

Swedish Biogas Industry Education Tour 2004: Observations and Findings





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CALSTART Swedish Biogas Industry Education Tour Report

June 7 – 11, 2004

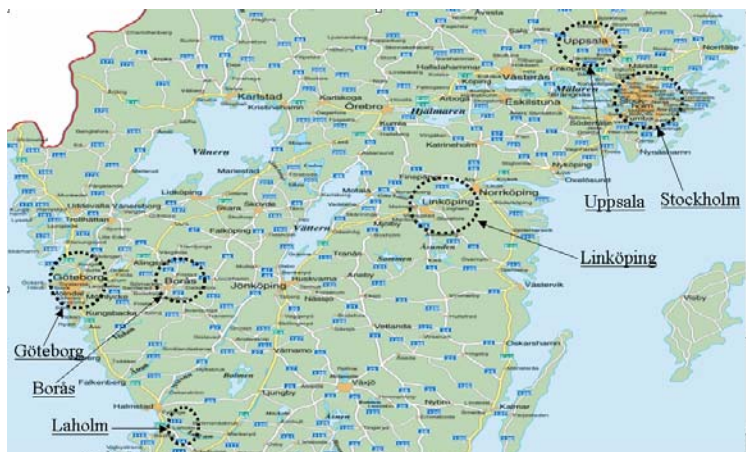
Overview

On June 7 – 11, 2004, WestStart-CALSTART, with support from the Federal Transit Administration (FTA), led a group of eight representatives from the California biogas industry on an educational tour of the Swedish biogas industry. The group represented a cross-section of business, university, non-governmental organizations (NGOs) and government officials, including a Commissioner from the California Energy Commission (CEC). The purpose of the tour was to learn from the experiences of the Swedish biogas industry, with particular emphasis on the use of biogas as a vehicle fuel, and determine which parts of the Swedish model could be applicable to the currently less advanced biogas industry in California and the rest of the US.



Over the last decade, Sweden has become the world leader in the usage of biogas as a renewable fuel for transportation applications. Sweden currently has approximately 4,500 natural gas vehicles (NGVs) including most municipal transit buses in the major cities. Today approximately 45% of the fuel for these vehicles comes from biogas and 55% comes from natural gas (NG). The refueling infrastructure currently consists of 24 biogas refueling stations and 20 NG refueling stations. While biogas currently accounts for less than 1% of the annual consumption of transportation fuel in Sweden, biogas production capacity, the number of vehicles operating on biogas and biogas refueling station infrastructure are all increasing rapidly. By 2020, there are projected to be approximately 200,000 vehicles operating on biogas and 150 biogas refueling stations. Estimates indicate that approximately 20% of Sweden’s annual transportation fuel needs could eventually be met by locally produced biogas.

During the course of the week-long tour through the southern part of Sweden, the group traveled to Göteborg, Laholm, Borås, Linköping, Stockholm and Uppsala. In total, the group visited five biogas facilities and met with many organizations representing various aspects of the Swedish biogas industry including:





- municipal authorities
- NGOs
- energy providers
- biogas technology providers
- biogas plant operators
- farmers
- waste haulers
- biogas distributors including refueling station owners and operators
- transit fleet operators
- biogas/NG vehicle and bus original equipment manufacturers (OEMs)
- universities performing biogas research
- government agencies involved with energy, transportation and environmental protection.

The biogas plants visited encompassed a wide variety of technologies and business models including successful co-digestion of multiple types of organic wastes, multiple gas upgrading technologies and distribution options including injection of upgraded gas into the NG pipeline network. Briefings and presentations were held in coordination with site visits to biogas plants and other facilities to explain the technology, economics and other factors contributing to the success of the Swedish program as well as lessons learned from problems encountered during startup, etc. By examining the full range of biogas-related activities from production to consumption, the group gained a much clearer understanding of the coordination of activities necessary between diverse stakeholders in order for such a system to be effective and economically viable.

Major Findings

While the concept of using biogas as vehicle fuel is not new, it has never been successfully implemented in the US to the extent that it has in Sweden. The key findings below are those areas that were considered critical to the success of the Swedish program and which were either significantly different or lacking in previous attempts to encourage the use of biogas for transportation applications in the US:

- Government Support - Startup and continuing government support has played a critical role in the development of the Swedish biogas industry. Government commitment to reductions in greenhouse gases (GHGs) and an increased usage of non-fossil fuels has resulted in flow-down support for municipal biogas programs.
- High Level of Cross-Industry Cooperation – There is an extremely high level of cooperation between the different industries involved with biogas including agriculture, waste hauling, biogas technology, national and municipal government, biogas distribution, transit authorities, energy providers, vehicle manufacturers and consumers among others. The Biogas Väst Program overseen by Business Region Göteborg (BRG) is an excellent example of how all these organizations have been successfully coordinated.
- Co-digestion of Multiple Waste Streams – Use of co-digestion technology to successfully digest multiple types of organic waste simultaneously is one of the



key technological areas in which the Swedish biogas industry is significantly more advanced than the digester technology currently used in the US. Use of multiple feedstocks presents significant opportunities to increase digester output and efficiency and improve the biogas business case.

- *Biogas Upgrading Technology* – Multiple biogas upgrading technologies are in use in Sweden today. While some biogas upgrading technologies have been demonstrated in the US, they have not been widely used or successfully commercialized.
- *Biogas Distribution Systems* – Multiple possibilities for biogas distribution have been successfully demonstrated in Sweden. These distribution options include dedicated biogas pipelines between biogas plants and biogas refueling stations, injection of “partially cleaned” biogas into “town gas” pipeline networks for residential use, multiple options for over-the-road transportation of compressed biogas, and injection of upgraded biogas into the national NG pipeline network.
- *Bi-fuel Vehicles* – Bi-fuel vehicles (vehicles using either compressed natural gas or gasoline as fuel) have limited availability in the US. In Sweden, however, bi-fuel vehicles with no significant compromises in functionality or performance are commercially available and have helped greatly in expanding the market for NGVs to private individuals.
- *Transit Buses as “Anchor Customers” for Biogas Plants* – In Sweden, municipal transit bus fleets designed to operate on compressed natural gas (CNG) typically act as the “anchor customers” for new biogas plants. Transit buses are excellent candidates for biogas consumption due to their high fuel usage, fixed routes and centralized refueling facilities.

Areas for Future Research

The following areas were considered technically noteworthy and are recommended for further investigation in future efforts related to biogas, energy efficiency, emissions reductions, and other environmental aspects of the transportation industry:

- *Effect of Pasteurization on Methane Yield* – Swedish research has shown that digestion of pasteurized animal by-products (typically accomplished by heating the waste to 70°C for one hour) yields four times more methane than non-pasteurized animal by-products due to increased access to lipids (fats) after heat treatment. If similar results can be obtained by pasteurization of other types of lipid-rich waste, this may prove to be a simple, effective method for dramatically increasing the potential methane yield associated with digestion or co-digestion of many types of biomass feedstocks.
- *Electric-Powered Hydraulic Compaction for Refuse Trucks* – There is currently a demonstration project in Sweden involving hybrid refuse trucks with separate power sources for propulsion vs. trash compaction. The fleet of 15 vehicles uses a CNG engine driven by biogas for propulsion and a separate hydraulic trash compaction system that uses an electric battery pack as its power source. This separation of propulsion and compaction power sources eliminates the need to



idle the propulsion engine during compaction (thus reducing fuel consumption and emissions), and greatly reduces noise during compaction, a significant benefit to both operators and the community.

- *Water-Based Hydraulic Fluid for Refuse Trucks* – There is currently a demonstration project in Sweden involving replacement of the normal hydraulic oil in the compaction system with an environmentally friendly water-based hydraulics fluid. Using a mixture of water, anti-freeze and anti-corrosive agents, early results indicate equivalent performance from the non-petroleum-based hydraulic fluid. This technology has the potential to contribute to a reduction in the use of petroleum-based products in the trucking industry, as well as problems associated with the disposal of used hydraulic oil.
- *Horizontal Digging Vs. Trenching* – In Sweden, horizontal digging has been shown to reduce pipe-laying costs by up to 75% compared to conventional trenching methods. This technology may have a significant impact on the economics associated with biogas distribution in future biogas projects.

Next Steps

1. The Swedes have been very open and willing to share information with the US. We should continue to build on the relationships already established with the Swedish biogas industry and leverage their knowledge and experience to help establish a successful biogas industry in California and the rest of the US.
2. The economic, regulatory and political conditions affecting the viability of producing biogas for vehicle fuel in Sweden are significantly different than in the US. A critical next step is to establish an economic framework such that potential biogas projects in the US can be evaluated.
3. The biogas industry in the US is typically limited to gas production at waste water treatment plants, landfills, and to a lesser extent, via on-farm digestion of livestock waste, with the vast majority of the methane gas produced used for heat and electric power generation. Industry and government agencies are not fully aware of the enormous potential for biogas production including co-digestion and upgrading to vehicle and/or pipeline quality fuel. In order to spur development of the biogas industry, this information needs to be further disseminated to key stakeholders in the US. One way to accomplish this could be by arranging conferences where representatives of the Swedish biogas industry present their technology and experiences to their counterparts in the US.



Biogas Tour Briefing Notes

The notes are broken up by presentations at each of the site visits and are given in the following order:

1. Göteborg Biogas Program including Volvo Perspective
2. Laholm Biogas Plant
3. Borås Biogas Plants (Sobacken and Gässlösa)
4. Linköping Biogas Plant and SWECO Meeting
5. Meetings at Swedish Environmental Protection Agency (EPA)
6. Uppsala Biogas Plant

June 7 - Briefings in Göteborg (1 of 8)

- **Bernt Svensén, Biogas Väst Project Manager, Business Region Göteborg**

Highlights:

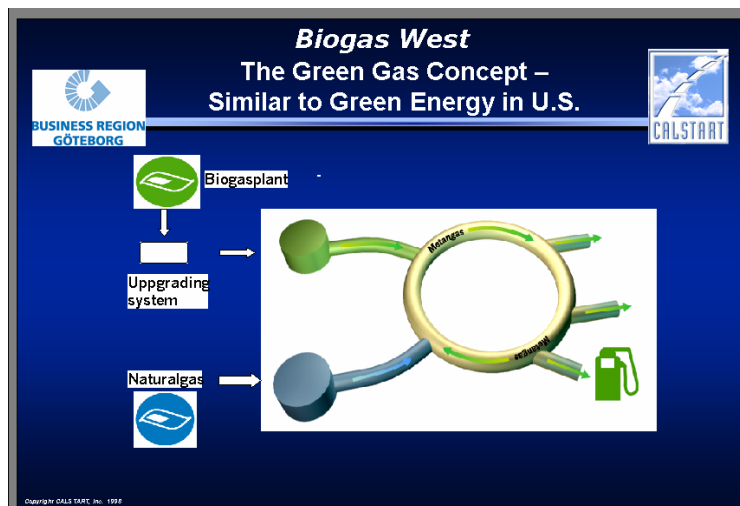
- Sweden focusing on alternative fuels to increase energy security and reduce greenhouse gases (GHGs) in accordance with Kyoto Protocols.
- Biogas Väst project is a joint cooperative effort between municipalities, businesses and other agencies to promote production, distribution and usage of biogas as a vehicle fuel.
- In Göteborg and the surrounding areas in western Sweden, there are currently 2,300 vehicles that can use CNG/biogas as a fuel and 18 CNG/biogas refueling stations. By 2007, this is expected to rise to 7,000 vehicles and 35 refueling stations.
- Eventually Sweden plans to move towards a “green gas” concept where biogas is injected directly into the national NG pipeline network and can be used to supply NGVs and bi-fuel vehicles at distributed biogas refueling stations.
- It is estimated that local biogas production could potentially supply up to 20% of Sweden’s transportation fuel needs.

