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Lessons learned from operation of NER 300 projects

2017-2019

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Abstract
NER 300 is an EU funding programme for the demonstration of carbon capture and storage (CCS) and innovative renewable energy (RES) technologies at the pre-commercial stage. Knowledge sharing requirements are built into the legal basis of the programme as a critical tool to lower risks in bridging the transition to large-scale production of innovative renewable energy and CCS deployment. Projects have to submit annually to the European Commission relevant knowledge gained. The European Commission assesses the relevant knowledge with a view to establishing whether the project has adequately complied with its obligations. This report summarises the lessons learned from the operation of the NER 300 projects during the period 2017-2019.

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1 Introduction

NER 300 is an EU funding programme for the demonstration of carbon capture and storage (CCS) and innovative renewable energy (RES) technologies at the pre-commercial stage. The programme aims at supporting a wide range of CCS and RES technologies. NER 300 also seeks to leverage a considerable amount of private investment and/or national co-funding across the EU. On top of that, it focuses at boosting the deployment of innovative low-carbon technologies and stimulating the creation of jobs in those technologies within the EU.

NER 300 is funded from the sale of emission allowances from the new entrants' reserve (NER) set up for the third phase of the EU emissions trading system (EU ETS). 300 million allowances are reserved for the financing of commercial-scale CCS and innovative RES demonstration projects according to Art. 10a(8) of the EU ETS Directive [DIR 2009/29/EC].

Knowledge sharing requirements are built into the legal basis of the programme as a critical tool to lower risks in bridging the transition to large-scale production of innovative renewable energy and CCS deployment. The legal basis obliges project sponsors to submit annually to the European Commission relevant knowledge (RK) gained during that year in the implementation of their project (see Annex 2 and 3 of the Award Decision [C(2012) 9432 final]). The knowledge sharing element of NER 300 requires the European Commission to collect and assess the relevant knowledge with a view to establishing whether the project has adequately complied with its knowledge sharing obligations. The disbursement of annual payments is conditional to the positive opinion of the Commission on the fulfilment of the KS obligation.

The NER 300 programme differentiates two types of relevant knowledge to be collected and shared defined by the level of sensitivity. Level 1 (L1) knowledge is only to be shared with other projects in a particular technology category. One L1 community will be set up for each technology category. Level 2 (L2) knowledge is of general interest and includes collated and anonymised L1 knowledge. The target audience for L2 is the general public, industry, research, government, NGOs and other interest groups and associations.

The Directorate-General for Climate Action (DG CLIMA) is in charge of managing the NER 300 programme for the European Commission. The Joint Research Centre (JRC) supports DG CLIMA in the implementation of the knowledge sharing requirements[1]. This report provides an aggregation of anonymised L1 knowledge and L2 knowledge shared over the period 2017-2019 with a special attention on the lessons learned.

[1] Administrative Agreement N °340201/2016/737812/SER/CLIMA.C.3

2 Aggregation process

This report is based on the knowledge that has been shared by two bioenergy projects and four wind energy projects since their entry into operation.

These projects are:

- the bioenergy project BEST from Italy;
- the bioenergy project Verbiostraw from Germany;
- the wind project Windpark Blaiken from Sweden;
- the wind project Veja Mate Offshore from Germany;
- the wind project Nordsee One from Germany and;
- the wind project Windpark Handalm from Austria.

The BEST project belongs to category BIOg (Lignocellulose to ethanol and higher alcohols via chemical and biological processes with capacity 40 Ml/y of the final product).

The Verbiostraw project belongs to the category BIOh (Lignocellulose and/or household waste to biogas, biofuels or bioliquids via chemical and biological processes with capacity 6 M Nm3 /y of Methane or 10 Ml/y of the final product).

The Windpark Blaiken project belongs to category WINf (On-shore wind turbines optimised for cold climates (compatible with temperature lower than -30°C and severe icing conditions) with nominal capacity 25 MW).

The Veja Mate Offshore project belongs to category WINa (Off-shore wind (minimum turbines size 6 MW) with nominal capacity 40 MW).

The Nordsee One project belongs to category WINa (Off-shore wind (minimum turbines size 6 MW) with nominal capacity 40 MW).

