MINUTES
IEA Bioenergy Agreement
Task 33: Thermal Gasification of Biomass
Fall 2004, Task Meeting, October 25-27
Copenhagen, Denmark
Prepared by
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The second Task Meeting for the 2004-2006 triennium was hosted by the Danish Energy Authority (DEA), from October 25-October 27, 2004, in Copenhagen, Denmark. The list of Task Meeting attendees and the complete list of invited speakers and observers for the one day seminar on "Gas Cleaning and Gas Engines for Small Scale Biomass Gasification (BMG) Applications" are shown in Attachment 1. The Agenda for the entire Task Meeting is shown in Attachment 2.

Day 1: Monday, October 25, 2004: Workshop on Gas Cleaning and Gas Engines for Small-Scale BMG Applications (12 speakers, total 35 participants)

While introducing the workshop, Suresh Babu, Leader Task 33 recognized the historical event that took place during the previous week, in which the lower house of Russian Parliament overwhelmingly approved the Kyoto Treaty. It is anticipated that Russia will formally submit the fully executed treaty agreement within the next 3 to 4 months. Once formalized the Kyoto treaty could very well initiate an active search for a variety of renewable energy technologies. In many countries, biomass may emerge as the largest underutilized source of renewable energy. Further, advanced BMG could be one of the few technologies that can significantly reduce greenhouse gas emissions.

In his opening remarks, **Peter Helmer Steen, DEA, Denmark** has summarized the accomplishments of Denmark in reducing greenhouse gas emissions and the introduction of renewable energy. Between 1992 and 2002, Denmark has reduced $CO_2$ emissions by 12 to 13%. During the same period biomass use has increased rapidly. In 2002 biomass contributed 12.5% of the primary energy in Denmark and 19% of total electricity, produced mostly by combustion of biomass. Several examples of installing biomass based decentralized CHP, and central power plants, and windmill parks were cited. Between1991-2003, the overall thermal efficiency of CHP plants have increased from 68 to 87% and the efficiency of power generation has increased to the 35 to 40% range. In some Danish CHP plants, equal quantities (in heating value) of natural gas and biomass are fired. The incentives for biomass derived electricity are significant. Biomass and CHP electricity sales prices are set at 8 € cents/kWh while coal based CHP electricity is only 3€ cents/kWh.

**Pekka Simell, VTT, Finland**, described the NOVEL BMG demonstration project under construction in Kokemaki, Finland. Start-up is expected in the first quarter of 2005. VTT improved the Bioneer Process to develop the Novel Process and licensed the process and gas cleanup technology to Condense OY for the Kokemaki demonstration. Biomass feed, up to 50 mm in size and with up to 60% moisture, is fed to the top of the downdraft gasifier. Part of the air required to sustain gasification is injected into the top 1/3 of the gasifier bed, primarily to to decompose the tar leaving with the raw product gas. The raw gas containing about 2000 mg/Nm$^3$ tar, 800 ppmV, $NH_3$, 320 ppm HCN, and <10 mg/Nm$^3$ of dust, is introduced into the Ni-monolithic catalytic tar reformer. The Ni-monolith catalyst has been tested for over 3000 hours in a product-gas slip-stream at the Lahti plant. The fuel gas then passes through a scrubber for final cleanup. The scrubbed gas contains about 40 mg/Nm$^3$ tar, very small quantities of $NH_3$, and 10-20 ppmv of HCN. The clean fuel gas is subsequently fed to a JMS 316 Jenbacker Engine to produce electricity at 30-36% efficiency (function of feed moisture content). About €4.5 MM are invested in the Kokemaki CHP demonstration which supplies about 1800kWe and 4300kWth heat to about 8500 people. The CHP system includes a condensing heat exchanger to improve the overall thermal efficiency and to circumvent the need for any process water.