Day 1 began with formal introductions and a number of presentations given at Business Region Göteborg’s (BRG’s) offices in Göteborg.

Biogas Väst (Biogas West) is a joint project between diverse stakeholders in western Sweden to promote the production, distribution and use of biogas as a transportation fuel. Business Region Göteborg (BRG) is the project manager for the Biogas Väst project and has done an impressive job of coordinating activities throughout the chain from biogas production to distribution and consumption. Over the past decade, NGV and bi-fuel vehicle use has been steadily rising. Today there are 2,300 NGVs and bi-fuel vehicles and 18 CNG/biogas refueling stations in western Sweden. By 2007, this is expected to rise to 7,000 vehicles and 35 refueling stations.

The Green Gas Concept.

While there are currently multiple methods used for distribution of biogas, the long-term goal is to inject upgraded, vehicle fuel quality biogas into the national NG pipeline network. Biogas refueling stations connected to the NG grid at remote locations will then be able to deliver the biogas to vehicles as needed. Since the biogas is mixed with the NG in the NG pipeline network, in practice, the actual fuel delivered to a vehicle will be a





combination of biogas and NG. The quantity of biogas added to the NG grid is considered “green gas” (i.e. gas generated from renewable sources) and will be available for purchase at refueling stations at relatively lower prices than NG because it is not subject to so-called “CO₂ taxes”. This is similar to the “green energy tags” associated with the sale of energy produced from renewable sources such as wind and solar in the US.

The primary drivers for the development of Sweden’s biogas industry have been the government’s commitment to reducing GHGs in accordance with the Kyoto Protocols as well as a strong desire to reduce their dependence on foreign energy suppliers. (Note that Sweden does not have any domestic sources of oil or NG.) Sweden has committed to using 2% biofuels for its transportation sector by 2005 with the figure rising to 5.75% by 2010 and 8% by 2020. It is estimated that local biogas production could potentially supply up to 20% of Sweden’s transportation fuel needs.

Other Advantages of Biogas. Other incentives for use of biogas vs. fossil fuels include:

- Reduced emissions of criteria pollutants such as NO_x, hydrocarbons and particulate matter resulting in reduced impacts on health and the environment.
- Biogas production is a by-product of a sustainable waste treatment system whereby organic waste is converted to energy and the resulting digestate is used as biofertilizer.
- Adoption of gaseous fuels like biogas is a step towards a future hydrogen-based technology and infrastructure.



June 7 - Briefings in Göteborg (2 of 8)

- *Anders Roth, Environmental Manager, Traffic Authority, City of Göteborg*

Highlights:

- Göteborg is creating a role model for environmentally sustainable transportation that it hopes other cities will follow.
- The city of Göteborg has created a program to promote and encourage the use of biogas and other clean vehicle technologies through the use of tax incentives, environmental fees, regulations, procurement policies, information campaigns and other incentives.
- The clean vehicle program in Göteborg has been very successful. 27% of the municipal bus fleet (300 buses) currently operates on biogas, 50% of municipal fleet vehicles are clean vehicles, and 2-3% of all new vehicle purchases in Göteborg are clean vehicles.

The traffic authority in the city of Göteborg has worked closely with the Biogas Väst project to create incentives to encourage the use of biogas by public fleets including municipal buses, private fleets and personal vehicles. The goal of the city of Göteborg is to create a model for sustainable transportation that other cities can follow.

City of Göteborg's Environmental Transportation Program. Incentives for "clean vehicles" (including NGVs and bi-fuel vehicles) include:

- Free parking
- Priority bays for clean taxis
- Annual environmental fees for non-clean vehicles
- Required percentage of new clean vehicle purchases for municipal fleets
- Clean vehicle usage by suppliers considered in bids for public contracts
- Clean vehicles required for public transport
- Prohibition on use of old, heavily polluting trucks in inner city
- Information on clean vehicles supplied to fleet owners, individuals and dealers
- Joint website (www.miljofjordon.se) with Stockholm and Malmö to provide information about biogas, vehicles, filling stations, costs, taxes/incentives, etc.

The program in Göteborg has been very successful. Today 27% of the 300 municipal buses in Göteborg use biogas and the percentage is increasing. 50% of all municipal fleet vehicles in Göteborg are currently clean vehicles and the goal for 2008 is 90%. In Göteborg, 2 – 3% of all new vehicles sold today are clean vehicles and the goal for 2008 is 5%. In addition, there are no longer any trucks older than 10 years old used in the city center.



June 7 - Briefings in Göteborg (3 of 8)

- *Ola Ståleby, Renova*

Highlights:

- The city of Göteborg is considering a biogas plant to generate biogas from the organic fraction of municipal solid waste. The upgraded biogas would be injected directly into the NG grid and sold as vehicle fuel at remote refueling stations connected to the NG grid. (Currently the Laholm biogas plant is the only place in Sweden where biogas is injected directly into the NG grid.)

Renova is the largest waste hauler in Göteborg and the surrounding area. Renova is currently performing a biogas feasibility study for the city of Göteborg. The proposed biogas plant would inject upgraded biogas directly into the NG grid and be distributed to vehicles via refueling stations connected to the NG grid (this is the “green gas” concept previously described by BRG).

Biogas Feasibility Study for City of Göteborg. Renova is examining the following aspects of a proposed biogas plant in Göteborg:

- Input feedstocks
- Market for biogas output
- Market for biofertilizer output
- Biogas plant design
- Biogas plant economics

Inputs – 35 tons/year of source-separated household waste collected from 13 municipalities in the Göteborg region. Waste will be optically sorted when received at biogas plant (similar to waste receiving stage at Borås biogas plant). Private households incentivized to source-separate waste via lower fees for collection of separated waste. Some industrial waste likely to be co-digested but they believe it may be difficult to obtain this waste due to competition from competing waste processing options.

Market for biogas output – Biogas output is projected to be approximately 27 GWh/year (equivalent to approximately 2.7M liters diesel). The market for biogas as vehicle fuel in the Göteborg region is considered to be very good due to the success of the biogas promotion efforts in the area. The upgraded biogas will be injected into the NG grid (with the addition of a small amount of propane to raise the heating value of the biogas). The biogas refueling stations in the Göteborg region are connected directly to the NG grid where customers will be able to purchase less expensive “green gas” for their vehicles.

Market for biofertilizer output – Biofertilizer output is projected to be approximately 28K tons biofertilizer/year. There are sufficient farmlands in the Göteborg region to constitute a reasonable market for the biofertilizer however the biofertilizer needs to be certified for organical purity which can present problems. In addition, the economic value of the biofertilizer is not high.

Biogas plant design – Details were not given however the block diagram of the proposed plant (unfortunately an English version was not available) shows household waste and



additional solid and liquid organic waste received trucked in to the plant. Household waste is optically sorted and the organic fraction is mixed with the additional solid and liquid organic waste. The mixture is pasteurized, digested and upgraded (no specific technologies were discussed, perhaps they have not been decided yet. Some percentage of propane is added to the upgraded biogas to upgrade its calorific value prior to injecting the biogas into the NG grid. The digestate is de-watered and liquid and solid components are trucked away separately, presumably for land application at local farms.

Biogas plant economics – Projected costs for the proposed biogas plant are approximately USD \$20M capital costs with annual operating costs of USD \$1.8M (9% of capital costs).

June 7 - Briefings in Göteborg (4 of 8)

- *Niklas Gustavsson, Manager of Governmental Affairs and Environmental Issues, Volvo Car Corporation*

Highlights:

- Volvo Car has been making bi-fuel vehicles since 1996 and is a long-time supporter of the Biogas Väst project.
- The high cost of gasoline in countries like Germany and Sweden is the main driver behind the sale of bi-fuel vehicles. Note that biogas is significantly less expensive than gasoline in these countries.
- Volvo's bi-fuel vehicles are impressive and exhibit no compromises in functionality or performance.
- Bi-fuel vehicles are not currently sold in the US where the price of fuel is still too low for bi-fuel vehicles to make economic sense.
- Bi-fuel vehicle sales account for < 1% of the annual European vehicle sales.

The presentations by Volvo Car and Volvo Bus (AB Volvo) took place at Volvo Cars' Torslanda facility in Göteborg.

Volvo Car Perspective on Bi-fuel Vehicles. Volvo Car has been making bi-fuel vehicles (vehicles that can use both gasoline and CNG/biogas as fuel) since 1996 and is a major partner in the Biogas Väst project. Bi-fuel vehicles are currently only sold in Europe with Germany and Sweden as the biggest markets. The major driver for bi-fuel vehicles is the high cost of fuel in these markets. In Germany, CNG is less than half the price of gasoline and there is significant government support to expand the CNG refueling infrastructure. According to Volvo, CNG is the only alternative fuel that can be type-certified in Europe (*not sure if they meant CNG vehicles vs. CNG fuel*).



Bi-fuel Vehicle Performance. Bi-fuel vehicles operate on CNG/biogas as the default fuel with an automatic switchover to gasoline when the vehicle runs out of CNG/biogas. However since vehicles also include a manual switchover, it's possible to run the vehicle purely on gasoline. The range of the Volvo light duty passenger vehicles is approximately 150 miles with CNG and an additional 150 miles using the gasoline backup. In addition, the CNG tanks are now located underneath the vehicle so there is no loss of cargo space. The main advantage of bi-fuel vehicles is CO₂ emissions reductions of 25% (CNG) or 100% (biogas) when operating in CNG/biogas mode.

There was a ride and drive opportunity showcasing Volvo bi-fuel vehicles. The vehicle I drove impressed me with its level of comfort and performance with no apparent compromises in functionality or performance.



Bi-fuel Vehicle Market. There are approximately 50K bi-fuel vehicles sold each year in Europe compared to annual vehicle sales of 30M vehicles, i.e. bi-fuel vehicles are < 1% of the European vehicle market.

June 7 - Briefings in Göteborg (5 of 8)

- **Peter Danielsson, Manager, Environment Development, AB Volvo**

Highlights:

- AB Volvo is the largest producer of heavy duty drive systems in the world.
- Volvo believes that the incremental costs of heavy duty CNG vehicles such as transit buses are still too high, especially the CNG fuel storage tanks.
- CNG transit bus sales in Europe account for only about 400 – 450 vehicles/year compared to approximately 1,000/year in the US.
- Biofuel interest in Europe is driven by EU commitments to GHG reductions and increased energy security.
- There is increasing interest in dimethyl ether (DME), a gaseous fuel similar to LPG, as the future biofuel of choice in Europe and Japan whereas the US has shown more interest in Gas-to-Liquid (GTL) fuels.