The Windpark Handalm project belongs to category WINe (On-shore wind turbines optimised for complex terrains (e.g. forested terrains, mountainous areas): with nominal capacity 25 MW).

These six projects entered respectively into operation on 1 June 2013 and 30 January 2014 for the bioenergy projects and 1 January 2015, 1 July 2017, 1 January 2018 and 1 January 2018 for the wind energy projects (Table 1). Bioenergy project BEST stopped its activities in 2018 due to economic constraints. All the other projects are running.

Project	**Country**	**Technology category**	**Date of entry into operation**	**RK Template**
BEST	Italy	BIOg	01/06/2013	RK/RES/BIO
Verbiostraw	Germany	BIOh	01/01/2017	RK/RES/BIO
Windpark Blaiken	Sweden	WINf	01/01/2015	RK/RES/WIN
Veja Mate Offshore Project	Germany	Wina	01/07/2017	RK/RES/WIN
Nordsee One	Germany	WINa	01/01/2018	RK/RES/WIN
Windpark Handalm	Austria	WINe	01/01/2018	RK/RES/WIN

Table 1: Overview of NER 300 projects having submitted relevant knowledge in 2019.

The information will refer to the Relevant Knowledge Collection Forms that have been submitted, the respective Requests for Clarification and their answers:

- ➔ for the years 2016 and 2017 for BEST;
- ➔ for the years 2017 and 2018 for Verbiostraw;
- ➔ for the years 2015, 2016, 2017 and 2018 for Windpark Blaiken;
- ➔ for the years 2017 and 2018 for Veja Mate Offshore Project;
- ➔ for the year 2018 for Nordsee One and;
- ➔ for the year 2018 for Windpark Handalm.

The submitted forms distinguish between Relevant Knowledge to be distributed to both Level 1 (L1) and Level 2 (L2) recipients. Level 1 recipients are all NER 300 projects in their respective category, i.e. the wind energy category (WINa/b/c/d/e/f) and the bioenergy category (BIOa/b/c/d/e/f/g/h/i), and any other project which has agreed to share information with the Commission on terms equivalent to Annex II of the Specifications for Legally Binding Instrument (SLBI) (for example offshore wind projects funded by the European Energy Programme for Recovery-EEPR). Level 2 recipients are the wider CCS and renewable energy community (Commission, Member States, researchers, non-governmental organisations, (NGOs), international organisations and other projects) and, where appropriate, the public.

The Commission may decide when appropriate, to aggregate Level 1 Relevant Knowledge to be shared beyond Level 1 Recipients (i.e. at Level 2), with the objective that the result cannot be ascribed to individual projects, organisations or persons.

3 Aggregated knowledge – Bioenergy section

3.1 Technical set-up and performance

The two biomass projects have an identical pattern, as both are demonstration bio-refinery facilities using lignocellulosic biomass (wood or straw) to produce, either bio-ethanol, or biogas, i.e. methane. At the same time heat and electricity is consumed and other organic by-products are produced. These by-products may be used to provide some of the energy needed during the process. The energy output of the plants in 2018 was in the range 40-80 GWh.

The first steps linked to the biomass treatment are similar and include i) the handling and conditioning of the biomass, ii) a pre-treatment stage and iii) a fermentation stage that either produces bio-ethanol or bio-methane, where both have their own treatment requirements before being put on the market.

For the bioethanol producing plant, the quality of the end product has been evaluated using standard EN 15376:2011 "Automotive fuels – Ethanol as a blending component for petrol – Requirements and test methods". The results obtained are in accordance with the limits specified in Table 2 below.