Benny Gøbel, Danish Technology University (DTU), Denmark described the success achieved with the 70 kWth feed capacity VIKING, 2-stage gasification project. The feed wood chips contains about 50% moisture. In the first stage, biomass is dried and pyrolyzed by indirect heating, starting at about 50$^o$C and going up to 600$^o$C. The pyrolysis product contains about 50,000 mg/Nm$^3$ tar. As the products pass through the 1100$^o$C partial oxidation zone, maintained at this temperature by air injection above char gasification zone, the tar content is reduced to about 500 mg/Nm$^3$. The gases leaving the gasifier are cooled from 750$^o$C to about 90$^o$C before entering a bag filter. The clean gas with <1mg/Nm$^3$ tar and < 5 mg/Nm$^3$ of dust is cooled to about 50$^o$C, thus recovering the condensing moisture, and it is then introduced to a gas engine to generate power at about 25% electrical efficiency. The Viking gasification and power generation system has been operated for about 2220 hours. Each test campaign lasted for about 500 hours. The only waste material leaving the process is biomass ash. The primary cyclone located immediately after the gasifier operates at 400$^o$C. The pressure drop through the bag filter reaches about 100 mm water gauge. Most of the un-decomposed tar leaves the system by depositing on the ash particles collected in the bag-filter house. The fuel gas is cleaned further by a cartridge 'police' filter located in the gas engine fuel gas inlet line. The Viking demonstration project produces about 2-6 liters/hr of condensate with 1.0 g/liter of $NH_3$, < 20 mg/liter of Naphthalene, < 2 mg/liter of other PAHs, and traces of ammonia. This process waste water can be cleaned-up further by conventional biological treatment. The problems that need to be resolved prior to further scale-up of the 2-stage gasifier include tar deposition in heat exchanger, lumps of carbonate deposits on the ash discharge grate, and installing a refractory lining to protect the partial oxidation zone.

The internal combustion engine employed in the Viking demonstration is a Dentz MUM G2268, 3 liter, 3 cycle gas engine. The NOx emissions are about ¼ of emissions from natural gas operation (about 5% by volume) and the THC emission is about 21 ppmv compared to 366 ppmv for natural gas operation.

After the last test campaign, the DTU Viking gasifier has been cut open for inspection and reactor wall material analysis. Plans are underway to scale-up the process to a 500 kWth capacity system with separate drying (by super heated steam) and high-temperature pyrolysis. Future process scale-ups are targeted for 1-2 MWe systems with an overall electrical efficiency of 35%. It was pointed out that natural gas fired Caterpillar gas engines now operate at 41% electrical efficiency with little or no particulate emissions.

**Thomas Koch of TK Energie, Denmark** described the 3-stage, down-draft gasifiers developed by his company. They are built and operated in Denmark and Japan. The gasifier includes pyrolysis and partial oxidation zones, and a reformer based char gasification zones with a rocking grate for ash discharge. The two gasifiers were designed for 833 kWth (for Japan) and 3.125 MWth (for Denmark) capacities, at a cost of € 1 MM and € 3.1MM, respectively. The thermal efficiencies are 60 and 56% while the electrical efficiencies are estimated to be 24 and 32%, respectively. The gasifiers are designed for 7000 hours of continuous operation. In these initial designs, the gasifiers operated satisfactorily for the first 200 hours. Around 500 hours of operation, the gasification system required major mechanical repairs. Problems were generally encountered in the biomass feed system, in handling tar-laden gases, and in containing air leakage into the system.

The internally heated pyrolysis reactor has no mechanical grate that could be exposed to the high temperatures. Thermal stresses and thermal transients are kept at an absolute minimum. Designs with air-cooling of refractory and simultaneously preheating the gasification air did not work. Hence, high-temperature refractory materials are now employed.

So far, the Japanese gasifier has been operated for about 200 hours and the Danish gasifier for a total of 1200 hours. Performance observations include about 3-10% of char-loss, throughputs up to 2 MWth/m$^2$ grate area (note 250 kWth gas is approximately 1.2 MWth/m$^2$), and an overall thermal efficiency of 70 to 80%.

**Pasquale Giordano, Xylowatt, Switzerland** described the scale-up and operation of the 10 to 650 kWe capacity, Indian Institute of Science (IISc) gasifier. The Swiss application at Bulle, is designed for 2 MWe. This unit is designed to use 140,000 m$^3$ of woody biomass per year. Air is introduced into the down-draft gasifier mid-section to promote gasification and to reduce tar production.