This presentation took place at Volvo Cars' Torslanda facility in Göteborg. AB Volvo includes Volvo Trucks, Mack, and Renault Trucks. Volvo is the largest producer of heavy duty drive systems in the world with Detroit Diesel Corporation (DDC) and Cummins #2 and #3 respectively.

Volvo Bus Perspective on NGVs. Volvo Bus (which operates primarily in Europe) did not appear to be as enthusiastic about biogas or the market for heavy-duty CNG vehicles. Volvo pointed out that the energy density of CNG is 1/3 that of diesel and a typical CNG fuel storage system for a transit bus costs about USD \$25K. (Note that there have been some preliminary experiments with leasing CNG fuel tanks in Europe as opposed to selling them as part of the vehicle.) Volvo did mention, however, that drivers like the quieter NG engines compared to the loud diesel engines.

After the presentation there was a ride and drive of a Volvo CNG/biogas bus which was scheduled to be delivered to the Göteborg municipal transit bus fleet. It was an articulated 60 foot bus, modern, comfortable and quiet during operation – overall a very pleasant riding experience. An interesting technical aspect of the CNG engine was that it was a 6-cylinder, *horizontally mounted engine* (see pictures below).



CNG Transit Bus Markets. The US transit bus market is approximately 5K vehicles/year, about 20% of which is CNG. For Europe, the figures are approximately 8 – 9K vehicles/year and 5% CNG.



Bio-fuels. The driving force behind bio-fuels in the European Union (EU) is CO₂ credits and it appears likely that bio-fuel legislation will emerge in the near future. Today 50% of Europe's energy is generated internally. It is estimated that due to increased energy demands, only 30% of Europe's energy will be generated internally in 2020. This could potentially lead to an even greater reliance on imported energy and consequently less energy security, a situation that the EU would like to avoid by developing local renewable energy sources. Europe doesn't have enough extra land to grow energy crops (e.g. wheat to make ethanol) and importing energy crops is expensive.

There is increasing interest in DME (dimethyl ether) as the potential biofuel of choice in Europe and Japan compared to the US which is more interested in Gas-to-Liquid (GTL) technology. DME is a gaseous fuel that liquefies at 5 bar and room temperature. It has an energy density of approximately 60% of diesel however engines will need to be redesigned to accommodate its usage.



June 7 - Briefings in Göteborg (6 of 8)

- **Bo Ramberg, Managing Director, Fordonsgas Väst**

Highlights:

- Raw biogas is injected into Göteborg's "town gas" grid (separate from the NG grid) for residential use (primarily for cooking). The same quantity of NG is then made available for purchase at non-taxed "green gas" prices at refueling stations in Göteborg connected to the NG grid.
- The main biogas refueling station in Göteborg is capable of refueling approximately 70 transit buses/night.
- CNG/biogas transit buses have a range of approximately 500 km (300 miles).
- Biogas is about 30% cheaper than gasoline in Sweden, partially due to the fact that biogas as a renewable transportation fuel is not taxed.
- Fordonsgas Väst has been in the business of selling biogas for almost a decade and has always been profitable.

Later that day there was a site visit to a large biogas refueling station at Falutorget in Göteborg. The site visit included a tour of the refueling station, a demonstration of Renova's biogas refuse trucks and several presentations.

Fordonsgas Väst owns and operates a number of biogas refueling stations in Göteborg and the surrounding area and is one of the key stakeholders in the Biogas Väst project.

Mixing of Biogas with "Town Gas" in Göteborg. In the Göteborg area, "raw" biogas (perhaps with minimal removal of water and impurities) is mixed into the "town gas" pipeline network where it is used primarily for cooking on natural gas stoves. The same quantity of biogas injected into the "town gas" grid is then made available for purchase as "green gas" at local refueling stations connected to the NG pipeline network. This is similar to the "green energy" purchase concept in the US. Hence the NGVs being refueled in Göteborg are actually being filled with CNG, not compressed biogas.

Biogas Refueling Station. The biogas refueling station at Falutorget was the first CNG refueling station in Göteborg. In addition to public refueling facilities, it is also the main biogas refueling station for Renova's garbage trucks and the city's municipal CNG transit bus fleet. The city of Göteborg's municipal CNG transit bus fleet is the "anchor customer" for the biogas refueling station. The station sells 2.5M liters³ biogas/year to transit



buses (and Renova's biogas refuse trucks?) and 0.5M liters³ biogas/year to private vehicles. The buses (and refuse trucks?) are refueled at night (8 hours) whereas the public refueling facilities are open 24 hours/day. Total refueling station capacity is 1100 m³/hr which corresponds to a typical refueling of approximately 70 buses overnight. In fast-fill mode, a bus can typically be refueled in about 10 minutes. Station backup storage is 4,000 liters³ biogas at



250 bar as a backup when demand is high or maintenance is being performed on the compressors, etc.

CNG Transit Buses. There are about 100 CNG transit buses in Göteborg but not all buses must be refueled each night. The energy storage on board the transit buses is 150/200 m³ at 200 bar for a single/articulated bus giving a range of about 500 km (300 miles).

Business Case. Biogas as a vehicle fuel is not taxed by the Swedish government, a fact which contributes significantly to the overall biogas business case. Fordonsgas Väst sells biogas at about 30% less than gasoline. Compressed Biogas (CBG) is approximately USD \$3.50/gasoline gallon equivalent (GGE) compared to current gasoline prices in Sweden of approximately USD \$5.00/gallon. Fordonsgas Väst guarantees their prices for 3 years via contracts which is another advantage to fleet customers. Fordonsgas Väst was started in 1995 and has always been profitable. Last year they had revenues of approximately USD \$7M and had a profit margin of 10%.

June 7 - Briefings in Göteborg (7 of 8)

- **Lars Thulin, Fleet Manager, Renova**

Highlights:

- Renova is the largest waste hauler in Göteborg and the surrounding area.
- Approximately 40% of Renova's 125 refuse trucks are currently operating on biogas.
- Renova has 15 "electric hybrid" refuse trucks with a unique, non-propulsion on-board battery pack to provide electric power for hydraulic trash compaction. These vehicles also have a built-in anti-idling feature which turns off the engine 30 seconds after the driver has gotten out of the vehicle.
- Renova has replaced the hydraulic oil in four of their "electric hybrid" refuse trucks with a water-based solution showing positive preliminary results.

Renova is the largest waste hauler in Göteborg and the surrounding area and is one of the key stakeholders in the Biogas Väst project.

Fleet Composition. Renova's fleet is broken down by engine type (CNG vs. diesel) and power source for hydraulic compaction (battery pack vs. diesel engine).

- 125 refuse trucks total
- 15 CNG/biogas with electric-powered hydraulic compaction ("electric hybrid")
- 33 CNG/biogas with CNG/biogas-powered hydraulic compaction
- 77 diesel with diesel-powered hydraulic compaction



Electric-Powered Hydraulic Compaction. For the vehicles with electric-only compaction, the CNG engine automatically shuts off 30 seconds after the driver gets out of the vehicle. 100% of the power for the hydraulic trash compaction is provided by an on-board battery pack. (Note that the battery pack does not provide propulsion power.) The battery pack is charged while driving and at night by plugging into an electric outlet (similar to a plug-in hybrid concept). It can also be charged from an on-vehicle power take-off (PTO) as a backup charging source with power supplied by the vehicle engine.



Water-Based Hydraulic Fluid Demonstration. Four of Renova's CNG refuse trucks are involved in a technology demonstration project using a water-based hydraulics system. In these vehicles, the oil in the hydraulic system has been replaced by a mixture of 77% water, 20% anti-freeze and 3% anti-corrosive agents. Results so far appear promising. The motivation for replacing the hydraulic water is both economic and environmental (40 tons of hydraulic oil must be disposed of annually in Sweden).



June 7 - Briefings in Göteborg (8 of 8)

- **Carina Bergsten, Head of Gas Department, Göteborg Energi**

Highlights:

- Göteborg Energi is the local electric/gas energy provider in Göteborg.
- Göteborg Energi buys raw biogas from the municipal waste water treatment plant and mixes it into the Göteborg “town gas” grid (max. 40% biogas) which primarily supplies gas to residences for cooking. This is the only example in Sweden where raw biogas is injected into a “town gas” grid.
- Göteborg Energi sells “green gas” credits to Fordonsgas Väst, allowing them to sell an equal amount of CNG from the NG grid as “green gas” for vehicle fuel.
- Göteborg Energi is planning a new biogas upgrading plant in Göteborg to upgrade raw biogas and inject it directly into the NG grid.
- There are no taxes on biogas in Sweden. The greatest tax advantages are gained by selling biogas to replace NG in heating and vehicle fuel applications.

Göteborg Energi is the local electric/gas energy provider in Göteborg and the surrounding area.

Role of Göteborg Energi. Göteborg Energi owns the Göteborg “town gas” grid. They currently purchase about 45 GWh of biogas annually from Gryaab, the Göteborg waste water treatment plant. The raw biogas is mixed into the “town gas” grid where it is primarily used in residences for cooking on NG stoves. Göteborg Energi sells “green gas” credits associated with the biogas to Fordonsgas Väst which allows them to sell a corresponding amount of CNG fuel from the NG grid to their customers as “green gas”. Since biogas is not taxed by the Swedish government, “green gas” can be sold to customers at a lower price than NG.

The “town gas” is a mixture of approximately 50% methane and air. The percentage of raw biogas in the “town gas” grid is limited to a maximum of 40% in order to maintain the necessary gas quality for appliances. Note that Göteborg is the only place in Sweden where raw biogas is injected into the “town gas” grid.

Future Plans. Göteborg Energi is planning to build a biogas plant to upgrade additional biogas from Gryaab and inject it into the NG grid. (Gryaab is planning to increase its biogas production to 60 GWh.) At the moment, Laholm is the only place in Sweden where upgraded biogas is injected into the NG grid.

Göteborg Energi is also considering selling biogas to customers for use in home heating due to the favorable tax situation regarding biogas vs. NG for heating applications.

Tax Situation. Biogas is not taxed in Sweden, unlike NG which is a non-renewable, fossil fuel. As can be seen in the table at the right, the greatest tax advantages are gained from the sale of biogas to replace NG for heating and vehicle fuel applications.

	Natural Gas (\$/kWh)	Biogas (\$/kWh)
Heating	0.027	0
Electric Power	0.0036	0
Vehicle Fuel	0.013	0

June 8 - Briefings in Laholm (1 of 7)

- *Pål Börjesson, Associate Professor, Ph.D, Lund University*

Highlights:

- Lund University is investigating optimization of anaerobic digester designs for both on-farm and large scale operations.
- Methane losses must be minimized (e.g. < 1 – 2%) during biogas upgrading in order to preserve system reductions in GHGs.
- With proper pre- and post-treatment waste handling and agricultural processes, the indirect environmental benefits of using biogas can be greater than the direct benefits in emissions and GHG reductions.

Day 2 was spent visiting the Laholm biogas plant about 2 hours south of Göteborg. After being welcomed by Jan Gustavsson, the Mayor of Laholm, there were several presentations followed by a tour of the biogas plant.

