include even better acceleration of CO_2 capture, the reduced biocatalyst requirements, the flexibility of replacing the biocatalyst *in situ* (i.e. on-line without taking the unit out of service) and the ability to scale-up and manufacture the biocatalyst using conventional equipment.

Akermin's second generation design uses an advanced process flow scheme and a proprietary carbonate-forming solvent (AKM-24) to further reduce energy consumption and capital and operating costs.

Technology Validation

Under a project funded by the US Department of Energy National Energy Technology Laboratory (DOE/NETL Cooperative Agreement No. DE-FE0004228), Akermin performed a long-term test of Akermin's first generation design in a continuous, lab-scale reactor. This test commenced in November 2011 and continued for over one year demonstrating a superb long-term performance. The results of these laboratory tests were used to support a second phase of this project where Akermin successfully installed and operated a field pilot plant at the National Carbon Capture Center (NCCC) in Wilsonville, AL (see photo). The attached chart provides capture data from 3,500 hours of testing, capturing CO_2 from flue gas from a coal-fired power plant using two different solvents. For a portion of the testing, the flue gas was diluted with air to simulate flue gas from a natural gas combined cycle power plant (~4% CO_2). Over the course of the testing, the pilot operated with 99% availability, minimal observed degradation of performance and no replenishment of biocatalyst. Disruptions in the power plant operations did not affect pilot performance.

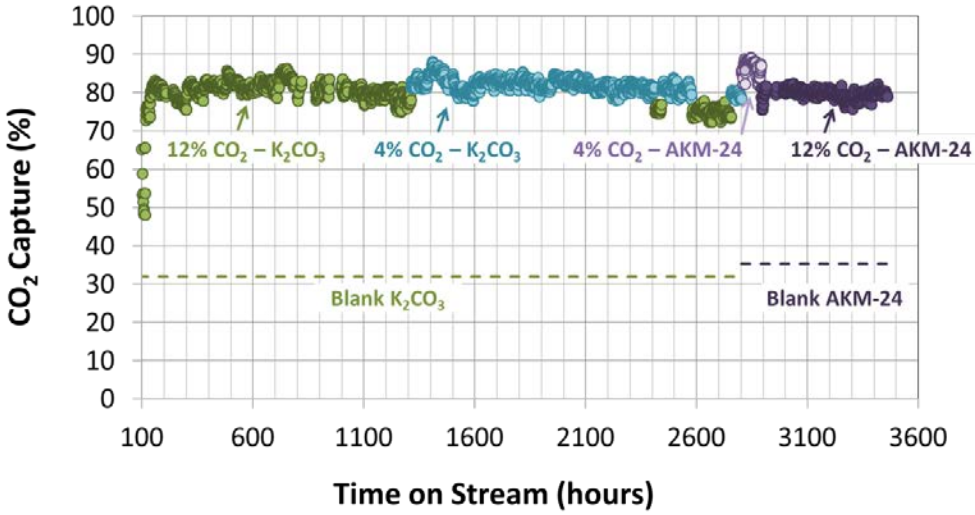

Figure 3. Akermin Field Pilot Plant Installed at the National Carbon Capture Center in Wilsonville, AL and Long-Term Data for CO_2 Capture

The key results from the field pilot testing at NCCC include:

- Significant acceleration of CO_2 capture using immobilized CA in the absorber
- ~80% capture using both K_2CO_3 and AKM-24 carbonate solutions
- 3,500 hours online with 99% availability
- Negligible heat stable salts accumulation
- Minimal corrosion
- Over 99.9% purity of CO_2 product
- Near zero aerosol formation

Akermin was awarded a second DOE grant last year to develop and pilot test the second generation design using microparticles with the AKM-24 solvent. This project commenced in October 2014. So far Akermin has designed a bench-scale unit (Figure 4) for testing the second generation design. The results of this and extensive laboratory and field testing have been incorporated into dynamic, rate-based simulation models to predict unit performance to develop the process design for the upgrading unit for Project ENZUP.

