Bioenergy:

from Research to Market Deployment in a European Context

BESTF

Content

Foreword

The BESTF programme, now in its third iteration, has provided impactful innovation projects with the opportunity to demonstrate de-risk and scale up their technologies, opening up opportunities towards commercial reality. The collaborative nature of the programme, with multiple national agencies pooling their experience, resources and innovation funding, in partnership with the European Commission allowed the most recent BESTF3 ERA-Net Co-fund to offer up to €22.3M of grant funding towards projects enabling the greater use of bioenergy. A remarkable offer which allowed a range of demonstration projects in terms of scale, cost and complexity to make a case for support.

The BESTF programme has been a success, but we should not rest on the illusion that innovation programmes of this scale, involving multiple private and public sector stakeholders are easy. There are valuable lessons to be learned for project participants, ERA-Net programme funders as well as the European Commission. These have been considered and shared as part of the continued development of the **European Strategic Energy Technology Plan (SET-Plan)**.

The success of the programme would not have been possible without the dedication and ambitions of all the EU consortium members, continued support from the European Commission and the enthusiasm of the bioenergy community to rally together to develop collaborative projects.

As we look to the future the SET-Plan Key Action 8 aims to accelerate the development and deployment of low-carbon technologies in 'Renewable Fuels and Bioenergy' with a particular focus on reducing costs and increasing integration of these technologies within the energy system. BESTF has already contributed significantly to these aims. This brochure presents some of the background and initial outcomes of some of those innovative projects.

I am convinced that collaborative international programmes such as this will offer one of the most significant opportunities to achieve our common aims within the energy sector.

Bart de Leeuw
Department for Business, Energy & Industrial Strategy
United Kingdom

About Bioenergy Sustaining the Future (BESTF)

The European Union (EU) is committed to combating climate change and to increasing security of its energy supply. Bioenergy is a renewable energy source that, if produced sustainably, saves greenhouse gas emissions and could play a key role for both EU targets. Bioenergy already accounts for more than two thirds of total renewable energy in the EU, and importantly, is a reliable, non-intermittent source of energy.

The European Industrial Bioenergy Initiative (EIBI) has been one of the industrial initiatives launched under the SET-Plan, which is the technology pillar of the EU's energy and climate policy. The EIBI has aimed to contribute to the commercial availability of advanced bioenergy at large scale by 2020, aiming at production costs which allow competitiveness with fossil fuels at the prevailing economic and regulatory market conditions. In 2016, EIBI was integrated into the European Technology and Innovation Platform Bioenergy (ETIP Bioenergy) which evolved from the European Biofuels Technology Platform (EBTP).

A consortium of nine EU Member States comprising of Austria, Denmark, Finland, Germany, Netherlands, Poland, Spain, Sweden and the UK is implementing a public to public partnership entitled **Bioenergy Sustaining the Future (BESTF)**. Funding for the activity is provided by the participating Member States and the European Commission. Funding is awarded to collaborative bioenergy projects that demonstrate at least one innovative step and will result in demonstration at a pre-commercial stage.

In previous years two calls BESTF1 and BESTF2 have been carried out under the FP7 programme and the results are presented in this document. At present the BESTF3 call is under negotiation.

BESTF3

Bioenergy Sustaining the Future (BESTF3) is a European initiative which aims to encourage the commercialisation of bioenergy projects, and increase renewable energy production across the EU.

The ERA-Net Co-fund, BESTF3 brings together a number of national and transnational organisations with an interest in promoting the greater use of bioenergy. It follows on from two previous BESTF ERA-Net Plus initiatives that were launched respectively in 2012 and 2013 and, like its predecessors, aims to kick start large scale investment in close-to-market implementation of bioenergy, thereby helping to achieve the key objectives of the European Industrial Bioenergy Initiative (EIBI) Implementation Plan and the Strategic Energy Technology (SET) Plan.