Lund University is one of the top universities in Sweden and is very active in environmental research. Pål Börjesson is an associate professor in Environmental and Energy System Studies in the Department of Technology and Society.

Research Areas. Lund University is conducting biogas research in 3 areas:

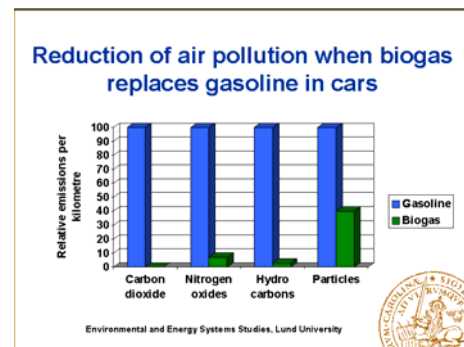
- Biogas processes
- Biogas conversion
- Biogas systems analysis

Biogas Processes. Lund University is investigating digester design optimization, real-time process monitoring and feedstock composition. The digester designs include both on-farm and large scale operations. Since capital costs are typically more than 80% of the total costs of a biogas plant, improving yield through in-line monitoring of pH, alkalinity, temperature, etc. can have a large payoff.

Biogas Conversion. Using biogas as a transportation fuel is potentially worth about 10x using the biogas for heating and even more for power generation. Hence reducing the cost of biogas upgrading is a high priority.

Biogas Systems Analysis. There are significant direct environmental benefits when biogas replaces gasoline in vehicles. However by properly addressing the handling of organic wastes and other agricultural processes, the indirect environmental benefits (including reductions of GHGs and pollutants) can be even larger than the direct benefits. Minimizing the loss of methane during the biogas upgrading process is a critical factor in retaining the GHG reduction benefits of using

biogas as a vehicle fuel since methane is 21x more reactive GHG than CO₂. Note that losses can typically be limited to less than 1 – 2% with today's technology.





June 8 - Briefings in Laholm (2 of 7)

- *Roland Gottfridsson, Laholm Plant Manager*

Highlights:

- The Laholm biogas plant is the only biogas plant in Sweden which injects upgraded biogas into the NG grid.
- The biogas plant co-digests pig/cow manure and industrial (slaughterhouse) waste. The industrial waste is very important both economically (due to tipping fees) and to increase methane production (due to its high fat content).
- The biogas plant has a profit margin of about 14% on sales of upgraded biogas to Sydkraft, the local natural gas provider.

The Laholm biogas plant is currently the only biogas plant in Sweden where upgraded biogas is injected directly into the national NG distribution grid.

Biogas Plant Operation. The Laholm biogas plant receives about 150 m³ of manure and industrial waste/day with about 10% solids content. The composition of the waste is:

- 33% pig manure
- 27% cow manure
- 40% slaughterhouse waste

The digester produces approximately 60 m³ raw biogas (70% methane)/m³ waste resulting in a raw gas output flow rate of 400 m³/hr. Following biogas upgrading (separate presentation), a small amount of propane is added to the upgraded biogas to raise its heating value to meet NG pipeline requirements prior to injecting the biogas into the NG grid. The final upgraded biogas output flow rate is about 350 m³/hr.

Swine and cow manure are trucked to the plant from 20 farms located within a 5 –10 km radius of the plant. Biofertilizer and liquid effluent produced by post-treatment of the digestate is trucked back to the same farms for land application. Per European digester standards, all waste must be minced to 12 mm in diameter or less prior to being added to the input mixing tank.

Industrial waste is often trucked in from considerably further distances, e.g. 50 – 100 km. In addition to receiving tipping fees for accepting industrial waste, the high fat content of the waste raises the percentage of methane in the raw gas output.

Some of the key operational parameters and equipment capacities of the biogas plant are given below:

- Mixing (input) tank: 700 m³
- Pasteurization tanks: 2 x 30 m³
- Pasteurization time: 1 hour at 70°C
- Digester tanks: 2 x 2200 m³
- Hydraulic detention time: 21 days at 35°C (mesophilic)
- Output tanks: 700 m³ + 2000 m³

Plant Economics. The plant pays for manure and biofertilizer transportation however these costs are partially offset by the tipping fees the plant receives for accepting industrial waste. Other costs include operating costs for digestion and upgrading and depreciation of capital equipment. Total costs are about \$0.29/m³ of upgraded biogas and revenues from sales of the upgraded biogas to Sydkraft, the local NG provider, are about \$0.33/m³, giving a profit margin of close to 14%. It is interesting to note that without the tipping fees for accepting industrial waste, the biogas plant would not be profitable.

Biogas Plant Tour. The major components of the biogas plant include a receiving hall with an underground mixing tank, 2 pasteurization tanks, 2 digestion tanks, 2 output tanks for the raw biogas, a small shed holding the biogas upgrading equipment, and tanks to hold the digestate and liquid effluent outputs. Plant personnel emphasized that a “smell plan” to control odors was a key element of the overall biogas plant design.



June 8 - Briefings in Laholm (3 of 7)

- *Rune Simonsson, Director of Energy Department, Malmberg Waters AB*

Highlights:

- Biogas upgrading at Laholm is based on Selexol technology for CO₂ absorption. Incoming gas is 70% methane and output gas is 97% methane.
- A small amount of propane (8%) is added to the upgraded biogas to increase its Wobbe index (heating value) prior to injecting the biogas into the NG grid.
- The cost of the biogas upgrading equipment at Laholm was \$1.2M. Biogas upgrading costs are approximately \$0.16/ m³.

At the end of the Laholm biogas plant tour, Malmberg Waters gave a brief explanation of the biogas upgrading equipment.

Malmberg Waters is a major Swedish manufacturer of energy system solutions including biogas refineries and refueling stations. Malmberg Waters was responsible for the design and installation of the biogas upgrading equipment at the Laholm biogas plant.

Biogas Upgrading Equipment Operation. The biogas upgrading equipment at Laholm is based on using Selexol (glycol) as the CO₂ absorption agent. The incoming gas is 70% methane and the output is 97% methane. The CO₂ is then removed from the Selexol in a desorption column by forcing a stream of air through the Selexol at an appropriate pressure and temperature. (Note this is where most of the methane losses occur.)



In addition to CO₂ removal, the upgrading equipment also includes a secondary H₂S removal stage where H₂S levels are brought down from 200 – 2000 ppm to less than 50 ppm. (H₂S production is also limited by the addition of manganese to the slurry in the mixing tank.) Prior to injecting the upgraded biogas into the NG grid, it is dried (dewpoint reduced to approximately - 50°C), 8% propane is added to increase the Wobbe index (heating value) of the gas to meet NG pipeline requirements and it is compressed to 4 bar (standard NG distribution pipeline pressure).

Economics. The incoming gas capacity is approximately 500 m³/hr and the output capacity is approximately 350 m³/hr. Total cost of the biogas upgrading equipment was \$1.2M. Biogas upgrading costs are approximately \$0.16/m³. The Selexol technology is somewhat outdated and there are cheaper, more efficient technologies available today.

June 8 - Briefings in Laholm (4 of 7)

- *Lars-Gunnar Johansson, LRF (Federation of Swedish Farmers)*

Highlights:

- Swine manure flushed from pens daily and stored in concrete holding tank.
- “Crust” on top of manure combined with cold weather limit methane production and escape while manure is in holding tank.
- Liquid manure pumped out periodically (e.g. 1 – 2x/month) and delivered to biogas plant.
- Liquid effluent returned to farmer for land application as fertilizer.
- Farmers satisfied with manure/fertilizer exchange and their role in biogas production.

Following the Laholm biogas plant tour, there was a brief visit to a local swine farm to discuss the farmer's role in the biogas system.

LRF is the Federation of Swedish Farmers, an agricultural industry organization representing many of the farmers in Sweden.

Swine Farm Visit. On the swine farm, the manure is flushed from the pens daily and travels by gravity down through underground pipes to a 300 m³ concrete manure holding tank. The liquid manure enters from the bottom of the tank such that the hard “crust” formed on top of the manure in the tank remains intact. The crust and the cold weather limit the production and release of methane while the manure is in the holding tank. The contents of the manure tank are pumped out as needed (typically every 1 – 4 weeks) and the tanker truck transports the liquid manure to the biogas plant. Since the tanker truck only holds about 30 m³, it typically takes several trips to empty the manure holding tank. The farmer has a separate tank to hold the effluent that is delivered back to him for later use as a liquid fertilizer. The particular farmer we talked with seemed quite satisfied with the whole system.





June 8 - Briefings in Laholm (5 of 7)

- *Staffan Ivarsson, Director of Gas Development, Sydkraft*

Highlights:

- The Swedish NG pipeline network currently extends from Malmö to Göteborg with plans to expand to Stockholm and central Sweden.
- Sydkraft currently owns 14 CNG refueling stations and is in the process of expanding their network significantly. By 2008, they anticipate that 10 – 25% of their CNG vehicle fuel sales will come from biogas.
- European regulations require that biogas producers be allowed access to the NG grid provided that the biogas meets national gas quality standards.
- Sydkraft uses a mobile gas storage trailer concept capable of holding 2400 m³ at 300 bar to transport and supply CNG to public CNG refueling facilities.

After lunch there were several additional presentations at Sydkraft's facilities in Laholm.

Sydkraft is the largest energy provider (including electricity and NG/biogas) in southern Sweden.

Swedish NG Network. The Swedish NG pipeline network currently extends from Malmö to Göteborg (both in southwestern Sweden) with plans to expand to Stockholm and eventually central Sweden. NG is imported to Sweden by pipe from the Danish part of the North Sea. (Note that Sweden does not have any NG reserves itself and hence all of the NG it uses must be imported.) Sydkraft is actively working to develop the NG/biogas market in Sweden.

Swedish CNG Market. Sydkraft owns 14 CNG refueling stations in southwestern Sweden which provide fuel for approximately 1,150 vehicles. By 2008, they plan to increase CNG vehicle fuel sales by 400% with 10 – 25% coming from biogas and expand their CNG refueling station network significantly.

Biogas Development. Sydkraft owns and operates the biogas upgrading equipment at Laholm and 4 other locations. Laholm is the only location where upgraded biogas is injected into the NG grid, specifically the low pressure (4 bar) NG distribution grid. Upgraded biogas is not injected into the high pressure (80 bar) transmission grid because it would be too costly to increase the pressure of the biogas.

Biogas Regulations. EU Directive 98/30/EG in 2003 (referred to as the Gas Directive) requires that biogas be allowed full access to the NG grid provided that the national specifications for gas quality are met. The Swedish national specifications for gas quality (SS 15 54 38) require >97% methane content but this is not consistent throughout the EU.

Biogas Refueling. Sydkraft has formed a partnership with a national gas station chain ("OKQ8") to colocate CNG dispensers with gasoline/diesel dispensers for public





refueling of CNG vehicles. Sydkraft uses a modular compressor concept coupled with mobile storage containers with a capacity of 2400 m³ at 300 bar to transport and supply CNG to public refueling stations. (The mobile storage containers consist of 100 80-liter CNG tanks connected in parallel in a trailer.) The baseline capital costs to provide CNG refueling at an existing public gasoline/diesel refueling station are approximately \$250K for the dispenser, compressor and storage equipment.