In the present design, the raw product gas is cleaned by a cyclone, cooled by a heat exchanger, two water cooled scrubbers (one scrubber with chilled water), a drop-let separator, and polyester filter bags located before the induced draft fan. The cleaned product gas, at 10$^o$ to 15$^o$ C, is introduced into a naturally aspirated 6-cylinder engine to generate power. The Bulle operation replaced the 6-cylinder with a 4-cylinder engine in September 2004. Pine wood is sized in a knife or hammer mill (for top-size), with up to

25% moisture is used without separating the saw-dust. At a feed rate of 54 kg/hr of wood, 1 kg/hr of ash and 14 liters/hr or 0.2 kg/hr of sludge is discharged. Approximately 130 $Nm^3$/hr of product gas is produced with a LHV of 4.9 MJ/$Nm^3$. The measured thermal efficiency is 48% (108 kWth) and the electrical efficiency is 22% (50kWe). The raw gas tar content is 254 mg/$Nm^3$ with a dust content of 197 mg/$Nm^3$, while the corresponding numbers for clean product gas equal to106 and 42 respectively. The process discharge waste water has a pH of 8 and a $\lambda$=1.4 with the turbo generator.

**Richard Bain, NREL, USA** spoke about the Community Power Corporation(CPC) open-top, stratified, (no grate) gasifier. In addition to the aspirated air, secondary air is introduced into the char bed zone in the 310 stainless-steel gasifier. The micro-processor controlled CPC gasifier, coupled to a 15 kWe gas engine, employs dry gas cleaning to eliminate waste water disposal problems. The Alpha and Beta versions were built and tested in 2001 and 2002 respectively, and the pre-commercial unit was built and tested in Philippines in 2003. The CPC gasifier at Northpark High School in Walden, Colorado operates 6 to 8 hours per day. Operation includes 30 minute per week maintenance, primarily to replace the dust filter. The next demonstration, Biomax 15 biopower system producing 8 to 12 kWe, is also operated 6 to 8 hours per day. The measured and estimated emissions are summarized below:

| | **Conc., ppm** | **Est. lb/MWh** | **Calif. Regulation (Lb/MWh)** | |
|---|---|---|---|---|
| | | | Power | CHP |
| NOx | 30 | 0.65 | 0.5 | 0.7 |
| CO | 2 | 0.03 | 6 | 6 |
| THC | 4 | 0.03 | 1 | 1 |

Short duration tests were conducted with an ITN SOFC stack.

**Kari Salo of Carbona, Finland** talked about Evolution of Gas Cleaning in BMG Development and Applications. The primary focus was on research conducted from 1978 to 1984 at VTT and from 1985 to 1989 at Bioneer and Ahlstrom/Pyroflow (the present Foster Wheeler Co.,) on thermal decomposition of tar, gas scrubbing and dust filtration, It is noted that same biomass feed produces different types of tar with different types of gasifiers. Gas-to-gas heat exchangers designed to recover heat from raw product gases tend to be large in size. During 1989 to 1995, at Tampella Power/Enviropower hot-gas clean-up and catalytic tar decomposition were tested in a slip-stream. After 1996, Carbona investigated tar reforming in combination with gas filtering and scrubbing. The tar contained in the Carbona/Renugas fluidized bed gasifier is about 5mg/ $Nm^3$. In the most recent catalytic tar reforming tests conducted at VTT, at about 900$^o$C, using the 15cmx15cmx30cm long catalytic monoliths, the tar contents were reduced to low-enough level that the product gas could be introduced into a gas engine without wet-scrubbing. Future work with the VTT monoliths will strive to reduce the tar reforming temperature to about 700$^oC$. Although most of the raw gas contaminants can be reformed to clean burning compounds, heavy metals such as Cd, Hg, and As pose problems for the life and endurance of the catalytic monolith elements. Although Cl as HCl in raw gas is a problem most of it can be removed with filter ash ahead of the catalytic monolith.