ERA-NET Bioenergy

BESTF3 joined forces with ERA-NET Bioenergy, which was an EU FP6 funded ERA-Net until 2014 and has been self-funded since then. ERA-Net Bioenergy brings together national ministries and funding agencies that support research and development in bioenergy.

In such a European network, participants can coordinate national research efforts and thus achieve higher quality results, as well as a more efficient use of their limited financial resources. Currently there are eight ERA-Net Bioenergy partners from Austria, Germany, Ireland , the Netherlands, Poland, Sweden, Switzerland and the United Kingdom. Observers come from Brazil, Denmark, Finland, France and Spain.

In order to widen the scope of the BESTF Joint Call to support initiatives at all TRL levels, a cooperation with ERA-Net Bioenergy through the “Additional activities” of BESTF3 has been set up. These activities will bring together the BESTF and ERA-NET Bioenergy stakeholders and align their activities to maximise effective exploitation and the cost- and resource-efficiency of the groups, bringing a greater opportunity for coordination and knowledge sharing. With the joined forces of BESTF and ERA-Net Bioenergy, a total of four calls are envisaged, as well as an increased number of dissemination activities in the 5 years duration of BESTF3 (until 2020).

The second joint call of BESTF and ERA-NET Bioenergy for R&D&I proposals is planned to be published this autumn

Please follow us under http://www.eranetbioenergy.net/ and http://eranetbestf.net/!

Boosting the contribution of bioenergy to the EU climate and energy ambitions.
Summary of Projects:

Action	Project Acronym	Countries	Company	Budget euros
BESTF1 2012-2016	BioSNG	United Kingdom	Advanced Plasma Power Progressive Energy Limited	4,900,000
		Germany	Schmack Carbotech	
	BioProGReSS	Sweden	Goteborg Energi Chalmers University of Technology Renewtec	5,300,000
		Germany	TU Berlin	
BESTF2 2013	CoryFee	Denmark	Terranol	3,927,500
		Sweden	SEKEB E-Technology SP Technical Research Institiue of Sweden	
	MSWBH	United Kingdom	Wilson Steam Storage University of York University of Nottingham	6,000,000
		The Netherlands	Wageningen Food and Biobased Research	
		Norway	Artech Automation AS	
	BioWaterMethanisation	Spain	Aqualia	2,107,558
		The Netherlands	Delft University	
		United Kingdom	University of Southampton	

BESTF Projects in Detail

Name of Project:
Bio-SNG – Bio Substitute Natural Gas

Project Duration:
3 years (completed)

Coordinator:
Andy Cornell, Advanced Plasma Power, United Kingdom

Partners:
Chris Manson-Whitton, Progressive Energy, United Kingdom
David Pickering, National Grid, United Kingdom
Alfons Schulte-Schulze, Schmack Carbotech GmbH, Germany

Project budget:
€4,900,000

Project Summary
BioSNG addresses the issue of decarbonising heat as well as providing a low carbon solution for the transport sector. The funding and strategic backing for the project comes from the BESTF ERA-Net programme as well as Ofgem's Network Innovation Competition.

The project aims to develop an innovative process to convert waste and biomass into bio substitute natural gas (BioSNG) which can be used in the existing gas network for use by customers without disruption. This approach would greatly expand the supply of renewable gas over and above existing solutions such as anaerobic digestion (AD).

Chris Manson-Whitton, Progressive Energy, UK

Previously unused waste products diverted from landfill and other biomass material can act as the feedstock for gas generation.

The technology has been showcased at a new demonstration process plant at Advanced Plasma Power's headquarters in Swindon. The test plant was designed to show the potential of BioSNG from both a technical and commercial perspective - and moves the technology from concept to reality. It demonstrates the potential for communities to access locally generated renewable gas. The approach helps solve an issue facing governments, energy suppliers, policy makers and consumer groups across the world: how to produce low carbon energy for heat and heavy goods vehicles in a sustainable way through the development of advanced technology that is commercially viable, affordable, and acceptable to the energy consuming public.

