Joint RTD programme on Gasification

Achieved Results

in the framework of ERA-NET Bioenergy

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Summary

Background
In the framework of ERA-NET Bioenergy, the second joint call was launched on June 1st 2007 for proposals on the topic “Gasification: cleaning and treatment of product gas from biomass gasifiers”. Seven countries participated with their national programmes in this coordinated activity: Austria, Denmark, Finland, Germany, the Netherlands, Sweden and the United Kingdom. The call was coordinated by Agency NL (formerly SenterNovem) from the Netherlands.

Common processes
National processes used in a call differed between the participating countries. Therefore, every single step had to be made transparent and discussed in detail before launching the call. Consensus over submission, pre-check, jury process, project evaluation, national clearing process and contract negotiations were important steps in the process in order to have a succesful call.
The jury was composed of experts in the field of biomass gasification, one from each participating country. The jury experts evaluated the 10 submitted proposals according to 10 evaluation criteria with points given for each criterion. The jury experts had the right to reject a proposal if they had strong objections against a proposal. The final result from the jury session was a ranking list. Taking the budgets from the participating countries into account the jury recommended 6 projects for funding and 4 projects for rejection. The 10 projects had a total budget of 6.8 million euro.

Projects funded
The recommendations of the jury were followed by the participating countries during the national clearing processes: 6 proposals were funded and 4 proposals were rejected.
From the participating countries different budgets were available. The average requested budget for the funded proposals was 616,000 euro and the total requested budget was 3.7 million euro. The rejected proposals had a total requested budget of 3.1 million euro.

Evaluation
The evaluation of this Joint European R&D initiative shows that the corresponding projects have focus, that the results reported so far are very promising and attractive for the industry. Research institutes, industry and policy makers have common interest in making innovations successful.
International collaboration offer interesting new opportunities for innovations to pay off in the near future, and support development towards affordable sustainability in Europe.
Continued support of joint initiatives is recommended, based on further consolidation of international collaboration a.o. through effective monitoring of innovation.

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1 Introduction

ERA-NET Bioenergy is a network of national government agencies and ministries responsible for coordinating and funding national research efforts on bioenergy. The goal of this network is to strengthen national bioenergy research programmes by enhancing cooperation and coordination between national agencies. The aim is that, through collaboration, the individual national programmes produce higher quality results, and through coordination complement each other, avoiding duplication.

To reach these goals the network is pursuing four lines of activity:

- Establishing structures for the systematic exchange of information
- Identifying common strategic issues to form a basis for integrated programmes and projects
- Undertaking joint activities such as common programme monitoring
- Implementing joint research activities

One of the tasks of ERA-NET Bioenergy is to carry out and gain experience from pilots of joint transnational research. The implementation will be done with transparent mechanisms such as evaluations, project co-operation and calls for research proposals. The second joint call was launched on June 1st 2007 for proposals on the topic “Gasification: cleaning and treatment of product gas from biomass gasifiers”. Seven countries participated with their national programmes in this coordinated activity: Austria, Denmark, Finland, Germany, the Netherlands, Sweden and the United Kingdom. France did not participate, but joined as an observer. The participating countries agreed on a common call text and common procedures concerning e.g. submission of proposals, jury process and evaluation of the proposals.

Organisation	Country	Acronym	Dates
SenterNovem/NL Agency	The Netherlands	ANL (co-ordinator)	Since start
Ministry of Economic Affairs	The Netherlands	MinEA	Since start
Finnish Funding Agency for Technology and Innovation	Finland	Tekes	Since start
Swedish Energy Agency	Sweden	SEA	Since start
Department of Trade and Industry	United Kingdom	DTI / BERR	Till 1-9-2007
Engineering and Physical Sciences Research Council	United Kingdom	EPSRC	Since start
Federal Ministry of Transport, Innovation and Technology	Austria	BMVIT	Since start
The Austrian Research Promotion Agency	Austria	FFG	Since start
Austrian Energy Agency	Austria	AEA	Since start
Fachagentur Nachwachsende Rohstoffe	Germany	FNR	Since start
Federal Ministry of Agriculture, Food and Consumer Protection	Germany	BMELV	Since start
Energinet.dk	Denmark	Energinet.dk	Since 1-4-2006
French Environment and Energy Management Agency	France	ADEME	Since 1-4-2006
The National Centre for Research and Development	Poland	NCBiR	Since 1-12-2008
Sustainable Energy Ireland	Ireland	SEI	Since 1-12-2008

Table 1. Members of ERA-NET Bioenergy. Members involved in the Joint call gasification are highlighted

This report summarises the results of this joint call.