Sydkraft also owns and operates filling stations for transit buses in Malmö. They use a slow fill system with a fixed amount of pressure such that the time to fill a bus is dependent on how many buses are being filled simultaneously.





June 8 - Briefings in Laholm (6 of 7)

- *Owe Jönsson, Project Manager, Research & Development, SGC (Swedish Gas Institute)*

Highlights:

- SGC has been developing hythane (HCNG) – a blend of hydrogen (H₂) and NG – as an alternative to CNG.
- The benefits of HCNG compared to NG or biogas include reduced emissions, better fuel efficiency and a way to gradually introduce H₂ into the transportation refueling infrastructure. In addition, HCNG blends of up to 8% H₂ can be used in CNG engines without modifications. The primary obstacle to using HCNG is the cost of generating the H₂.
- H₂ is created via electrolysis at a HCNG refueling station in Malmö. The electrolysis unit is powered by electricity generated from wind power.

SGC (the Swedish Gas Institute) is a Swedish organization performing gas technology research and development, similar to the Gas Technology Institute in the US.

Hythane (HCNG) Development. SGC has been developing hythane (HCNG) as an alternative fuel since 1995. Hythane is a mixture of hydrogen and natural gas used in CNG engines without modifications (max. 8% H₂). SGC has experimented with HCNG transit buses operating on 8% and 25% blends of H₂. The benefits of HCNG compared to NG and biogas are:

- Decreased NO_x and CO emissions
- Reduced fuel consumption
- One step closer to future widespread use of hydrogen as a transportation fuel

The primary obstacle to the use of HCNG today is the cost to create H₂.

HCNG Refueling Station. HCNG refueling station in Malmö generates H₂ by hydrolysis from renewable electricity. Hydrolysis unit capable of generating 36 m³ H₂/hour at either 25 bar or 10 bar. Energy usage by the hydrolysis unit is 3.9 kWh/ m³ H₂ and is generated by wind power at the refueling station.



June 8 - Briefings in Laholm (7 of 7)

- **Peter Boisen, Chairman, European Natural Gas Vehicle Association (ENGVA)**

Highlights:

- Key drivers for biogas production in Europe include needs for environmentally sustainable waste handling, reductions in GHGs, decreased dependence on imported oil and building a pathway to a hydrogen future.
- Landfilling of organic waste will be prohibited in Europe starting in 2005. This is another driver for increased interest in anaerobic digestion of organic waste.
- It is estimated that on average, most countries in Europe could supply approximately 25% of their vehicle fuel needs from biogas.
- Sweden and Switzerland are currently the only countries in Europe using biogas for vehicle fuel.

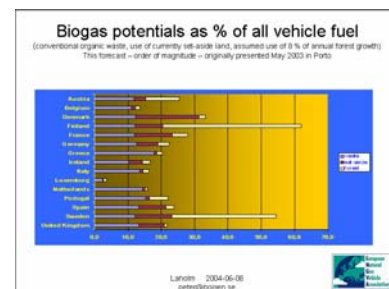
ENGVA is a major industry organization promoting NGVs in Europe.

Why Biogas? The primary drivers for biogas production in Europe are:

- Efficient use of biomass sources to produce energy
- Environmentally sustainable waste handling
- Gradual phasing out of nuclear power
- Minimize GHG emissions
- Energy security

There is increasing pressure in Europe to eliminate landfilling and instead use composting and incineration or anaerobic digestion to generate energy from waste. (Note that landfilling of organic waste will be banned in Europe starting in 2005.) Independence from imported oil is also a concern for the EU as sources of oil in the North Sea begin to dry up.

Biogas Potential in Europe. There was a discussion of the hypothetical potential of biogas to supply the vehicle fuel needs of various European countries. Biomass sources considered included waste, set-aside land (which could be used to grow energy crops) and forestry by-products. Countries like Finland and Sweden with large forested areas scored highest in biogas potential with more than 50% of vehicular fuel needs potentially met by biogas. It is estimated that on average, most countries in Europe could potentially supply about 25% of their vehicle fuel needs from biogas. In Europe today, however, only Sweden and Switzerland are currently using biogas for vehicle fuel.



Pathway to Hydrogen. NG and biogas are seen as pathways to a hydrogen future since both are gaseous fuels. Reforming NG or biogas is considered the most economical way to produce H₂ in the short run and small reformers could be efficient at refueling stations.

June 9 - Briefings in Borås (1 of 2)

- **Anders Assarsson, Head of Sanitation Department, Borås Municipality**
- **Jöran Eriksson, Chief Engineer, Sobacken & Gässlösa Biogas Plants**

Highlights:

- There are two biogas facilities in the municipality of Borås. At the first facility in Sobacken, the organic fraction of municipal solid waste (MSW), restaurant organic waste and slaughterhouse waste are treated via anaerobic digestion. The resulting raw biogas is then piped 7 km to the second facility at Gässlösa where it is combined with raw biogas from the waste water treatment plant and upgraded to vehicle fuel. Some of the upgraded biogas is piped to a nearby refueling station for municipal transit buses and the remainder is piped back to Sobacken and used to refuel the municipal refuse truck fleet.
- The system for treatment of the organic fraction of MSW relies heavily on source separation of household waste. This is accomplished by sorting organic vs. paper/plastic waste into different color bags at residences and then optically sorting the bags at the MSW plant where organic waste is sent to the digester and the remaining waste is incinerated to produce electricity and heat.
- Borås has an integrated waste management system which is intended to serve as a model for other communities. Their goal is that 100% of their municipal waste should either be recycled or turned into energy.

On Day 3 we left Göteborg and traveled by bus about 1½ hours east to Borås to visit the municipal biogas and upgrading facilities. The first facility visited was the municipal solid waste (MSW) handling operation at Sobacken. After being welcomed by Anders Assarsson, the head of the Borås Sanitation Department, there were several presentations followed by a tour of the Sobacken biogas plant.

Borås is a small-to-medium-sized city (by Swedish standards) with a population of about 100,000. They have successfully instituted an integrated waste handling system which is often held up as a potential model for other communities.

The Borås Biogas Plants. There are 2 facilities involved in biogas generation and upgrading at Borås. The first facility is the municipal solid waste (MSW) handling plant at Sobacken. This facility produces raw digester gas from the organic fraction of MSW, restaurant organic waste and slaughterhouse waste. The raw digester gas is then piped 7 km. to the second facility at Gässlösa for upgrading. Gässlösa is the site of the municipal waste water treatment plant (WWTP) which also creates raw gas through anaerobic digestion of waste water. The raw gas from the Sobacken and Gässlösa facilities are upgraded to vehicle fuel at Gässlösa. Some of the upgraded biogas is piped back to Sobacken for refueling of the municipal refuse truck fleet. The remainder of the upgraded gas is piped to a nearby biogas refueling station for the city's CNG transit buses.





Source Separation of Household Waste. The Borås model is highly dependent on source separation of household waste. The municipality has instituted a source separation system at the residential level involving different colored bags for different types of waste. Organic waste such as food leftovers is placed in black bags while paper, plastic wrappings and similar types of waste is placed into white bags. All bags regardless of color are dumped into the same waste bins and collected via municipal CNG refuse trucks running on biogas. At the MSW plant, the bags are optically sorted – the contents of the black bags are sent to the digester to produce raw biogas while the white bags are sent to an on-site incinerator to produce electricity and heat. As a result of a vigorous public education campaign and financial disincentives for not sorting waste, it is estimated that 85% of the residences in Borås are currently sorting correctly.

Additional Recycling Efforts. The goal of the Borås system is that all waste should either be recycled or turned into energy. The waste which does not fall into the black and white bag sorting system described above is handled via 85 recycling centers in the Borås area. These recycling centers handle glass, plastic bottles, cans, grass clippings and electronic appliances among others. The current statistics for treatment of household waste in Borås are:

- 26% Recycling
- 29% Anaerobic Digestion
- 41% Incineration
- 4% Landfill (EU regulations require 0% starting in 2005)

June 9 - Briefings in Borås (2 of 2)

- *Jesper Slöjdare, Sales Manager, Läckeby Water*
- *Lars-Evert Karlsson, Engineer, Läckeby Water*

Highlights:

- Läckeby Water has designed and built more than 20 turnkey biogas plants and upgrading facilities in Sweden including the Borås biogas plants. Läckeby has experience in building both large scale (e.g. municipal) and farm-scale biogas plants.
- Gässlösa is currently the only biogas upgrading facility in the world based on COOAB technology. COOAB is based on amine absorption of CO₂ and operates with extremely low methane losses (< 0.1%). The COOAB system also allows the possibility of capturing and selling CO₂ for other uses.
- The biogas upgrading equipment at Gässlösa includes automatic monitoring of output gas quality to prevent low quality biogas from being released by the system.
- Biogas upgrading costs at Gässlösa are approximately \$0.20/m³ upgraded biogas.

Following the presentations at the Sobacken facility, the group traveled by bus to Gässlösa 8 km away to see the biogas upgrading equipment in operation.

Läckeby Water Group has designed and built several turnkey biogas plants in Sweden. Purac is the name of the “Contracting” sub-group within Läckeby that handles biogas production and upgrading projects.

Biogas Projects. Läckeby Water designed and built the biogas plants at Borås. To date, Läckeby has built 20 biogas plants in Sweden and 4 biogas upgrading facilities. The biogas plants operate on a variety of liquid and solid substrates. While the majority of the biogas plants are larger scale plants, a few smaller plants have been built on farms (called “agricultural biogas plants”). Läckeby also designs and manufactures many of the components that are used in biogas plants, such as heat exchangers, grit separators, screw conveyors, etc. As a rule of thumb, biogas plants typically use about 10 – 15% of their output to provide electricity and heat to run the plant (including hygenisation).



Upgrading Technology. The biogas upgrading equipment for Sobacken and Gässlösa is located at the Gässlösa facility. Biogas upgrading at Gässlösa is based on LP COOAB (Low Pressure CO₂ Absorption) technology manufactured by Cirmac International, a Dutch company. COOAB is a relatively new technology based on amine absorption of CO₂ with extremely low methane losses, e.g. less than 0.1%. The system is regenerative in that COOAB chemically absorbs CO₂ at 37°C and desorbs (gets rid of) the CO₂ at 105°C.

Gässlösa is currently the only biogas facility in the world using COOAB technology. The basic upgrading process is as follows: First a blower pulls the raw biogas out from a storage tank and pressurizes it to about 4 – 5 bar (1 bar = 14.5 psi) to be compatible with the requirements of the COOAB system. H₂S and ammonia (NH₃) are then removed by sending the gas through a two-bed system with activated carbon. Next CO₂ is removed in a COOAB contactor. The CO₂-rich COOAB is then sent to a CO₂ stripper for regeneration and the resulting CO₂-lean COOAB is sent back to the COOAB contactor. (Note that the COOAB must be replaced about every 5 years.) Heat exchangers are used to achieve the necessary temperatures for the rich and lean COOAB solutions. The CO₂ stripped from the CO₂-rich COOAB is released to the atmosphere although it could be upgraded and captured for industrial or food processing purposes. The water-saturated methane gas from the COOAB contactor is pressurized to meet the local delivery pressure requirements (typically 5 – 8 bar) and then dried to remove the water (dewpoint -80°C). Drying is necessary to prevent water from condensing when the biogas is compressed to high pressure to be used as vehicle fuel. The final steps prior to injecting the upgraded, dry biogas into the delivery network are to odorize the gas by dosing with THT (the same odorant used in NG) and run automatic analyses of the final gas quality. If the biogas does not meet any of the required criteria (e.g. H₂S/O₂/CH₄/NH₃ concentration, Wobbe index and dewpoint), the biogas is automatically routed back to the input of the upgrading system for reprocessing.