Property	Unit	Limits		Test method [a]
		minimum	maximum	(See Clause 2. Normative references)
Ethanol + higher saturated alcohols content	% (*m/m*)	98,7		EN 15721 [b]
Higher saturated (C3-C5) mono-alcohols content [c]	% (*m/m*)		2,0	EN 15721 [b]
Methanol content	% (*m/m*)		1,0	EN 15721 [b]
Water content [d]	% (*m/m*)		0,300	EN 15489 EN 15692
Total acidity (expressed as acetic acid)	% (*m/m*)		0,007	EN 15491
Electrical conductivity	µS/cm		2,5	EN 15938
Appearance		clear and colourless		EN 15769
Inorganic chloride content [e]	mg/kg		6,0	EN 15484 prEN 15492
Sulfate content	mg/kg		4,0	prEN 15492
Copper content [f]	mg/kg		0,100	EN 15488 EN 15837
Phosphorus content [g]	mg/l		0,15	EN 15487 EN 15837
Involatile material content	mg/100ml		10	EN 15691
Sulfur content [h]	mg/kg		10,0	EN 15485 EN 15486 EN 15837

a See 4.6.1.
b The result of this test method refers to the water free sample.
c Higher saturated alcohols have the chemical formula $C_nH_{2n+1}OH$, where n is 3, 4 or 5.
d See 4.6.2.
e See 4.6.3.
f See 4.6.4.
g See 4.6.5.
h See 4.6.6.

Table 2: Generally applicable requirements and test methods for undenatured ethanol.

The yearly production of bioethanol reached 5 900 tons in 2017, which corresponds roughly to 44 300 MWh.

For the bio-methane producing plant, the biogas is purified and conditioned to the quality of natural gas and fed into the existing natural gas grid. The standard DIN 51624 has to be fulfilled for biomethane, which will be sold as Compressed Natural Gas (bio-CNG),

The yearly production of biomethane was about 59 000 MWh in 2018. As seen in Figure 1, this production underwent some variations during the year due to some downtime of the installation following i) some upgrading (installation of a second hammer mill) and ii) high humidity of the feedstock. Once these issues were solved, the plant ran very well even exceeding the monthly target production of 6 250 MWh, i.e. 75 000 MWh per year.

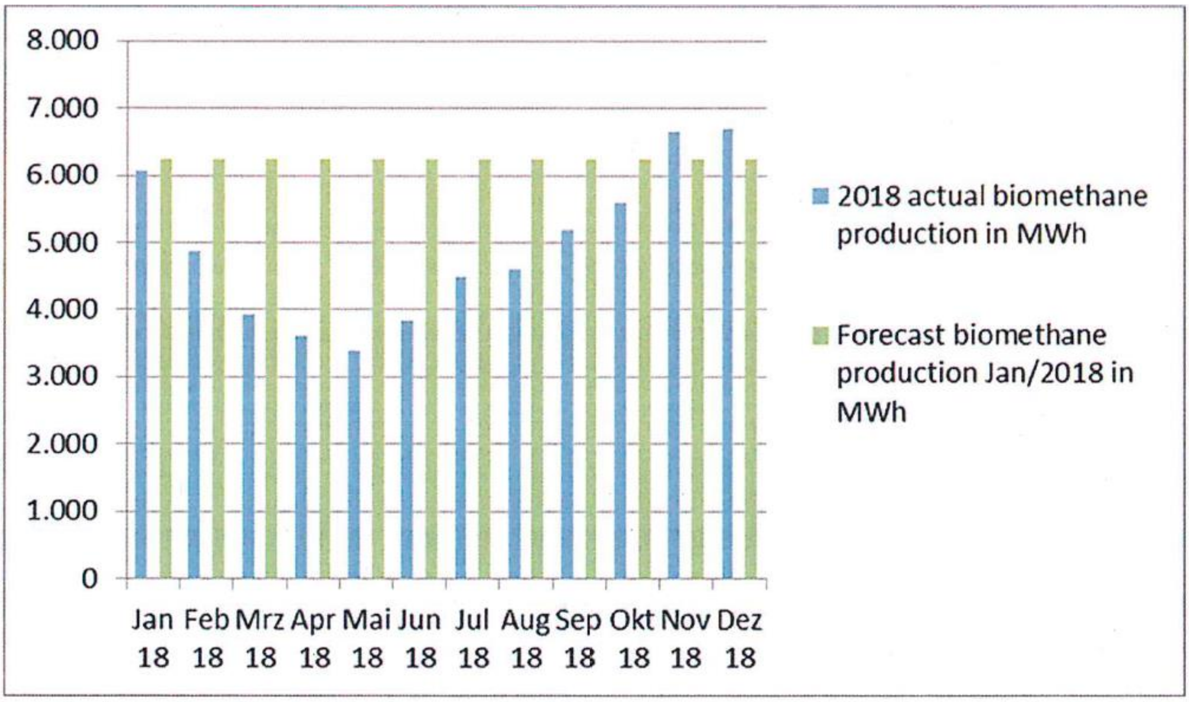

Figure 1: Monthly biomethane production in 2018 compared to forecast.