2 Accomplishing the programme

2.1 Opening the call for proposals

On June 1st 2007, the joint call for proposals on the topic "Cleaning and treatment of product gas from biomass gasification" was launched. In this coordinated activity, seven countries participated with their national programmes: Austria, Denmark, Finland, Germany, The Netherlands, Sweden and the UK. France did not participate, but joined as an observer.

Proposals were invited from companies and/or research organisations depending on national funding conditions. There should have been at least one industrial partner in the consortium that is able to implement the developed technological and scientific know-how to reach the goal of the call. Research project outputs are expected to provide benefits to all partner countries. The proposed consortia in the projects had to consist of partners from at least two of the countries involved in the call.

Each partner in the consortium applied separately to the relevant national agency. The proposal had to be submitted in two parts:

- The common proposal – written jointly by the applicants of the consortium. The common proposal had to be in English, as it was evaluated by an international jury and formed the basis for the funding decision.
- The national standard application form(s) – following the rules of the agency.

In total twelve proposals were submitted. Ten proposals were eligible applying for in total 6.8 M€.

2.2 Evaluation of proposals

The evaluation of proposals was conducted by an international jury who provided recommendations for funding. The ERA-NET Bioenergy member NL Agency (formerly SenterNovem), from the Netherlands, was the secretariat of the call, collecting all the inputs from the various evaluation processes and hosting the jury process. For information exchange, a virtual office was used for sharing the documentation emanating from the evaluation process.

The evaluation process was enclosed by a number of sub-processes, as follows.

2.2.1 Pre-check of proposals

The evaluation of proposals started with a pre-check conducted by the responsible persons at the agencies. The aim of the pre-check was to guarantee that the proposals met all formal and financial requirements and that the projects fit into the participating national programmes. The pre-check dealt only with formal aspects and did not evaluate the scientific quality of the proposals.

2.2.2 Jury evaluation process

The jury was composed of one expert from each country participating in the call.

Firstly, the jury experts made pre-judgements of the proposals that had passed the pre-check. The judgements were made using an evaluation form based on 5 indicators:

- contribution to the goals of the call
- technical and scientific quality

- qualification of the consortium
- project management
- outputs and exploitation.

Thereafter, the final judgements were made during a meeting lead by a chairman. The members from the ERA-NET Bioenergy countries not participating in the programme were welcome to join the jury meeting as observers. During the jury meeting, the experts discussed their scores for each of the evaluation criteria. Scores were summed to a total score for a project. The total scores resulted in a ranking list of the proposals. In case a jury expert had strong objections against a proposal a veto could be used to block a proposal from being ranked. Using a veto was restricted to the jury experts from participating countries in a project. The veto mechanism was only used in very reasonable manners. In case a veto was used the score for this particular project was ‘0’.

In addition, the jury experts had to formulate recommendations for all projects and comments on each proposal to help to formulate the rejection and invitation letters. The ranking list projected whether the projects were

- probably funded with recommendations on possible obligations to be fulfilled by the proposers. These were the ‘green’ projects.
- probably rejected with recommendations regarding the reasoning and wording in the rejection letter. These were the ‘red’ projects.

Green projects were to be funded following the ranking list top down as long as as there were resources available following individual country lists. Red projects were not te be funded even if sufficient resources would have been available.

2.2.3 National decisions for granting proposals

The final decisions about the projects were made nationally by the ERA-NET Bionergy partners according to each country’s national rules, based on the recommendations of the jury and following the ranking list. Countries were not allowed to change the order of the ranking list. It was agreed that in case one country should reject a joint project during the national decision process, this whole project would not be funded. It was also agreed that nothing should be published before the national decisions had been made.