Kari Salo reported that ground breaking for the 5.4 MWe, Carbona demonstration project in Skive, Denmark, employing the low pressure Renugas Process, has taken place. The process will initially employ wood pellets.

**Bram van der Drift, ECN, The Netherlands** reviewed the Olga gas cleaning process employing biomass derived tar as the scrubbing agent. The NH3 containing aqueous phase is air stripped to remove $NH_3$ which could be subsequently thermally decomposed (around 850$^oC$) by reinjecting $NH_3$ into the gasifier. Wet ESP has been demonstrated to be effective in producing a fuel gas suitable for gas engines.

**Jesper Ahrenfeldt, DTU, Denmark** described the power generation part of the DTU Viking demonstration project. The last test campaign showed that the gasification system was able to follow and keep-up with the power demand from the gas engine. The system was operated over the range of $\lambda$=1.2 to 2.4 with an estimated electrical efficiency from 32 to 25%. The system includes a naturally aspirated gas engine, operated under medium lean conditions ($\lambda$=1.5 to 1.8) and a high compression ratio of 16 to 20. The measured NOx and CO emissions were 2.4 ppm and 1.2 ppm respectively. Jesper recommends natural aspirated engines for small-scale biomass gasification power generation systems.

**Reinhard Rauch, TUV, Austria** presented an update on the Guissing BMG demonstration project. The TUV demonstration gasifier has logged in 9750 hour of operation. Some of the operational observations include:

- commercial pressure controllers designed for natural gas operation get spoiled with biomass gasification contaminants
- condensation of naphthalene on filter elements
- small deposits of tar do not pose problems for long-term operations

**Cordner Peacoke, Conversion And Resource Evaluation Ltd. UK** described the evaluation of a Capstone microturbine, at Biomass Engineering Ltd., on biomass derived LCV fuel gas (CO=17.5%, H2=17.5, CH4=2.3%, CO2=14, balance N2). Compared to operation with natural gas, the microturbine output was derated by 50 to 52%, when switched to the LCV fuel gas. Emissions from the microturbine were within the permitted levels. The calculated electrical efficiency at 29 kWe output is 28% (18% at 5 kWe). At this scale of operation the estimated cost of electricity is very high about 20p/kWh. However, scaling-up to use larger turbines, such as the 250 kWe Ingersoll Rand, should reduce the cost of electricity.

**Nick Barker, AEAT, UK** summarized the status of the small-scale UK biomass gasification projects. The biomass programs are driven by the UK Renewable Energy obligation of €¢10.8/kWh. The Royal Commission strongly recommends building biomass based CHP plants. Barriers to BMG applications include, poor reputation, poor reliability (in particular the integrated operation of the gasifier with gas engine), high purchase cost because of a lack of mass market to support volume production and with each application being unique the engineering costs are high, concern about waste water and emissions, high cost of grid connection, and other institutional challenges. The current RD&D projects are:

- Biomass Engineering Ltd: See Cordner's presentation given above. An 80 kg/h capacity downdraft gasifier was operated in conjunction with a Capstone C-330 Microturbine. Besides demonstrating fuel flexibility, a ceramic filter was investigated to remove dust prior to introducing the fuel gas into the microturbine. The scale-up to test and evaluate a 250 kWe Ingersoll Rand is under investigation.
- Exus Energy: The commissioning of the 90 kWe, Blackwater Valley demonstration was described. The catalytic cleaning of the IC engine flue gases was shown to be effective. The 120 kWe, BEDZED demonstration plant is operating satisfactorily with silencers at 90 kWe.
- Stirling Engines: Tests with an 8 kWe Stirling engine were completed. There is not much interest with this device in UK.
- SEL Cyclone Gasifier – Project Terminated
- Brook Hall Rural Generation in Eniskillen: Operated the Fluidyne down-draft gasifier for more than 17,000 hours. Cost of maintenance is high. Installing this technology with a turbine at Queens University, Belfast is under consideration.
- Compact Power: Employs preheated wood and found to be expensive.
- Talbots Head: Tests with an indirectly heated microturbine cycle have shown that this system is less sensitive to fuel than a gasification based system. Although, the emissions are better, the efficiency of electricity generation is not good. The metallic heat exchangers in a 50 kWe PDU has performed satisfactorily. Efforts are underway to find a site for demonstrating this system.