Both plants are demonstration plants and many improvements have been made, essentially following downtimes that were remarkably reduced. For example, some issues have been:

Table 2 Issues and solutions of the projects

Traced issues	**Solution provided**
Humidity in the lignocellulosic biomass	More efficient harvesting and conditioning
Impurities in the biomass resulting in fast wear and mechanical damages	Better control of the impurities and an optimised repair strategy with a faster replacement of the damaged parts, including availability of the spare parts
sub-systems blockings	Improved

Maintenance is a fundamental issue attaining to some basic points, like the availability of spare parts and the periodic greasing of all bearings, which have a significant positive effect to reduce downtime. Therefore, continuous greasing systems were tested with positive results.

Depending on the feedstock, some specific problems can rise. For example, the handling of straw bales weighing 400/500 kg is a difficult task that requires tight safety measures.

The added value and innovation of these plants is the use of lignocellulosic biomasses. On top of that, the use of agricultural and forestry residues together with energy crops which do not damage biodiversity. On the contrary, their use is considered the first innovative and environmentally friendly handling of second generation technologies.

To that extend, both companies continued to develop and implement innovative process solutions. For example, the ethanol producing plant succeeded in obtaining, at low costs, separate high purity sugars streams and lignin respectively to be further valorised to biochemicals and biofuels. An evaluation of the innovative technological solutions able to improve the scale up factors was carried out for all the plant sections according to their specific requirements.

Improvements were obtained on:

- Increasing the interaction between enzyme-substrate and all the related processes,

- Increasing yeast tolerance to inhibitors and

- Decreasing the fermentation time required.

Attention was mainly given to the use of agricultural residues, among which rice straw has been deeply studied, as it is a typical residue in the plant surrounding area. Rice straw has never been used as a feedstock to produce biofuels or other bio-materials at commercial scale. A study of the availability of the resource around the bio-refinery showed that this residue has a potential of 400 000 ton every year, which is significant. Nevertheless, even if its utilization is sustainable and beneficial for the environment, some technical and non-technical points exist and must be addressed. The overall area around the biorefinery is surrounded by 100 000 hectares of rice farms, scattered in more than 2 000 farms of less than 60 hectares each. Based on the experience of wheat straw handling, specific solutions were developed to optimize the handling and soaking system, making it flexible to use different kinds of feedstocks (such as homogenous samples of rice straw and heterogeneous mixture) in order:

- to safeguard the process equipment (possible abrasions by the presence of silicates) and efficiency;

- to reach maximum of accessibility in the hydrolysis step;

- to minimize the consumption of water maximizing the internal water reuse;

- to evaluate an optimal configuration to pre-treat rice straw as biomass;

- to minimize the scale-up risk and reach a shorter technology time-to-market.

3.1.1 Future developments

Further research is ongoing in order to fully optimize the pre-treatment conditions and to validate the process improvement at demo scale. To that extend, the bioethanol process will not be optimized step by step, but considering all the interactions between the different process elements of the whole chain. Following this analysis, an optimization of the process configuration will be carried out in order to improve the energy efficiency of the ethanol production. So, the pre-treated material will be tested with the aim of measuring the cellulose accessibility using a dedicated enzymatic solution. An optimization of the enzymatic hydrolysis process will be carried out in order to:

i) increase the hydrolysis rate and yield and

ii) decrease the formation of inhibitory compounds during the subsequent steps of fermentation.

Since the different unit operations are strongly interlinked, enzymes cocktail and microorganisms have to be tested in integrated process conditions, having a constant feedback of the process parameters. Experiments and research trials will be conducted in order to fine-tune the process. Special consideration will be given for assessing the interaction of enzymatic cocktails with the pre-treated biomass and for identifying any possible contamination associated with the use of this new feedstock.