2.2.4 Clearing process

After the national decisions had been made the participating partners were informed on the outcome of the national decision processes. Not until all national decisions had been made by the participating countries a binding feedback was sent to the proposers.

2.3 Funded projects

The funded projects are listed in Table 2.

Project No	Title of project	Project acronym	Participating country	Total budget €	Granted support €
JWP2-1	Tar removal from low-temperature gasifiers		DK	470,000	410,000
			NL	274,000	250,000
JWP2-1 Total				**744,000**	**660,000**
JWP2-3	Energy efficient selective reforming of hydro carbons		DK	202,700	203,000
			SE	535,458	238,095
JWP2-3 Total				**738,158**	**441,095**
JWP2-6	Development of a photoionization-detection technique for on-line measurement of biomass tar concentrations	Tar-online	NL	249,959	250,000
			SE	244,740	216,762
JWP2-6 Total				**494,699**	**466,762**
JWP2-7	Cleaning and treatment of Product Gas from biomassgasifiers optimisation of the H2:CO -ratio in synthesis gases for the production of 2nd generation biofuels	OptiBtL	AT	194,685	146,000
			DE	635,707	417,772
JWP2-7 Total				**830,392**	**563,772**
JWP2-9	Mop Fan and Electrofilter: an innovative approach to cleaning product gases from biomass gasification	EMF	DE	542,417	426,203
			UK	313,716	251,000
JWP2-9 Total				**856,133**	**677,203**
JWP2-10	Intensification of Syngas Cleaning and Hydrogen Separation	Synclean	UK	325,616	222,000
			DE	614,500	349,870
JWP2-10 Total				**940,116**	**571,870**
Total				**8,503,293**	**3,380,702**

Table 2. Budgets and grants of the projects approved

3 Evaluation of the joint programme

The results of the funded projects were evaluated by using the same approach and criteria, as initially applied in the project proposals assessment process. For this reason, the evaluators proposed to take the national incentive policies into account as well, in an attempt to find more balanced answers to the questions concerning innovation, as set out in the Joint Call and ERA-NET Bioenergy.

Based on information arising from queries amongst project owners and Joint Call coordinators, compliance with Joint Call objectives was examined first. Subsequently, the national policies with respect to biomass gasification were analysed in order to gain a greater understanding of the essence (potentials) of the project results, and to gain a better feeling as to whether continued R&D would be necessary or not.

3.1 Conclusions

Compliance with **Joint Call objectives**

1. *Good progress was madein the porjects and interesting R&D results were reported, which offer clear perspectives for further quality and product gas composition improvement.*

Three projects (**P1**, **P2**, **P4**)[1] basically concern the improvement of quality and composition of product gas i.e. online detection and cleaning technologies in order to enable integrated and energy efficient operation with downstream equipment and subsequent conversion processes.

It appeared in projects **P3**, **P5**, **P6** that robustness (reproduction), and reliable cost indications through solid model calculations, open new ways towards further integration or intensification of treatment systems and conversion processes. Beyond application in the energy & heat production sector industrial and research partners also seek for challenges on behalf of the petro & chemicals sector.

2. *Projects revealed industrial relevance, focussing on actual innovation trajectories (projections), niches and participation of industrial partners.*

The projects fossued on a range of innovative research issues in gasification innovation. Results show an even division of research effort into both High-Temperature (P3, P6) and Low-Temperature technology innovations (P4, P1) i.e. oil based gas washing of tars from the product gas.

The HT-gasification systems include the so-called Integrated PIM (Proc. Intensif. and Miniaturization) technologies, having a specific and central role for gasification, and allothermal and autothermal oxygen steam gasification incl. CO-shift.
The LT-gasification systems concern (OLGA) and cooling, filtration and partial oxidation of the product gas).
These are current known systems in and outside Europe.