**Henrik Christiansen, DEA, Denmark,** presented the challenges and issues related to advancing new BMG processes and projects in Denmark. During the last ten years, in Denmark while the cost of biomass fuels remained fairly constant at 40 DKK/GJ, gas and oil prices increased from about 85 DKK to 100 DKK/GJ. The Harboore plant is now in the 10$^{th}$ year of its development and operation. The focus on biomass energy R&D in Denmark is on standardization of wood fuels, gas and tar measurements, gas cleaning, waste water and other contaminants

<u>Day 2: Tuesday, October 26, 2004</u> : plant visits to Babcock and Wilcox Vølund - Harboore BMG power plant, BioSynergi's Two-stage BMG plant, and the Viking/2-stage demonstration plant and the low-temperature CFB BMG pilot plant at DTU.

<u>Day 3: Wednesday, October 27, 2004: Task Meeting</u>: Following the approval of the draft Agenda, the members approved the draft Minutes from the Spring Task Meeting, held in Vienna, Austria, May 25-27, 2004.

**COUNTRY REPORTS:**

**New Zealand**: Ian Gilmour, University of Canterbury reported that NZ is supporting a \$2.5 MM/year biomass R&D program for the next 4 years. At the University of Canterbury, a laboratory scale, 20 kWth, 2-stage gasifier, similar to the Battelle

Columbus/FERCO Sylvagas BMG process, has been built. $100K is set-aside to design and build a flexible research unit that could be operated as a FB or CFB, either at low or high pressure. A two-stage gasifier/cyclonic combustor is under testing and evaluation at the Waterville plant. The Fluidyne down-draft gasifiers are considered to be appropriate for NZ's CHP applications. Eventually, NZ would like to build, test, and evaluate the performance of a 50 MWth BMG IGCC plant. NZ's main gas fields are depleting and there is an increasing awareness to develop renewable energy technologies.

**Switzerland**: Ruedi Buehler, Umwelt+ Energie reported that the Pyroforce/Xylowatt BMG system has logged in 6000 hour of operation with an Jenbacher IC engine. Paul Scherrer Institute is working on biomass utilization for synthesis gas and SNG. The synthesis gas and SNG research is conducted on a slip-stream of the product gas from the Güssing BMG CHP plant in Austria. The raw gas stream is scrubbed to remove Cl and passed through a ZnO bed to remove sulfur. These tests are conducted at 10 bar pressure. A single-step, combined water-gas shift and methanation catalyst has been tested for over 200 hours. The raw product gas contains 45% CH4, 6% H2, 1% CO, and the rest is mostly CO2 (and 2% N2).

**The Netherlands**: At present NL derives only 1% of the 35 PJ consumed annually from biofuels. The targets are to raise the contribution of bioenergy to 10% by 2020 and to 30% by 2040. The Essent/Amer BMG co-firing project has been reactivated with demolition wood after some downstream plant modifications. This includes raising the raw gas handling temperature from 200$^{o}$C (primarily to remove ammonia) to about 400 to 450$^{o}$C. The cyclone separator operates at 65 to 70% efficiency to remove carry over dust. The estimated cost for biomass derived electricity is about €¢7/kWh. Other BMG RD&D projects include the activities at NUON, Siemens?, BTG, ECN, University of Delft (ceramic filter bag research), ChrisGas project, University of Twente, etc., The Milena Process, similar to the TUV Process, produces a product gas with 40% CO, 15% H2, 17% CH4, 6% C2+, 1% C6H6, 12% CO2, and 9% N2 and Ar. The Dutch Torrefaction process preheats biomass at 200C before subjecting it to gasification.