Figure 4. Bench-scale Closed Loop Reactor at Akermin's Research and Development Facility

Novozymes' Enzyme Technology

The enzyme which will be used for Project ENZUP is a thermo-stable carbonic anhydrase of microbial origin developed by Novozymes. Novozymes enzymes are produced by fermentation in non-toxigenic, non-pathogenic microorganisms which are removed from the enzyme-containing liquid preparation before final processing and delivery.

The developmental enzyme product is being supplied in amounts that match the project scale-up requirements, while allowing for developmental adjustments to ensure efficient performance in Akermin's Industrial Biocatalyst. The excellent performance of this enzyme within Akermin's field pilot trial demonstrates its readiness for evaluation in a larger scale demonstration.

PROJECT DESCRIPTION AND DESIGN

Figure 5 provides a process flow scheme for the proposed project.

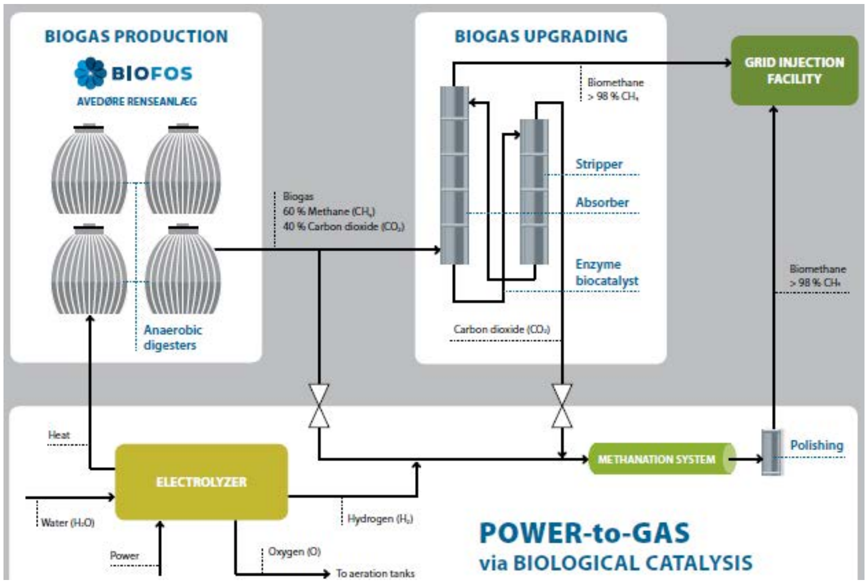

Figure 5. Process flow scheme of Project ENZUP and adjacent Power to Gas Project.

Figure 6 provides an aerial view of the Biofos waste-water treatment plant. The upgrading unit for Project ENZUP will be located in the area shaded in red (4). Raw biogas from the four AD units (1) is pumped into the temporary storage tank (2). From there, the raw biogas is cooled and conditioned to about 60% to 70% humidity at 15°C. Siloxanes and H_2S are removed using a packed bed sorbent reactor (3) that contains an activated carbon material. Oxygen will be added to partially oxidize the hydrogen sulfide gas to elemental sulfur, which subsequently becomes trapped within the carbon bed. Oxygen flow will be trimmed until H_2S is in the desired range of 1.7 to 1.84-ppmv (dry basis) upstream of the upgrading.

In the upgrading unit (4), CO_2 is separated from the low sulfur biogas feed using chemical absorption in a gas-liquid contacting tower filled with structured packing. A non-volatile and non-toxic solvent (AKM-24) enhanced with Akermin's Industrial Biocatalyst is circulated throughout the system. The feed gas blower operates to provide a constant gas supply pressure (2 Bara) at the bottom of the absorber. An inlet vane damper attached to the blower is adjusted to achieve the desired feed gas flow rate. Biogas flows upward in the absorber in counter-flow relative to a downward flowing capture liquid that continuously absorbs CO_2 from the biogas. Upon exiting the absorber, the treated RNG stream is piped to near ground level where the gas is transferred across the technical boundary limit at approximately 40°C. The saturated RNG undergoes further compression, drying and conditioning (5; shaded green) to between 4 and 5 barg. From there, the RNG is transported via pipeline to the nearest connection to HMN's distribution grid for sale to local customers.