[1] Codes: P1 (JWP2-6), P2 (JWP2-9), P3 (JWP2-10), P4 (JWP2-1), P5 (JWP2-3) en P6 (JWP2-7); see for more details also chapter 7: Project summaries

3. *Within the projects a suitable range of research issues were covered including both innovative conditioning/handling and detection techniques and, in addition process and equipment design.*

All gasification projects focussed, generally speaking, on gas cleaning and conditioning issues in order to overcome application hurdles. Three projects (**P3, P5**, **P6**) put specific additional attention to catalysis and synthesis.
Projects evidently concentrate on a range of research issues covering innovative cleaning/handling and detection techniques for both low and high tar and dust concentrations (**P1**, **P4** and **P5**), process and equipment design (**P2**, **P4**, **P6**) not only for improved cost and energy efficiency, but also for improved operational flexibility and convenience from compatibility with, or integration of, various downstream process units of equipment.

4. *Projects provide a source of knowledge for the development of competitive, reliable and environmentally friendly solutions.*

Projects focussed on competitive and sustainable solutions, and considered possible future availability of competitive alternative (measuring) techniques (**P1**), tools for comparative process evaluation of optional component/unit sequences (**P2**), process integration and process intensification (**P3**, **P6**) and high Bio-SNG yields.

Industrial partners collaborated in the projects to develop solutions. These reflect the industrial demand and operational needs of the actual market of biogas producers/users, which are currently familiar with various HT- and LT-gasification and subsequent cleaning and handling processes.

3.2 Observations

Compliance with **ERA-NET Bioenergy objectives**

It is not possible to provide conclusive answers to the questions addressed in the evaluation of the Joint Work Programme in the rpesent evaluation. Such answers should provide clear evidence as to what extent the Joint Work programme, and Joint Calls, contributed to the ERA-NET Bioenergy objectives. The evaluation method applied by the evaluators, however, does offer interesting new opportunities for sensoring and monitoring innovations. A brief discussion on the method is given in the main part of the evaluation report.

Although non-exhaustive for this purpose, analysis of the short-term project results was carried out to “assess” compliance with ERA-NET objectives. Some interesting observations are listed here.

Pre-conditions for quality improvement of bioenergy research programmes do appear to be sufficiently present. Programmes offer comfortable room for cooperation between Member States.

- Most incentive policy programmes on gasification show rather broad themes (e.g. mitigation of Climate Change);
- The Dutch policy programme has a relatively specific political theme, i.e. Green Gas;
- Respective policies in those countries leading the projects fit in well with the political themes of partners in projects, e.g. UK and DE combine their respective political themes and likewise DK and SE combine their political themes with NL.

National incentive policies share focus. International relevance, interest and participation of industrial parties in various settings are quite evident.

- The overall focus from the political point of view appears to be on *heat & power production*;
- Five projects were aimed to produce syngas for energy applications; all projects show focus on the energy sector;
- The sectoral focus in the project partner countries corresponds well with the focus in the project leading countries;
- At least one industrial partner is represented from the country of the project leader in most projects.

3.3 Recommendations

Evaluation of this Joint European R&D initiative shows that the corresponding projects have focus, that the results reported so far are very promising and attractive for the industry. Research institutes, industry and policy makers have common interest in making innovations successful.
International collaboration offer interesting new opportunities for innovations to pay off in the near future, and support development towards affordable sustainability in Europe.
Continued support of joint initiatives is recommended, based on further consolidation of international collaboration a.o. through effective monitoring of innovation.

4 Project summaries

Project No	Title of project	Project acronym	Participating country	Total budget €	Granted support €
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4.1 JWP2-1 Tar removal from low-temperature gasifiers

Abstract from the report

Biomass is considered an important source of renewable energy needed to realise national and European renewable energy goals and goals for CO2 reduction. Biomass gasification as a technology is recognized generally as highly desirable because of its high efficiency towards all kind of energy products. Biomass can be gasified using many different technologies ranging from high-temperature processes as high as 1500°C to low-temperature processes as low as 500°C. The project "tar removal from low-temperature gasifiers" focuses at gasification processes below 800°C. These so-called low-temperature biomass gasification processes have certain advantages, i.e. they are suitable for fuels with low ash melting points, have a high cold gas efficiency and low tar dew point, require easier gas cooling and cleaning, provide longer residence times, and are associated with less heat transfer limitations within gasifier compared to gasifiers operated at 800 to 900°C.