Costs. The COOAB upgrading equipment at Gässlösa cost approximately \$1.5M and is rated for 388 m³/hr. Costs for upgrading and capital equipment depreciation are approximately \$0.20/m³ upgraded biogas.

In addition, there are two 125 mm diameter pipes between Sobacken and Gässlösa (7 km apart) carrying raw biogas from Sobacken to Gässlösa and upgraded biogas from Gässlösa back to Sobacken. The total cost for the 7 km of pipes and installation was approximately \$933K (\$213K/mile).

June 10 - Briefings in Linköping (1 of 4)

- *Carl Lilliehöök, Managing Director, Svensk Biogas*
- *Peter Undén, Sales & Marketing Director, Svensk Biogas*

Highlights:

- The biogas plant at Åby in Linköping is one of the largest and most modern in Sweden. It processes primarily slaughterhouse waste along with a smaller percentage of manure and crops. Vehicle fuel is provided for 67 transit buses and 250 light-duty vehicles.
- Svensk Biogas intends to market their biogas expertise both within Sweden and internationally.
- Swedish law does not allow digested human waste in biofertilizer for land application.
- Svensk Biogas believes there is potential in the digestion of energy crops to create vehicle fuel. They claim there is 39% more energy from converting wheat to biogas vs. ethanol.
- In addition to federal/municipal rebates and tax incentives on purchases of bi-fuel vehicles, biogas costs 15 – 20% less than gasoline in Linköping.

The morning of Day 4 was spent visiting the biogas plant in Linköping, about 2 hours west of Stockholm. There were several presentations at Tekniska Verken's main offices followed by a tour of the Åby biogas plant.

Svensk Biogas is a subsidiary of Tekniska Verken, the municipal energy provider and waste handling agency in Linköping. Svensk Biogas is responsible for biogas production and marketing of biogas technology in Sweden and internationally.

Background and Business Objectives. Svensk Biogas currently provides biogas fuel for 67 transit buses and 250 light duty vehicles in Linköping and sales are increasing steadily. (It was implied that Svensk Biogas also owns and operates the biogas filling stations but this was not confirmed.) The Linköping biogas plant is the largest and one of the most modern biogas plants in Sweden. Having developed considerable expertise in biogas production, distribution, marketing, etc., Svensk Biogas intends to market its modular biogas production concepts and expertise internationally.

Åby Biogas Plant. The biogas plant is located in Åby on the outskirts of Linköping. The plant processes 54K tons of organic waste annually, 43K tons coming from slaughterhouse waste (Swedish Meats) and the remainder coming from livestock manure and crop residues. The plant produces 4M m³ biogas/year for vehicle fuel and 50K tons of biofertilizer. Note that human (sewage) waste cannot be combined with other organic waste streams or crops because biofertilizer derived from human waste may not be spread on fields according to Swedish law.





Gärstad Biogas Plant. Tekniska Verken also operates a large, municipal waste-to-energy plant in Linköping at Gärstad. At Gärstad, biogas produced from waste water treatment is used to generate electricity and district heating power. The total investment cost of the plant was approximately \$100M.

Agricultural Possibilities. Svensk Biogas believes there is significant potential in the digestion of energy crops to create vehicle fuel. They point out that there is 39% more energy available by converting wheat to biogas vs. ethanol. In particular, they are investigation growing energy crops such as wheat in fallow fields for this purpose.

Incentives for Biogas Use.

- Biogas costs 15 – 20% less than gasoline.
- Free parking for bi-fuel vehicles in the inner city.
- 20% lower tax on company cars which are bi-fuel vehicles.
- 30% rebate on the incremental cost of a bi-fuel vehicle.
 - Rebate \$ comes from Swedish EPA but administered by municipalities.
- Municipal purchasing policies favor environmentally friendly fleets.

Note that biogas is tax-free in Sweden until 2008. After 2008 an energy tax will apply to biogas but it will remain exempt from the CO₂ tax.



June 10 - Briefings in Linköping (2 of 4)

- *Jörgen Ejlertsson, Associate Professor, Tekniska Verken*

Highlights:

- The biogas plant in Linköping has one of the highest yields (if not the highest) of all biogas plants in Sweden. Tekniska Verken believes that one of the main reasons is their experience in digester process controls however the fact that their primary substrate is high-fat slaughterhouse waste and they have an extended hydraulic retention time are additional factors which may contribute significantly to their high biogas yield.
- Tekniska Verken uses laboratory scale digesters for process control development including optimization of co-digestion of different substrates.
- The amount of biogas generated from a particular substrate is highly dependent on the composition of the substrate, e.g. relative percentages of carbohydrates, proteins and fats.
- Tekniska Verken is conducting a project to develop digestion processes for energy crops. They currently hold two Swedish patents related to digestion of energy crops and pellets.

Jörgen Ejlertsson is an Associate Professor at the University of Linköping. Tekniska Verken contracts the University of Linköping to perform research on biogas production process control and optimization.

Linköping Digester Performance. Tekniska Verken presented a chart comparing the digester efficiency of 9 different biogas plants in Sweden. The amount of raw biogas produced per m³ of digested waste varied from 18 to 146 with Linköping being by far the highest, as well as far above the average of around 63. While the type of substrates used at each location certainly plays a huge role (Linköping uses primarily high-fat slaughterhouse waste which yields a much greater amount of biogas compared to a similar volume of manure, for example), Tekniska Verken believes that much of the credit is due to their knowledge and experience in digester process controls. In fact, Svensk Biogas has a patent on a method of increasing the efficiency of the bioconversion process, (i.e. a higher percentage of solids is digested). While it was not discussed at length, one item which may contribute to the higher digester efficiency is that the hydraulic retention time at Linköping is 30 days compared to the typical 20 – 21 days for mesophilic digesters. Since the waste is digested for a significantly longer period of time, this may partially explain why the biogas yield is significantly higher.

Process Development. Tekniska Verken utilizes laboratory scale digesters to develop process controls such as optimization for combining different types of waste streams (including crops). The laboratories also perform gas/liquid composition analyses. Tekniska Verken is interested in offering these kind of services on a consulting basis.

Biogas from Crops. Tekniska Verken believes that energy crops present potential good opportunities for biogas production. The advantages to using crops as a substrate are:

- Density of organic material
- Pasteurization unnecessary



- Uniform quality of substrate
- Agricultural systems in place

The amount of biogas generated from a particular substrate is highly dependent on the composition of the substrate (see viewgraph at right). The typical composition of energy crops is:

- Carbohydrates 60 – 70%
- Proteins 10 – 12%
- Fat 2 – 3%
- Water 10 – 15%

Biogas formation during total degradation of 1 kg substrate

Substrate	Biogas (Nm ³ /kg)	CH ₄ (Nm ³ /kg)	CH ₄ (%)
Fat	1,39	0,96	69
Proteins	0,65	0,51	78
Carbohydrates	0,84	0,42	50
COD	-	0,35	-
BOD	-	0,35	-

TEKNISKA VERKEN

The goals of the energy crop project at Tekniska Verken are to create a digestion process based on use of crops and water only as input to the digester with a high biogas yield and a residue suitable for agricultural use. Tekniska Verken currently has 2 Swedish patents on digestion of energy crops and pellets. One of their main lessons learned is that in-process monitoring and stimulation is necessary to produce a stable process.

June 10 - Briefings in Linköping (3 of 4)

- *Axel Lagerfelt, Farmer, Tolefors Gård (Tolefors Farm)*

Highlights:

- In 1993, Tolefors Gård began a small project involving on-farm digestion of cow manure and cow slaughtering waste to produce biofertilizer. The digestate proved to be a very effective biofertilizer with higher N content and lower P and K content compared to manure.
- Following the outbreak of mad cow disease, biofertilizer obtained from cow slaughtering waste is no longer allowed to be used on crops fed to cows.
- Tolefors Gård is now involved in a project to digest energy crops to create biogas and biofertilizer. Preliminary calculations indicate that it may be more profitable for the farm to produce energy and biofertilizer than traditional farm products.

Axel Lagerfelt is the owner of Tolefors Gård, a dairy/crops farm in the Linköping area. He has been involved in several on-farm biogas projects since 1993.

On-Farm Biogas Projects. In 1993, Axel initiated a small biogas project on his farm to obtain biofertilizer from manure and slaughtering wastes via anaerobic digestion. The results were positive in that the biofertilizer contained increased nitrogen and decreased potassium and phosphorus levels compared to the manure. In addition, the biofertilizer was more fluid and consequently easier to land apply and faster acting.



Following the outbreak of mad cow disease, however, the use of cow slaughtering wastes to produce biofertilizer for crops fed to cows was outlawed by ARLA (Swedish/Danish milk board). However cow slaughterhouse waste can be used to create biofertilizer for grain crops.

Axel is currently building a large on-farm digester to generate biogas and biofertilizer from energy crops. His preliminary calculations indicate that it could actually be more profitable for his farm to supply energy and biofertilizer instead of traditional dairy and agricultural products. He believes that he will be able to sell the biogas produced from the energy crops for more than he could sell the actual energy crops. In addition, the potential energy efficiency of producing energy crops for biogas is quite good. At Tolefors Gård, the 700 hectare farm would use 70K liters of diesel/year to produce energy crops that would yield approximately 1.5M m³ biogas/year. (Note that 1 m³ upgraded biogas is equivalent to approximately 1 liter of diesel.)

June 10 - Briefings in Linköping (4 of 4)

- *Peter (last name unknown), Plant Manager, Svensk Biogas*

Highlights:

- YIT Water and Environmental Services is a supplier of turnkey biogas plants.
- The Åby biogas plant in Linköping is the largest producer of biogas for vehicle fuel in Europe.
- Biogas upgrading at Åby is performed via water scrubbing technology.
- Biogas upgrading costs are approximately \$0.26/m³ excluding capital depreciation. Tipping fees for disposal of slaughterhouse waste are a significant component of the business case.

YIT Water and Environmental Services is a supplier of turnkey plants for waste water treatment, waste processing and biogas upgrading.

Biogas Plant Tour. The Åby biogas plant was designed and built by YIT Water and Environmental Services, a company in the YIT Group. The YIT Group is one of the main consulting companies in Sweden (similar to SWECO). YIT was unavailable that day and hence the biogas plant tour was conducted by Svensk Biogas.