Summary of Results

- **Commercial BioSNG Plant:** The primary objective was to enable delivery of a commercial BioSNG plant. This has been successfully achieved, as the project has directly led to the construction of a commercial BioSNG facility that will convert 10,000 tonnes of waste into 22GWh of low carbon BioSNG that will be injected into the local grid. This will start operation in the first half of 2018 and provide a reference facility that will catalyse the construction of larger scale commercial plants. The successful delivery of the commercial facility is reliant on the outcomes of the demonstration project, such as those set out below.

- **Technical Learning.** The results from experimental work have validated the process engineering models used to underpin the commercial design, including the kinetics of the water gas shift and methanation. The project has demonstrated that it is possible to generate a sufficiently clean syngas for catalytic conversion to methane through a once through process, and successfully remove CO_2 for grid injection.

- **Operational Learning.** The procedures and controls developed to operate the demonstration plant safely were successfully developed and implemented and provide the basis for commercial facilities.

- **Commercial Learning.** Designs for commercial scale plants were finalised, informed by the results of experimental testing, process modelling, an assessment of scale up risk and engagement with suppliers. Financial models show that whilst smaller first of a kind facilities will require subsidy support, the cost of gas produced by large scale nth of kind facilities operating on waste are expected to deliver gas at parity with fossil natural gas.

- **Environmental Learning.** A detailed greenhouse gas assessment was completed. This showed that BioSNG gives an overall saving of 80% compared to fossil gas. This increases to a saving of 142% if the benefit of diverting waste from landfill is taken into account and to 252% if carbon dioxide from the process is sequestered.

- **Dissemination.** The demonstration plant has increased the profile of BioSNG, and the facility has been visited by more than fifty organisations including ministers, civil servants, grid distribution companies, regulators, academics, industry and financiers.

Photograph of the BioSNG Plant

Name of Project:
BioProGReSs - Biomass Production Gas Reforming Solutions

Project Duration:
3 years (from 2014)

Coordinator:
Ingemar Gunnarsson, Göteborg Energi AB, Sweden

Partners:
Marin Seemann Chalmers University of Technology, Göteborg, Sweden
York Neubauer Technische Universität, Berlin, Germany
Jörgen Held Renewtec AB, Sweden

Project budget:
€5,300,000

Project Summary
This project involves partners from Sweden and Germany. It aims to demonstrate a novel technology to simplify gas clean-up following biomass gasification. Chemical looping reforming will be used to reform the tars and the olefins directly after the gasifier. The technology being demonstrated, if successful, could reduce the investment cost of biomethane plants by up to 30%, increase the efficiency of converting biomass to bio-methane by approximately 5-7% and reduce the operational costs by around 10 % compared to current processes.

Ingemar Gunnarsson,
Göteborg Energi AB, Sweden

Summary of results (so far)
The Chemical Looping Reformer (CLR) technique has been tested and approved in a pilot plant gasifier at Chalmers University of Technology and the next step is a full-scale demonstration in the GoBiGas-plant in Göteborg. At the same time a novel online gas quality measurement equipment has been developed which will also be demonstrated at GoBiGas.

Progress to date
Collaboration to date has been successful. TU Berlin have contributed to testing the technology (including measurement devices) at Chalmers pilot plant gasifier, and the results have been evaluated and used as input for improvement of the measurement system and for the planning of the installation at GoBiGas. There have been four joint meetings with the steering committee, including all project partners; five joint project meetings, for all members in the project; and several meetings with the different work packages.

The main activities so far include:

- Tests of process optimization and gas cleaning at Chalmers pilot biomass gasifier.
- Development of new online measurement equipment at TU Berlin and tests of the equipment at Chalmers and at the GoBiGas gasifier in Göteborg.
- Planning for tests and installation of test equipment at the GoBiGas gasifier in Göteborg.

The technology (including measurement devices) was implemented at GoBiGas and will be tested and evaluated during 2017. The funding organisations have been invited to a presentation of the project status and study tour at the installations at Chalmers and GoBiGas during 2017.