On the other side of the Compression and Drying unit, a separate demonstration project (shaded blue) will take the pure CO_2 stream from the Akermin upgrading unit and use a technology supplied by the company Electrochaea to convert the CO_2 into RNG through the microbial transformation of carbon dioxide and hydrogen to methane. So, instead of emitting the CO_2 into the atmosphere, the CO_2 from the upgrading facility can be used to increase production of RNG without additional biomass feedstock.

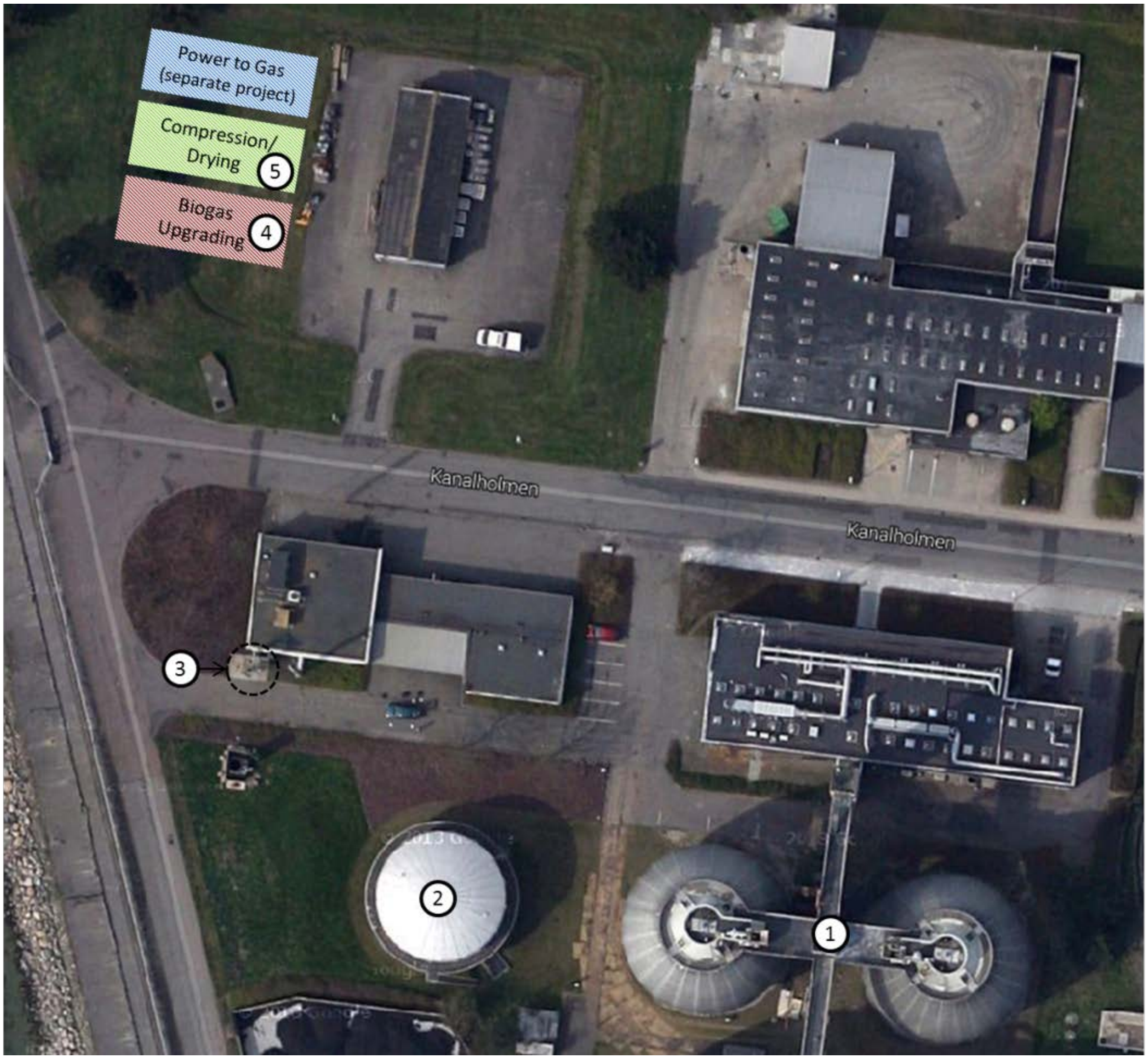

Figure 6. Aerial View of Biofos Waste Water Treatment Facility

The specified feed gas flow rate for the design of the upgrading unit is 500 Nm^3/hr. (dry basis equivalent, and excluding H_2S flow). However, because the biogas is received at 20°C and saturated at 1013 mbar (absolute), or 2.31% moisture, and could contain up to 780-ppm H_2S, the adjusted design raw biogas flow to the upgrading unit is 512.2 Nm^3/hr.

To support project design, digester gas samples were collected and analyzed in April 2013 by DGC. The bulk gas analysis is presented in Table 1 below on a dry basis.

Digester Gases (vol. %)	Tank-1	Tank-2	Tank-3	Average
CH_4	58.07%	59.50%	60.42%	59.33%
CO_2	41.50%	40.11%	39.33%	40.31%
N_2	0.36%	0.30%	0.16%	0.27%
O_2	0.011%	0.010%	0.011%	0.011%
H_2S	0.049%	0.072%	0.078%	0.066%
H_2	0.007%	0.005%	0.006%	0.006%
Total	100.0%	100.0%	100.0%	100.0%

Table 1. Bulk gas composition (dry basis) as reported by DGC for various digester tank samples

Based upon the results of this analysis, the design basis gas composition at the BTU boundary limits was defined as the feed gas to the H_2S sorbent unit before any auxiliary oxygen addition:

- *Maximum* Carbon dioxide (CO_2) concentration: 40.31% (dry basis); i.e., average reported in Table 2.
- *Maximum* sulfur in feed gas: 780 ppmv (dry basis), or 1186 mg/Nm^3 (dry).
- *Maximum* oxygen (O_2) concentration (before auxiliary oxygen addition): 0.012% (dry basis);
- *Maximum* total air diluents (N_2 + Argon + O_2) as fed to H_2S sorbent unit: 0.38% (dry basis);
- *Minimum* Methane (CH_4) concentration for design purposes (as fed to the H_2S sorbent unit): 59.22% CH_4 (dry basis); which is the net of all other gas constituents specified with exception of siloxanes.