The Åby biogas plant in Linköping is the largest producer of biogas for vehicle fuel in Europe. The digester feedstock is 75% slaughterhouse waste, 10% manure and 15% food by-products. There are 2 digester tanks which hold 3,700 m³ each. A total of 150 m³ of waste at 10 – 14% total solids are added to the digesters daily. Iron fluoride is added to the input mix to reduce H₂S content in the output gas. Like virtually all digesters in Sweden, it is a full mix type digester. Hydraulic retention time (HRT) was stated as 50 days (disagrees with 30 days HRT figure cited earlier by Tekniska Verken).



Biogas upgrading is performed via water scrubbing technology. The upgrading equipment can handle 1,360 m³ biogas/hour input. There are about 1% methane losses in the upgrading process and the final methane content of the output biogas is 97%. The biogas is dried to a dewpoint of –80 to –100°C prior to being distributed to local biogas refueling stations via dedicated pipelines.

Economics. The total cost of the Åby biogas plant was approximately \$15M. The upgrading portion of the biogas plant cost approximately \$2.1M. Operating costs excluding capital depreciation are approximately \$0.26/m³ upgraded biogas. The plant receives tipping fees for slaughterhouse waste disposal (\$26 - \$52/ton) which has a significant impact on the business case.



June 10 - Briefings in Stockholm (1 of 1)

- *Lars Brolin, Solid Waste Department Manager, SWECO*
- *Hans Kättström, Biogas Project & Business Manager, SWECO*

Highlights:

- The benefits of using biogas as a vehicle fuel include reduced emissions of pollutants and GHGs, a sustainable organic waste handling system and renewable (non-fossil) transportation fuel.
- Current biogas upgrading technologies include water scrubbing, pressure swing adsorption (PSA) with activated carbon, Selexol (glycol) scrubbing, membrane separation, and chemical absorption using amines.
- Biogas distribution options include dedicating local biogas pipelines, over-the-road transportation of compressed biogas in various types of containers, and injection into the NG pipeline grid if available.
- The Stockholm municipal transit fleet is the “anchor customer” for biogas in Stockholm. SWECO is involved in a project to move the entire Stockholm city bus depot including the biogas filling station underground by 2006.
- Stockholm officials are planning to institute a toll ring around the city and charge vehicles an environmental toll to enter the city (similar to the London toll ring). Bi-fuel vehicle will be exempt from this toll.
- SWECO expects that cryogenic refinement will become an effective biogas upgrading technology in the future although the process is currently very energy intensive. SWECO also believes there is a potential market for commercial grade CO₂ captured as a by-product of cryogenic biogas upgrading systems, for example, in refrigerated truck applications. (Note that while cryogenic biogas upgrading is not currently used in Sweden, there are some US companies now offering commercial systems to upgrade biogas to LNG.)

In the afternoon we traveled to Stockholm for the final presentation of Day 4 at SWECO.

SWECO is the largest engineering consultant company in Sweden. They have extensive experience in water and environmental engineering projects including biogas plants. SWECO is the primary consultant to BRG for biogas projects and they played a major role in helping BRG organize the Swedish biogas industry education tour.

Societal Benefits of Compressed Biogas (CBG).

- Reduced air pollution compared to diesel/gasoline
- Sustainable organic waste handling
 - Landfilling of organic waste forbidden in Sweden starting in 2005
- Renewable energy source
 - CNG (fossil fuel) vs. CBG (non-fossil fuel)
- Reduced GHG emissions (100% for CBG)

Biogas Upgrading Technologies.

- Water scrubbing
 - Need to use stainless steel pipes to avoid corrosion from H₂S in water
- Pressure swing adsorption (PSA) using active carbon as an adsorbent



- Selexol (glycol) scrubbing
 - Some problems with corrosion
- Membrane separation
 - Physical clogging of membranes often causes problems
- Chemical absorption (e.g. COOAB which uses amines)
 - Zero methane losses
 - Works at atmospheric pressure

Biogas Distribution Options.

- Dedicated biogas pipelines from upgrading plant to refueling stations
 - Approximately \$75/foot to lay pipe in Stockholm (dense urban area)
 - Most cost-effective in long run (assuming no local access to NG grid)
- Distribution by hydraulic trailers holding 1400 m³/trailer
- Distribution by gas bottle trailers holding 6000 m³/trailer
- Distribution via gas containers holding 2000 m³/container
 - Best temporary solution
- Distribution via NG grid an option where access to NG grid exists (e.g. Laholm)

Biogas in Stockholm. The south bus depot in Stockholm has a fast fill, temperature-compensated biogas refueling station for 130 municipal transit buses currently operating on biogas. SWECO is involved in a project to move the entire south bus depot underground by 2006 so that the land above can be used for housing and businesses in the crowded and expensive city center.

Stockholm is planning to create a toll ring around the city (like London) and charge an environmental toll for every vehicle entering the city. Bi-fuel vehicles will be exempt from this toll. It was interesting to note that biogas costs more than gasoline in Stockholm where there is no competition from NG because the NG grid does not currently extend to Stockholm.

Future Biogas Upgrading Technologies. SWECO believes that cryogenic refinement processes to produce LNG from raw digester gas are the long term solution to meeting requirements for zero methane losses and efficient gas storage and transportation. (Note that while this is not currently done in Sweden, there are some companies in the US advertising commercially available digester gas-to-LNG systems.) SWECO also believes there is a market for CO₂ captured as a by-product of this process to be used in refrigerated truck applications.



June 11 - Briefings at Swedish EPA (1 of 5)

- ***Lars-Erik Liljelund, Swedish Environmental Protection Agency (EPA)***

Highlights:

- The Swedish EPA is responsible for setting national environmental policy.
- The EPA administers grant programs to municipalities to implement local and regional environmental programs.
- Climate change, traffic and transportation programs are handled by the Department of Sustainable Energy Management within the EPA.
- Hydroelectric and nuclear power used to be the two primary energy sources in Sweden, however nuclear power is currently being phased out in favor of wind power, biofuels and other renewable sources of energy.

In the morning, we split into two groups. The first group met with Swedish government representatives at the Swedish Environmental Protection Agency (EPA). The second group traveled to Uppsala, a short distance from Stockholm, for presentations at the Uppsala biogas plant. In the afternoon, both groups returned to SWECO's offices for a press conference with Swedish media and a wrap-up meeting with BRG and SWECO.

The Swedish Environmental Protection Agency (EPA) is responsible for setting environmental policy and providing guidance to municipalities to implement those policies at a local level.

Overview of Swedish EPA Activities.

- Establish national environmental policies
- Distribute EPA grant money to municipalities to implement environmental programs
- Department of Sustainable Energy Management responsibilities include:
 - Climate Change Programs
 - Traffic Programs
 - Transportation Programs

Mix of Energy Sources in Sweden.

- Previously 50% hydroelectric and 50% nuclear
- Nuclear being phased out and replaced by wind power, biofuels, etc.
 - Primary concern with nuclear power is safety (Chernobyl, etc.)



June 11 - Briefings at Swedish EPA (2 of 5)

- ***Eric Herland, Federation of Swedish Farmers (LRF)***

Highlights:

- 20% of the energy used in Sweden comes from biofuels (primarily forestry).
- Less than 1% of the transportation fuel used in Sweden comes from biomass sources.
- A proposed biogas plant in Västerås near Stockholm will use energy crops (ley crops/ensilage) along with source-separated organic waste to generate biogas.
- The average number of cows on dairy farms in Sweden is about 40 (compared to about 1,000 cows/dairy farm in CA).
- Horizontal drilling can reduce the cost of laying biogas pipelines by up to 75% compared to digging trenches.
- Odor control is a key consideration when choosing a biogas plant location.
- Transportation of biogas feedstocks to a biogas plant can be very costly. Biomass feedstocks should generally be located fairly close to the biogas plant, e.g. within 10 – 15 miles.

LRF is the Federation of Swedish Farmers, an agricultural industry organization representing many of the farmers in Sweden.

Role of Farmers in Swedish Energy Industry.

- Most Swedish farmers own both farms and forests
- Most Swedish farms are part of collectives
- 20% of the total energy in Sweden comes from biosources, primarily forestry vs. agriculture
 - 50% of district heating comes from biofuels (mostly incineration)
 - 4 – 5% of electricity comes from biofuels
 - <1% of transportation fuel (e.g. biogas) comes from biofuels
- Mix of biomass feedstock for transportation fuels (e.g. biogas) in 2010
 - 35% sewage sludge
 - 25% manure and cultivated crops
 - 40% food industry waste

Biogas from Energy Crops.

The Växtkraft (“Growth Power”) Company is a company specifically formed to operate a planned biogas facility in Västerås near Stockholm. The company is part-owned by LRF, the local power utility and the local waste handling company. The feedstocks for the biogas plant will be source-separated organic waste, biogas purchased from the local sewage treatment plant and energy crops. The output of the biogas facility will be vehicle fuel (i.e. biogas), electricity and district heating. The local farmers will grow ley crops (ensilage) as an energy crop feedstock for the digester. Note that ley crops can increase the subsequent agricultural output of the land they are grown on by up to 30%. All participating farmers are located within 20 km. of the proposed biogas plant. Likewise all organic waste feedstock will come from local sources within 20 km. of the biogas plant. A relatively small amount of fossil fuel is used for transportation of the biomass feedstocks to the biogas plant, hence the system is very energy-efficient. The biofertilizer



produced by the plant will be used by the farmers for both conventional and organic farming.

Practical Considerations in Biogas Plant Design.

- Only about ten farms in Sweden have more than 400 dairy cows. The average number of dairy cows on a farm is about 40.
- Digging trenches for biogas pipelines costs about 2,000 SEK (\$260) per meter. Use of horizontal drilling equipment can reduce costs by 75% to about 500 SEK (\$65) per meter.
- The “smell plan” for controlling odors is a major consideration in the location of a biogas plant.
- Transportation of biomass feedstocks can be very costly. This is why biogas plants aren’t always co-located with sewage treatment plants. (The Västerås biogas plant design includes about 17 km. of biogas pipelines between the sewage treatment plant, the biogas plant and upgrading facility, and the biogas refueling station.)



June 11 - Briefings at Swedish EPA (3 of 5)

- **Lars Tegnér, Director of Development, Swedish Energy Agency (STEM)**

Highlights:

- The goal of the Swedish Energy Agency (STEM) is to create a secure, economically sustainable energy policy.
- Nuclear power is being phased out in Sweden due to public safety concerns and is being replaced by renewable energy sources such as wind power and biofuels.
- Incineration of waste to produce combined heat and power (CHP) is common in Sweden and is subject to strict combustion standards.
- Current renewable fuels projects in Sweden include wood gasification to produce H₂ as well as H₂ digester research.

The Swedish Energy Agency (STEM) is responsible for transforming the Swedish energy system into an ecological and sustainable system and administering state funds to research and other projects within the energy industry.

Goals of the Swedish Energy Agency.

- Develop a secure, economically sustainable energy policy
- Phase out nuclear power due to public safety concerns (Chernobyl, 3 Mile Island)
- Compensate for reduced nuclear power by increasing renewable energy portfolio

Renewable Fuels in Sweden.

- 50% hydroelectric power
- 50% digestion and incineration of forestry byproducts
- <1% biogas used for transportation fuel
- Efficiency synergies between biogas production, local industrial consumption and district heating
- Incineration of waste to produce combined heat and power (CHP) is common in Sweden
 - Strict combustion standards including output smoke composition

Renewable Fuels Projects in Sweden.