Name of Project:
CoRyFee - Cost Reduction in Yeast Fermentation for Commercial Production of Cellulosic Ethanol

Project Duration:
3.5 years

Coordinator:
Birgitte Rønnow, Terranol A/S, Denmark

Partners:
Thore Lindgren, SEKAB E-technology, Sweden
Emma Johansson, SP Technical Research Institute of Sweden

Project budget:
€3,927,500

Birgitte Rønnow, Terranol A/S, Denmark

Project Summary
The overall goal is to reduce the costs of 2G-bioethanol production by hydrolysis and fermentation, enabling commercial deployment with potential of 85% reduction of CO_2 emission compared to gasoline.

The objective is to demonstrate a new process regime capable of faster and more efficient use of the sugars available.

Summary of results (so far)
A basic design of a continuous fermentation system, including flow sheet, and basic unit process flow description to test in the Biorefinery Demo Plant in Örnsköldsvik, Sweden is now ready. A review of the functionality needed and the necessary updates have been made and upgrades of fermenter functionality and piping have started.

SEKAB have produced and delivered enzymatically hydrolyzed wheat slurry allowing Terranol to perform batch and fed-batch fermentations. A good final ethanol yield of 91% of theoretical was obtained in fed-batch fermentations.

Assessments of different technologies available for physical and chemical online characterization of the fermentation broth have been conducted. These include continued studies of CO_2 generation during the process, in terms of the amount of generated gas effluent, and technologies involving speed of sound, refraction and density. In the demo plant experiments suggest that online measurement of CO_2 is feasible. A trial has been made in the demo plant to control the substrate feeding by pumping air into the fermenters to simulate the CO_2 generation during fermentation and another test has been made during a real fermentation trial with yeast to study how the pressure increases during fermentation and relates to the CO_2 production.

Name of Project:
MSWBH - Municipal Solid Waste to Butanol and Hydrogen

Project Duration:
2 years 5 months (from 1st April 2016)

Coordinator:
Pete Metcalf, Wilson Steam Storage and
Joe Ross University of York, United Kingdom

Partners:
Peter Metcalf, Wilson Steam Storage, United Kingdom
Joe Ross, University of York, United Kingdom
Gregory Tucker, University of Nottingham, United Kingdom
Pieternel Claassen, Wageningen Food & Biobased Research, The Netherlands
Jorgen Jarvaag, Artech Automation, Norway

Project budget:
€6,000,000

Project Summary
This project will evaluate the technical and economic viability of the production of butanol, hydrogen fuels and other chemicals from autoclave-pretreated municipal solid waste (MSW), Grape Marc and Brewery Waste by hydrolysis and fermentation. It will develop pilot and demonstration scale plants to treat up to 1.5 tonnes of MSW a day, and provide the expertise and data necessary for a full assessment of a commercial scale process. The pilot and demonstration scale plants will be used to establish technologies for hydrolysis, fermentation, and separation of chemicals. The products will be removed from the fermentation broth by gas stripping followed by decantation and distillation. In addition, the hydrogen gas produced during the fermentation will be purified by using Pressure Swing Adsorption technology.

Joe Ross, University of York, United Kingdom

Summary of results (so far)
The pilot scale facility for processing 50kg batches of waste is operational and plans have been developed for the larger 1000kg demonstration scale plant. MSW, grape marc and brewery waste have all been processed at pilot scale and the outputs tested successfully for hydrolysis and fermentation to produce acetone and butanol. The procurement of larger hydrolysis facilities has been undertaken as the first step towards the demonstration scale plant.