For some applications the main disadvantage of low-temperature gasification is the relatively high tar level in the gas. This is why these processes generally are not considered being suitable for connection to gas engines, gas turbines, fuel cells or catalytic synthesis reactors. All the advantages mentioned above however, urge researchers to develop gas cleaning systems that can extend the application of low-temperature gasifiers from simple co-firing to also the mentioned applications. Being

able to handle tars in the 700-800°C interval would be very attractive. This temperature is high enough to have limited tar yield and low enough to have an acceptable tar dew point.

In the project, two gas cleaning technologies are adapted and tested in connection to low-temperature gasification, i.e. (i) the OLGA tar removal technology developed by the Dutch partners in the project and (ii) the cooling, filtration and partial oxidation developed by the Danish partners in the project. The project aims at judging technical and economical suitability of these up-scalable tar removal methods connected to high-efficiency low-temperature gasification. Suitability opens the way to high efficient and high fuel flexible biomass gasification systems for the connection to gas engines, gas turbines, fuel cells or catalytic synthesis gas reactors.

It is concluded that lowering the gasification temperature will require some modifications of the OLGA technology, though it is expected OLGA can remove also tars from the product gas of a gasifier operated at temperatures below 650°C to low enough levels that a gas engine should run, based on tars. For dust removal, bag house filters are suitable when operated above the tar dew point of the gas. If this would require too high temperatures technically or economically feasible for filters, the OLGA could be applied in which dust can be removed at a temperature below the original tar dew point of the gas. The cooling of gasification is a challenge as long as dust and tars result in fouling in shell and tube heat exchangers. To overcome such problems so called "evaporative coolers" can be used where the evaporative energy of water (or some other liquid) is used to cool the gas.

4.2 JWP2-3 Energy efficient selective reforming of hydro carbons

Abstract from the report

The research project "Energy efficient selective reforming of hydrocarbons", funded by the Swedish and the Danish Energy Agency has now reached its end, and we hereby present the final report. The report is an overview of the work. Details of the work within the different areas can be found in the reports from each part.

In this project, an innovative method for tar removal and reformation of hydrocarbons was investigated: Chemical Looping Reforming (CLR). This gas treatment has the potential to be economically competitive, reliable and environmentally friendly (due to higher energy efficiency, amongst others).

The aim of the CLR is to

• eliminate downstream problems with tar
• simplify the energy recovery from the hot product gas
• selectively save lighter hydrocarbons for the production of synthetic natural gas (SNG)

A guarantor for the outcome of the project is the engagement of Göteborg Energi, which has a commitment to build a 20 MW output SNG plant by 2012.

DTU (Danish Technical University) is responsible for carrying out the laboratorial part, where different oxygen carriers for the CLR have been considering their capability of selectively reforming hydrocarbons. The conclusion was that, of the four carriers tested, the Mnand Ni40 was the most promising.

CUT (Chalmers University of Technology) has installed a 600 W CLR unit connected to a slipstream from the gasifier. During the firing season 2010 the CLR has been tested with raw gas for 36 hours and the results so far show that the equipment works as intended and that it can reduce the amount of tars substantially.

GE (Göteborg Energi AB) together with SEP (Scandinavian Energy Project AB) and CUT have studied the integration of a methane production plant to an existing boiler. The main focus of the study has been the gasifier and the CLR. The integration of a 100 MW methane production plant is estimated to cost 1.3-2.4 billion SEK.

The different work packages have altogether shown that a CLR is a possible solution to the tar problem, both technically and economically.