- 2 syngas projects in southern Sweden
 - Wood gasification to produce H₂-rich gas
- H₂ digester research in Linköping



June 11 - Briefings at Swedish EPA (4 of 5)

- ***Pär Gustafsson, Vehicle Technology Section, Swedish National Road Administration (SNRA)***

Highlights:

- Energy security and greenhouse gas (GHG) reductions are the driving forces behind research into alternative fuels in Sweden.
- Short-term options for expansion of renewable fuels include ethanol, biogas and RME.
- Long-term solutions for renewable fuels will include syngas and to a lesser extent, biogas.
- Current syngas projects in Sweden include black liquor digestion and cellulose digestion.

The Swedish National Road Administration (SNRA) is responsible for the road transportation system in Sweden including environmental impacts on public health.

Alternative Fuels.

- SNRA believes that air quality problems are solvable
- Driving factors for research in renewable fuels are energy security and greenhouse gases (GHGs)
 - Oil production may peak as early as 2008
 - Increases in fuel efficiency and rate of substitution of non-fossil fuels insufficient to cope with increases in fuel demand
- SNRA believes that syngas will play a large role in Sweden's future energy supply
 - Current syngas projects in Sweden include black liquor (a byproduct of the papermaking industry) digestion and cellulose digestion
- Short-term options for expansion of alternative fuels:
 - Ethanol (pilot plant in Norrköping)
 - Biogas
 - Rapeseed Methyl Ester (RME)
- Longer-term solutions for transportation
 - Biogas (partial solution)
 - Syngas



June 11 - Briefings at Swedish EPA (5 of 5)

- *Petter Lydén, Swedish Environmental Protection Agency (EPA)*
- *Mats Björzell, Swedish Environmental Protection Agency (EPA)*

Highlights:

- Swedish government plans to reduce GHG emissions by 4% in 2010 compared to 1990 levels.
- Swedish government levies a carbon dioxide tax of 0.92 SEK (\$0.12)/kg CO₂ produced to promote use of fuels which do not create significant GHGs.
- Swedish EPA has allocated \$120M in “Klimp” grants for GHG emissions reductions projects at municipal level.
- 25% of the “Klimp” grants were awarded to biogas projects in 2003.
- Klimp grants typically provide 20 – 30% of GHG emissions reduction project costs.
- Total cost of GHG reductions approx. 0.48 SEK (\$0.06)/kg or \$58/ton CO₂ equivalent.
- Biogas expected to provide only 1% of Swedish transportation fuel in long term.
- Methane leakage at biogas plants must be kept to a minimum in order not to negatively impact system GHG emissions reductions.

Climate Investment Program (Klimp).

- Swedish climate strategy is to reduce greenhouse gas (GHG) emissions by 4% between 1990 and 2010 (exceeds Kyoto Protocol share for Sweden)
- Main political instruments to bring about climate change:
 - Carbon dioxide tax of 0.92 SEK (\$0.12)/kg CO₂ produced
 - Climate information campaign
 - Research funding
 - Grants for climate investment programs (Klimps and LIPs)
- Klimp grant funding 900 MSEK (\$120M) available for local GHG reduction projects between 2003 and 2005
 - Swedish Energy Agency distributes grants and acts as advisor to municipalities implementing local programs
 - 25% of grants (90 MSEK/\$12M) awarded to biogas projects in 2003
 - Grant is typically 20 – 30% of total investment cost of project
 - Cost effectiveness to date approx. 0.12 SEK (\$0.016)/kg. CO₂ equivalent based on government investment only
 - Total cost of GHG reductions approx. 0.48 SEK (\$0.06)/kg or \$58/ton CO₂ equivalent
- 5% ethanol is allowed in Swedish fuel for reduction of NO_x emissions

Regulatory Policy View on Biogas.

- Swedish government supports biogas projects but doesn't expect them to contribute more than 1% to the total vehicle fuel demand
- Methane leakage at biogas plants is a major concern as significant leakage could effectively nullify the GHG emissions reductions benefits of using biogas for transportation fuel

June 11 - Briefings in Uppsala (1 of 2)

- **Cecilia Ekvall, Municipality of Uppsala**

Highlights:

- Uppsala biogas plant and upgrading facility contribute to municipal waste treatment, energy recovery and nutrient recycling functions.
- Biogas plant uses multiple feedstocks including slaughterhouse wastes, restaurant and industrial organic wastes, pharmaceutical waste and animal manure.
- 50% of biogas production used for district heating (not upgraded), 50% upgraded for transportation fuel for city transit bus fleet.
- Biofertilizer provided to local farmers for land-application to replenish soil nutrients.
- Biogas upgrading facility co-located with wastewater treatment plant.
- Biogas from wastewater treatment plant and biogas plant mixed together at biogas upgrading facility.
- On-site LNG storage provides backup for biogas-fueled city transit bus fleet.

The second group traveled to Uppsala, a short distance from Stockholm, for presentations at the Uppsala biogas plant. Afterwards there was a tour of the biogas plant, followed by trips to see the biogas upgrading facility co-located at the wastewater treatment plant and the biogas refueling facility at the city transit bus depot.

Overview of Uppsala Biogas Plant.

- Biogas plant and upgrading facility serves multiple purposes
 - Waste treatment
 - Energy recovery
 - Nutrient recycling/management
- Multiple feedstocks for biogas plant
 - Slaughterhouse waste
 - Restaurant and industrial organic waste
 - Animal manure
 - Glucose (from pharmaceutical industry)
 - Slaughterhouse blood
 - Tipping fees for slaughterhouse waste/blood approx. 100 SEK (\$13)/ton
- Digestion process description
 - Pulper for solid wastes
 - Pasteurization at 70°C for 1 hour
 - Full mix digester
 - Thermophilic (55 °C) operation
 - Hydraulic retention time 20 days
 - Digester volume 2800 m³
- Digestate stored in 500 m³ buffer
 - Biofertilizer includes significant nitrogen, phosphorus and potassium
 - Biofertilizer given back to local farmers (free) for land-application
- Biogas storage tank 400 m³
- Biogas production approx. 2,000 – 3,000 m³/day with 65% methane content



- 50% of biogas piped to biogas upgrading facility several miles away
- 50% of biogas combusted for district heating

Overview of Biogas Upgrading Facility.

- Biogas upgrading facility co-located with Uppsala wastewater treatment plant
- Biogas from wastewater treatment plant mixed with biogas from biogas plant at biogas upgrading facility
- Upgrading technology is water-scrubber (8 bar)
 - “Purified” water supplied by wastewater treatment plant
- On-site LNG storage as backup supply for biogas-driven city transit bus fleet





June 11 - Briefings in Uppsala (2 of 2)

- Åke Nordberg, *Biological Waste Treatment, Swedish Institute of Agricultural and Environmental Engineering (JTI)*

Highlights:

- Anaerobic digestion of pasteurized vs. non-pasteurized animal by-products increases methane yield by a factor of four.
- Animal manure has a relatively low methane yield compared to other sources of organic waste.
- A biogas plant and upgrading facility proposed in Västerås would use energy crops (ley crops) in combination with source-separated household waste and animal manure as feedstocks for a large-scale anaerobic digester.
- *See also briefing by Eric Herland at Swedish EPA for further information regarding proposed Västerås biogas plant and upgrading facility.*

The Swedish Institute of Agricultural and Environmental Engineering (JTI) is an industrial research institute working with research, development and information in agriculture, environment, energy production and waste management.

Slaughterhouse Waste Legislation.

- Use of animal carcasses prohibited in animal meal (1988)
- Use of animal by-products prohibited in ruminant feed (1991)
- No incidents of mad cow disease in Sweden

Methane Yield.

- Digestion of pasteurized animal by-products yields four times more methane than non-pasteurized animal by-products due to increased access to lipids after heat treatment
- Methane yield from animal manure extremely low compared to other sources of organic waste
- The total methane potential from the slaughter of cattle is approximately nine times greater than for pigs (1300 MJ vs. 140 MJ/animal)

Waste source	Methane yield (m ³ ton ⁻¹)
Animal by-products (pasteurized)	225
Animal by-products (non-pasteurized)	56
Slaughterhouse waste mixture	160
Source-sorted household waste	130
Manure	13

Proposed Västerås Biogas Plant and Upgrading Facility.

- Co-digestion of energy crops, source-sorted municipal waste and manure
- Local farmers will grow ley crops (grass and clover) as the energy crop feedstock for the biogas plant
 - Ley crops will increase soil quality and reduce nutrient leakage
- Local refuse hauler will collect source-separated household garbage in color-coded paper bags
- Växtkraft Company formed as partnership between local energy utilities, refuse hauler and farmers to own and operate biogas plant and upgrading facility



- Biogas plant and upgrading facility will be co-located outside of city center
- Biogas from local wastewater treatment plant will be piped to biogas upgrading facility and mixed with biogas from biogas plant
- Biogas plant outputs include biogas piped to upgrading facility and biofertilizer (digestate) for farmers
- Upgraded biogas piped to transit bus depot in city center and used as vehicle fuel for transit buses, refuse vehicles and public/private light-duty vehicles
- Economic feasibility study indicates break-even operation with additional benefits of sustainable waste treatment and improved soil nutrition management
- Important factors in business case include:
 - Tipping fees (approx. \$50/ton)
 - Value of biofertilizer to farmers
 - Biogas used for vehicle fuel is not taxed vs. high taxes on gasoline and diesel vehicle fuel



June 11 – Wrap-up Meeting at SWECO

- ***Lars Brolin, Solid Waste Department Manager, SWECO***
- ***Hans Kättström, Biogas Project & Business Manager, SWECO***
- ***Jan Nordling, President, ÅF***
- ***Sten-Åke Barr, Business Development Manager, ÅF***

Highlights:

- Potential areas of Swedish in future US biogas efforts include biogas digester and upgrading facility specifications and design, supplier and technology guidance, and biomass feedstock handling, mixing and logistics.

In the afternoon both groups met at the SWECO offices for a press conference followed by a final wrap-up meeting. The press conference was given jointly by SWECO, BRG and WestStart-CALSTART. WestStart-CALSTART's statement covered our group's interest in the Swedish biogas industry and the primary lessons learned from our study tour. The wrap-up meeting afterwards included representatives from SWECO, BRG and Volvo Car Corporation. In addition there was a brief presentation by ÅF, a Swedish consulting company primarily involved with district heating and cooling system design.

ÅF Company Overview.

- ÅF is the second largest energy consulting company in Sweden
- Primary areas of expertise:
 - Energy
 - Environment
 - Pulp and paper
- ÅF performs technology and engineering consulting
- Core business is district heating and cooling and this is their main link to the biogas industry
 - “ÅF” is an abbreviation for “steam users group”

Future Swedish-US Cooperation.

- SWECO outlined possible areas where Sweden could assist further development of the US biogas industry:
 - Guidance in biogas digester specifications
 - Technologies
 - Suppliers
 - Guidance in specifications for biogas upgrading facilities, distribution and filling stations
 - Technologies
 - Suppliers
 - Biomass feedstock handling, mixing and logistics