The operational pilot scale facility for processing 50kg batches of waste

Name of Project:
BIOWAMET - BIO-Methane Production from Urban Organic Matter

Project Duration:
3 years 8 months (from 1st January 2015)

Coordinator:
Frank Rogalla, Aqualia, Spain

Partners:
Charles Banks, University of Southampton, United Kingdom
Jules van Lier, Delft University of Technology,
The Netherlands

Project budget:
€2,107,558

Project Summary
BIOWAMET involves the development of an anaerobic membrane bioreactor (AnMBR), at a demonstrative-scale, as a sustainable alternative to traditional aerobic wastewater treatment. As such, the traditional concept of wastewater treatment plants moves to a new approach that considers wastewater as a source of energy, nutrients and a directly reusable water resource thanks to the partial disinfection process that ultrafiltration (UF) membranes provide.

Wastewater treatment in anaerobic systems coupled to UF membranes allows:

- Energy recovery through organic matter valorization
- Treated water or "new water" production with characteristics suitable for reuse since nutrients have not been degraded in the process

José R. Vázquez Padín,
FCC Aqualia, SA, Spain

Reuse for agricultural purposes has gained interest in many countries, not only due to water stress, but also because water consumption for that use represents a large percentage of the total water consumption. Innovative technologies for membranes fouling control will be developed and tested.

Summary of results (so far)
Aqualia is finishing the implementation works of AnMBR systems at two demonstration sites:

- Business Park of Porto do Molle (Nigrán, Pontevedra): In the main office building, black water collected in a segregated pipe will be treated in an AnMBR system.
- Bitem WWTP (Tortosa, Tarragona): 3 septic tanks are being retrofitted into an AnMBR to achieve the treatment of 18 m3/d of urban wastewater. The effluent of the AnMBR will be reused downstream in an irrigation channel.

TU Delft has designed an apparatus that applies the Delft Filtration Characterization method (DFCm) to assess AnMBR sludge filterability, which will be tested at the demonstration sites. A first trial was already conducted on an AnMBR pilot running in Alcázar de San Juan (Spain). In addition, tests have been developed in order to select suitable additives to improve the sludge filterability. The final goal is to define an on-line fouling control tool, able to improve the flux in AnMBRs.

The University of Southampton is testing an ultrasonic cleaning device for membrane fouling control as an alternative to gas sparging. It is also developing the concept of using soft cleaning particles fluidized either in the anaerobic reaction tank or in a separate tank to lightly abrade the membrane surface and prevent the formation of biofilms. When used in the reaction tank they will also act as biomass support particles. After small-scale tests, a membrane bioreactor prototype of 200 L is under construction.

The Added Value of participating in the BESTF scheme according to the project Coordinators

BIOSNG

The BESTF scheme provided valuable funding which significantly leveraged partner and other resources to deliver the project. Without BESTF funding, this project could not have been delivered, and so the commercial plant would not be under construction.

The BESTF scheme has enabled international collaboration which would not otherwise have been possible. The partners have since undertaken further work together on Bio-hydrogen production.

The BESTF scheme has provided an increased profile for the project, enabling wider dissemination outside the UK.

BioProgress

BESTF has given us the opportunity to work with process development and pre-commercial demonstration of new innovative technology in a long term and fundamental way in cooperation with highly skilled researchers and engineers from different universities and companies in Europe.

CoRyFee

BESTF2 has given the partners an opportunity to demonstrate the potential of combining their respective technologies within 2G bioethanol production.

Further reduction of production costs is essential for this fuel to be competitive with fossil gasoline and 1G bioethanol on market condition and to become an attractive field for market driven investments. The project value will be the improvement of yield and reduction of CAPEX and OPEX and will eventually be demonstrated in the biorefinery demo plant.

MSWBH

The BESTF2 scheme is allowing evaluation at an industrially relevant scale of the conversion of 3 different waste stream into a range of chemical products.

The information will be very valuable in the design of full scale operations and has already led to interest from a broad range of potential investors.

BIOWAMET

The possibility to enroll 3 different entities from EU countries; in this case two top level Universities with a key water utility in Spain, a country where water reuse is already a must due to water scarcity. The fact that each partner has its own national reporting makes the administrative coordination easier compared to other funding sources.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 691637.