- *Maximum* Siloxanes concentration assumed to be less than 0.5 mg/Nm^3 total, removed by others upstream of the technical battery limit using best available control technology.
- Optionally, a *maximum* of 37 mg total siloxanes/Nm^3 gas would be specified if siloxane removal is to be required within the design scope of the biogas treating unit.

The facility has an existing filter that uses activated carbon to remove siloxanes and H_2S. In order to ensure that the CO_2 off gas from the upgrading unit meets environmental requirements and reliable operation of the upgrading unit, Akermin requires that the H_2S be removed to low levels (< 4ppm). To meet this H_2S specification, oxygen must be injected to partially oxidize the H_2S to elemental sulfur. There are two options to provide this oxygen; inject pure oxygen or inject air. Air injection is less expensive and thus preferred by the Partners. The downside of air injection is that further concentrations of Nitrogen and CO_2 are added to the treated biogas. The upgrading unit does not remove nitrogen nor oxygen so the total rate of air injection must be limited to ensure that the RNG meets specification requirements for nitrogen and oxygen. To meet the specification for total inerts and Wobbe Number, additional CO_2 must be separated in the upgrading unit.

Akermin defined two cases around unit performance; a minimum "perform to" requirement and "design to" requirement. These design basis assumptions are used to develop a mass and energy balance per the minimum performance condition and the design condition:

Design Basis Case:

- Max 98.5% CO_2 capture at design basis flow and composition.
  - 1.0% CO_2 (dry basis) in treated gas stream
- >99.764% H_2S removal at design basis flow and composition.
  - Max: 4.63 mg H_2S/Nm^3 (dry basis) in treated gas stream
- Methane (CH_4): 98.0% CH_4 when using design basis gas composition.
- Oxygen (O_2): nominally 0.35% O_2 per design, but not more than 0.48%.
- Wobbe Number: 51.76 MJ/Nm^3 per design performance, but not less than 50.81 MJ/Nm^3.
- Biomethane product: 302 Nm^3/hr. (dry basis).