4.3 JWP2-6 Development of a photoionization-detection technique for on-line measurement of biomass tar concentrations

Abstract from the report

Biomass gasification technology is suffering from a troublesome market penetration due to the simultaneous production of undesired contaminants like tar. Tar is recognized as the most problematic constituent of producer gas since most applications of producer gas require gas cooling. Tars will then condense downstream the gasification reactor, causing fouling, corrosion and blockages. There have been several attempts to avoid the production of tars or to remove and/or convert the tars. It is obvious that the measurement of the tar content in crude and cleaned gases is crucial. Conventional sampling methods based on cold trapping, solvent extraction/evaporation and a final determination by weight or gas chromatography are time consuming, cumbersome and always discontinuous. A real online method producing a continuous signal for low tar concentrations (below 500 mg/Nm^3) does not exist yet.

The project resulted in the “Proof of Principle” of an online tar analyzer based on Photo Ionization Detection (PID). The PID utilises ultraviolet light to ionize gas molecules; an electron can be removed from its molecule. The current generated by the lost electron(s) is a measure for the concentration of the organic compound.

Main findings of the project are:

1. the response of each model compound is linear but the slope is different
2. the PID is sensitive to gas flow rate, temperature and gas density
3. the PID signal responds rapidly on changes in concentrations of the model component.
4. the PID-signal and the naphthalene concentration as model compound (measured by SPA) are correlated according to: tar = 1.6 * PID-signal in mV
5. The correlation between the PID-signal and the real tar concentration (measured by SPA) appeared to be: tar = 6.1 * PID-signal in mV

The most important technical problem to be solved is to keep the properties of the flow to the PID constant (rate, density, pressure temperature). Furthermore, the UV-lamp is contaminating. The PID signal decreases linearly by 40% over a period of about 50 hours. A cleaning frequency of two days is acceptable while the cleaning itself is only a matter of few minutes.

4.4 JWP2-7 Cleaning and treatment of Product Gas from biomassgasifiers optimisation of the H2:CO - ratio in synthesis gases for the production of 2nd generation biofuels

Abstract from the report

Biomass gasification is a possibility to produce from a solid fuel a synthesis gas, which can be used for many different applications (production of chemicals like ammonia, production of heat and electricity, production of 2nd generation biofuels like FT diesel). In this project two different gasficiation technologies are utilised:

- Allothermal steam gasfication, developed by TUV
- Autothermal oxygen steam gasification developed by Cutec.

In this project the optimisation of the gas composition for the Fischer Tropsch synthesis and other possible synthesis reactions are investigated. This includes the reforming of hydrocarbons and the CO-shift reaction to adjust the correct H2:CO ratio.

The biomass CHP Güssing uses the allothermal steam dual fluidised bed gasifier and produces a high grade product gas, which is used at the moment for the CHP in a gas engine. As there is no nitrogen in the product gas and high hydrogen content, this gas can be also used as synthesis gas. At the biomass CHP Güssing there are about 10vol% of methane in the product gas, which means, that about 1/3 of the chemical energy is bounded in the methane and cannot be utilised in the Fischer Tropsch reaction. The aim of this project is to convert this methane over a steam reforming step to hydrogen and carbon monoxide and to increase the conversion efficiency from biomass to FT fuels in this way.

In the first experiment it was shown, that the reactor itself has no catalytic effects and the gas composition does not change over the reactor. It was also recognised, that there is soot formation, if the steam carbon ratio is too low.

In the experiments with the methane reforming catalyst it was shown, that the higher hydrocarbons are reformed almost completely, but the methane conversion was not as high as expected. Also a deactivation of the catalyst by carbon formation occurred.

The other 2 types of catalysts worked well without any deactivation by carbon formation or sulphur poisoning. With both types a parameter variation was done and with the aromatics reforming catalyst also long term experiments were done.

In the parameter variation the optimal temperatures and steam-carbon ratios were found , but it was not possible to get 100% conversion of methane. For the higher hydrocarbons 100% of conversion was reached, but for methane only about 50% of conversion could be reached. This was mainly due to the fact, that the heat transfer in the reactor was not good enough. To reach higher conversion not a 2 step reactor as used in this project, but a 3 stage reactor would be necessary.

Based on the results of WP2 the mass- and energy balances for a commercial plant were calculated. Here 5 different cases were done. As final product on the one side FT products on the other side hydrogen was used for the simulation. The results are also compared with previous results, where the steam reforming step was not included into the overall system.