**Finland:** The status of the 7 MW capacity, Novel Process demonstration at Kokemaki has been described on Day 1. The Entimos, 2 MWth BMG plant has been shutdown. Puhdasenergia OY is commercializing a down-draft BMG process in the 100 to 1000 kWth range. The process is coupled to a robust Russian tank engine to generate power. The Wisaforest CFB BMG plant has been shut-down after 20 years of operation. The 60 MWth Lahti and the 40 Mwth Corenso plastic waste gasification plants are in operation for the last 4 years. Two, 50 to 80 MWth MSW/RDF Corenso (?) gasifiers are currently being designed for co-firing application.

The main R&D focus is on gas cleaning for MSW gasification. VTT is evaluating a variety of gas cleaning concepts on a 3 MWth slip-stream at the Lahti plant. The objectives are to develop catalysts for gas clean-up for the Novel Process and the evaluation of synthesis gas production and processing schemes. Other research projects are looking at improving the economics of FB BMG processes by advanced ash management, development of a fly-ash oxidizer.

**Italy:** Now there is more opposition to operating the Greve/Chianti TPS RDF gasifiers. The feed system has been modified for the 160 kWe China BMG plant. Plans are underway to test and evaluate oxygen-blown BMG in China.

**USA:** The recently updated US report is posted on the Task 33 Website under Country Reports. In Mid October 2004, the MTCI, Big Island BLG plant has completed 500 hours of operation with a single gasifier. The $90 MM project includes 50% cost-share from industry.

Gas cleaning research includes investigations with three inorganic and three organic compound schemes(?) at Iowa State, NREL, and NETL??

**Austria:** The present credit for green electricity is €¢13/kWh. Austria is part of the RENEW project, along with Daimler Chrysler, Renault, Volvo, and Volkswagen AG. The 4-year project started in 2004 will investigate methods to produce 20% of transportation fuels from biomass by 2020. About 10 Nm3 of slip-stream gas at Guissing is used to investigate the production of Fischer-Tropsch diesel. The slip stream draw will be increased to 200 Nm3 in February 2005 and to about 600 Nm3 by the end of 2005.

**Denmark:** the Hogild project will be terminated. About 90% of engineering work is completed for the Energi/E2 straw gasification project. Other notable projects include the Carbona/Renugas CHP project in Skyvie, TK Energie project in Gjol and Graestad.

## STRUCTURE AND GUIDELINES FOR FUTURE TASK MEETINGS

The Task Members discussed the structure and the general program for the FUTURE semi-annual Task Meetings. The consensus recommendations are given below.

1. All Task members are urged to devote three full days to the Task Meeting. Late arrivals and early departures by Task Members diminish the value of group discussions and they also tend to interrupt the on-going proceedings.
2. In order to engage Task Members in discussion on technical issues and country activities, schedule these discussions along with other Task related matters for the **first day** of a three-day Task Meeting.
3. Day 2 should be set-aside for Task Workshop and Day 3 either for a plant/site visit or continuation of technical discussions, Country Reports and if required to extend the Workshop to a more than 1 day event.
4. In case there is no plant/site visit, the Task Leader should seek the majority concurrence of Task Members to move the Workshop to the 3rd day, so that there is continuity in discussion on matters from Day 1 that could be extended to Day 2.
5. To present detailed **technical** Country reports, allot adequate time and split these reports into 5 for each of the two semi-annual Task Meetings.
6. Develop an agenda with time assignments for all technical presentations and use the balance of time for the remaining 5 Country reports.
7. Plant/site visit is not a necessity for each Task Meeting. Visits should be scheduled primarily to see **new** and **informative** operations.

## FUTURE TASK MEETINGS

The schedule for Task Workshops is revised as follows:

**Spring 2005** – WS3: Hydrogen and Synthesis gas for Fuels and Chemicals (in cooperation with the Swedish SYNBIOS Conference), Coordinator: NL, May 18-19, Stockholm, Sweden

**Fall 2005**, **Spring 2006**, and **Fall 2006:**
1. State of the Art of Gas Clean-up – tentatively listed for fall 2005
2. Health and Safety of Biomass Gasification Installations – details TBD
3. Co-firing Applications involving Biomass and Waste Gasification- details TBD