Minimum Performance Case:

- Minimum 97% CO_2 capture at design basis flow and composition.
  - Yields 2.0% CO_2 (dry basis) in treated gas stream
  - Assumes *maximum* 40.31% CO_2 (dry basis) in feed gas.
- 99.764% H_2S removal at design basis flow and composition.
  - Yields 4.58 mg H_2S/Nm^3 (dry basis), but not more than 4.63 mg H_2S/Nm^3 (dry basis).
  - Assumes *maximum* 1186 mg/Nm^3 (dry) or 780 ppmv H_2S in feed gas.
- Minimum methane (CH_4) treated gas: 97% CH_4.
  - Assumes *minimum* 59.2% CH_4 in feed gas
- Oxygen (O_2): nominally 0.34% O_2 per design, but not more than 0.48%.
- Wobbe Number: 50.82 MJ/Nm^3, but not less than 50.81 MJ/Nm^3.
- Biomethane product: 305 Nm^3/hr. (dry basis).

The estimated performance for these two cases is further summarized in **Table 2** below:

	Biogas (dry basis) (Feed to activated carbon filter)		Oxygen Add to SRU (if needed)		Absorber Feed Gas (After ACF)		Treated Gas Design Basis: 98.5% CO2 Capture		Treated Gas Min Performance: 97% CO2 Capture	
Components	v/v	**Nm^3/hr**	v/v	**Nm^3/hr**	v/v	**Nm^3/hr**	v/v	**Nm3/hr**	v/v	**Nm^3/hr**
Net CH_4	59.29%	296.47			59.16%	296.47	97.99%	296.47	97.03%	296.47
Ave CO_2	40.31%	201.60			40.23%	201.60	**1.00%**	3.02	**1.979%**	6.05
Max N_2 + Ar	0.368%	1.84	79.1%	0.91	0.548%	2.75	0.91%	2.75	0.90%	2.75
Max O_2	0.0120%	0.060	20.9%	0.240	0.052%	0.263	0.09%	0.26	0.09%	0.26
Max H_2S	**0.0150%**	0.075			0.000184%	0.00092	0.00030%	0.00	0.00030%	0.00092
Ave H_2	0.006%	0.030			0.01%	0.03	0.01%	0.03	0.01%	0.03
Totals (dry basis)	100.0%	**500.08**		**1.15**	100.0%	**501.11**	100.0%	**302.54**	100.0%	**305.56**
Total (dry and H2S free)		**500.00**								
H_2S ppmv (dry basis)	**150**				**1.84**		3.05		3.02	
H_2S (mg/Nm3 dry)	228				2.80		**4.63**		**4.59**	
Total O_2 (mol%)	0.012%				0.052%		0.087%		0.086%	
Total air diluents (N_2, Ar, O_2):	0.380%				0.60%		1.00%		0.99%	
Gas MW_mix (kg/kmol)	27.34				27.33		16.39		16.66	
HHV_mix (kJ/kmol)	23.56				23.51		38.94		38.56	
Wobbe Number (MJ/Nm^3)	24.25				24.20		**51.78**		**50.84**	

Table 2. Design Basis Gas Composition and Minimum Performance Goals

The CO_2 product gas will be delivered at the system boundary at approximately 30°C and saturated at 0 barg. The CO_2 product will be > 99.8% pure (dry basis).

PROJECT SCHEDULE

As of the writing of this paper, the project is currently in the detailed design phase. Akermin has developed the basic process design package that has been provided to Ammongas. The Project Schedule is defined per **Figure** 7 below. The project is currently on schedule to commence commercial operations starting July 1, 2015.

Figure 7. Schedule for Project ENZUP