Based on the simulation results an economic analysis of the overall system was done and also with previous results compared, where the steam reforming step was not included. The main result of the economic evaluation is that hydrogen can be produced at costs between 20-30 Eurocents per Nm^3 or 6-9 Eurocents per kW and FT fuels at costs between 0,8-1 € per litre or 8-10 Eurocents per kW.

4.5 JWP2-9 Mop Fan and Electrofilter: an innovative approach to cleaning product gases from biomass gasification

Abstract from the report

The results of the EMF project showed that proper gas cleaning and conditioning in smaller gasification plants can be achieved by combining innovative components. All of proposed components of the innovative gas cleaning and conditioning system including the gascooler, the mop fan cleaning unit and the electrostatic precipitator (ESP) have been tested individually and collectively with biomass fluidized bed gasifiers. The mop fan cleaning unit has been thoroughly characterised at University of Nottingham (UNOTT), whereas the gas cooler, the ESP and the integrated system of the gas cooler, the mop fan and the ESP have been tested at Berlin Institute of Technology (TUB).

The mop fan cleaning unit was successfully applied to the cleaning of the product gas from the laboratory-scale (2 ~ 3 kg biomass/hr) biomass fluidized bed gasifier at UNOTT. Different fan rotating speeds and different flow rates of spray water were tested to optimise the performance of the mop fan gas cleaning unit. The particle removal efficiency with the tested mop was in the order of 50% without spraying water and as high as 90% if a small amount of water was sprayed on the mop fibres. The mop fan also showed a promising potential in removing water soluble species, e.g. N-species (ammonia etc.) in the product gas, with the removal efficiency of more than 80% achievable.

The gas cooler with structured tubes provided by ERK Eckrohrkessel GmbH has greater efficiency in heat exchange compared with the straight tube design. Preliminary qualitative analyses of residues in the heat exchanger indicated some minor deposition of tar compounds on the internal tubes. To quantify the fouling of the gas cooler, more operational time with the gas cooler on stream is needed.

Quench and ESP from Beth Filtration GmbH showed their capability for tar removal from the gas. The condensation of heavy tars takes place mainly within the Quench, whereas aerosols (droplets of water, tar and from the quenching medium (Rape Methyl Ester (RME)) or small particles are separated in the electric field of the ESP. Compounds which are present in the product gas in gaseous form or as vapour are almost unaltered by the electric field of the ESP. The quenching/washing unit before the ESP is necessary to bring down the temperature to a point where tar substances will condense on condensation nucleus. The removal of benzene, toluene, and xylenes (BTX) and parts of the naphthalene is strongly dependent either on a low temperature in the system or on an adequate washing medium. It seemed that not all RME was removed by the ESP. Improvement in the Quench design (nozzles, size and flow regime) and adaption of the gas velocity and residence time in the subsequent electric field could lead to better performance.

The testing of the integrated system has been carried out with the originally proposed component sequence (Gas Cooler, Quench, ESP and Mop Fan) with TUB gasification plant. The mop fan cleaning unit which uses a fine spray to enhance gas cleaning had led to problems with the pilot

burner (which burns off the cleaned product gas) at the TUB plant. The amount of the fresh water used by for the mop fan cleaning unit had to be reduced significantly.

The results obtained with the project show that the originally proposed setup should be modified: following the gas cooler, the quenching unit is used to further reduce the gas temperature. In accordance with earlier findings in literature, a quenching system with oil or a tarry fraction of the collected quenching medium could be used to separate heavy tars from the gas. The waste water generated in the mop fan cleaning unit was an oily light coloured liquid with a strong solvent-like smell and could be used as the quenching medium. The mop fan cleaning unit can then be used for the removal of lighter tars by applying a compact device rather than large washing columns and finally the ESP is used to remove droplets of water and condensed tars from the gas.

4.6 JWP2-10 Intensification of Syngas Cleaning and Hydrogen Separation

Abstract from the report

The ultimate objective of the Project is to develop integrated biomass based energy and feedstock technologies based on Process Intensification and Miniaturization (PIM) in which gasification has a central technological role while supply of biomass is essential for its sustainability. In gasification, the most important problem is the control of syngas composition; namely, concentration of tars and combustible gases. Although biomass supply was not part of the original aim of the project, materials used in syngas cleaning could also be used as 'synthetic rhizosphere', (SRS) to intensify growth of biomass or crops under water and fertilizer stress. These materials can be used as syngas cleaning media and when their capacity for tar removal is reached, they can then be used as soil additive which then function as SRS. In this Project, we have therefore developed and where appropriate, patented the following technologies:

1. Understanding of tar formation in gasification and the nature of tars formed
2. Primary tar removal within the gasifier, enhancement of syngas calorific value and hydrogen concentration,
3. Development of 3 different equipment for the intensified syngas cleaning and tar, removal - tar degradation which can also be integrated with the gasifier,
4. Re-designing of the gasifier and process conditions to generate low tar, high calorific syngas with in-situ hydrogen generation and removal and carbon dioxide capture,
5. Development of hydrogen-selective membranes for applications in syngas separation,
6. Development of nano-structured micro-porous materials for syngas cleaning, syngasto-energy carrier conversion and soil additive (SRS-media) applications,
7. Syngas cleaning and conversion to liquid fuel through the use of nano-structured microporous materials developed in the project through thermochemical and biochemical routes.

This current project (EP/F038453) is an extension of a previous grant from EPSRC (EP/E010725). Some of the work initiated in EP/E010725 (end date Jan 2009) was completed (to enable the completion of patent applications) in this current project (EP/F038453) and extended further opening new research areas while strengthening the technology base for the establishment of an 'Integrated Intensified Biomass Based Energy and Chemicals Technology'. These new research areas will be further developed and patent position will be strengthened through two new EU projects (COPIDE, start September 2009, 42 months) and POLYCAT, start November 2010, 42 months) with over 25 participants across EU and Europe (Russia and Switzerland). In the mean time, the IPR generated by

EP/F038453 and EP/E010725 will be commercialised by a second spin-off company, GAP Technologies Ltd.

Both EP/E010725 and EP/F038453 were small grants (ca. £150k each, lasting 24 months each). The augmentation of these grants is apparent through the number of researchers as well as the principle investigator's own financial contribution.

Annex I Participating countries

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Annex II: Overview of the parties involved

Funded proposals

Nr.	Title proposal	Countries involved	Parties involved
1	Development of a photoionization-detection technique for on-line measurement of biomass tar concentrations	The Netherlands, Sweden	Biomass Technology Group BTG (NL), KTH Kungliga Tekniska Högskolan (S)
2	Mop Fan and Electrofilter: an innovative approach to cleaning product gases from biomass gasification (EMF)	Germany, the United Kingdom	Technische Universität Berlin (D), AEROB-BETH Filtration GmbH (D), University of Nottingham (UK)
3	Intensification of Syngas Cleaning and Hydrogen Separation (Synclean)	The United Kingdom, Germany	Institut für Mikrotechnik Mainz GmbH (D), School of Chemical Engineering and Advanced Materials (UK), ITI Energy Ltd., Innovation Technology Centre (UK)
4	Tar removal from low-temperature gasifiers	The Netherlands, Denmark	Energy Research Centre ECN (NL), Dahlman (NL), COWI (Dk), Danish Technical University-MEK (Dk), Danish Fluid Bed Technology (Dk), Anhydro (Dk)
5	Energy efficient selective reforming of hydro carbons	Sweden, Denmark	Chalmers Uni (S), Scandinavian Energy Project AB - SEP (S), Göteborg Energi (S), DTU-Chemical Engineering (Dk)
6	OptiBtLGas - Cleaning and treatment of Product Gas from biomassgasifiers-optimisation of the H2:CO - ratio in synthesis gases for the production of 2nd generation biofuels	Germany, Austria	CU Tec Institut (D), H.P.C. Starck (D), Technical University Vienna (A), Repotec (A), Biomassekraftwerk Güssing (A)