In industrial conditions, approaches for the optimization of process chain mainly focus on criteria like quality, costs and time. The issues identified on the pilot plant, will be used to upgrade the new requirements at demonstration level. Tests at a larger scale are expected to be realized using data from the pilot plant. This approach will help to reduce the validation time of innovations, to achieve the adjustments needed to integrate the rice straw in the second-generation bioethanol production cycle and to also improve the process competitiveness in the market.

Improvements were also obtained regarding the use of sugars and lignin, leading to a number of patents concerning their utilization. Sugar solution, due to its purity and high concentration, could be used in chemical and biological processes to produce, for example, diesel substituting fuels or chemicals. Internal development and partnership with key leader biotech companies are giving very interesting results.

Similar issues are also considered by the biogas producing plant. Current key questions are:

- Cost for conversion of the raw material to bio-methane
- Minimum necessary investment cost
- Yields under steady state conditions in the straw plant
- Cost for the straw (baling/collection/storage)
- Conversion of lignocellulose to bio-methane

Further, collaborations with universities, in this case the Hamburg University of Technology and the Leibniz University Hannover have been set-up. In this frame, the project LignoMyc will investigate whether funghi could pre-treat the lignocellulose in a way, which makes it suitable to produce biogas. Other items are also tackled like the potential use of the final residues, and especially, the use of Lignin from residues.

3.2 Project Management

The two projects have a different approach to what concerns Project Management.

One project focusses on procedures and the establishment of a Management system summarising procedures of good practice. An example of these procedures is given in Table 3.

The other Bioenergy project focusses mainly on economic issues in aimed to guarantee the sustainability of its activity. Here, the main point of attention remains the competitiveness of the final bio-product produced. This implies a detailed study of the market risk and of the regulatory risk. Government decisions on whether to fund green products or to tax CO2 emitting products has a direct and significant impact on the competitiveness of bioenergy plants.

MANAGEMENT SYSTEM	
TITLE	**MAIN CONTENT**
ORGANIZATION	• Taking of engagement and retention • Roles and responsibilities • Management Review
DOCUMENTATION & COMMUNICATION	• Definition, Management and Control • Terms of customer communication
TRAINING	• Definition and Management of training plan
AUDIT AND INTERNAL CHECKS	• Methods and plans of periodical checks
NON COMPLIANCE	• Management of non-compliant aspects
MAINTENANCE, MONITORING & CONTROL	• Maintenance Plan • Checks on instrumental devices of field and laboratory • Check and control plans
MASS BALANCE & TRACEABILITY	• Document management: data collection, spreadsheet and e-checks (including GHG values)
SUPPLY & LOGISTICS	• Qualification of supplier and materials • Suppliers management • Warehouse management • Carriers management
RISK MANAGEMENT	• Analysis plan

Table 3: Example of Management System established in a Bioenergy plant.

One project suggests the following items as key lessons learned:

- Minimize the investments at the beginning to reduce the financial risks
    a. Try to be as close as possible to market prices for the products you are producing
    b. Do not rely on subsidies or other strong promotions; the business model itself should be promising without these subsidies

- Make a realistic time plan for the finances
    a. Consider delays in the start-up phase
    b. Consider lower production rates during the start-up phase
    c. Consider changes in the raw material prices and the final product prices
- Test part of the technology in real production scale and not only in pilot scale to reduce technological risks

Consequently and in general, good practices can be summarized as:

- ➔ Strong time and quality management during planning and construction
- ➔ Business model should be robust against deviations in the plan:
    - Quick response to significant changes in the plan
    - Consider changes before they occur and define realistic solutions
- ➔ Minimize investment costs at the beginning (extension of existing plants)
- ➔ Close monitoring of regulatory developments and fast response on changes

3.3 Environmental Impact

Considering the environmental impact, it appears that most issues have been identified during the permitting phase and have been corrected.

Nevertheless, the reduction of the environmental impact remains a topic of high interest. Therefore, future research and development activities are considered. The main issue concerning the environment appears to be the use of the lignocellulose in the residuals.

Further, the extensive testing on demo scale is expected to allow not only increased process yields together with better performance and stability of the system, but also a better environmental sustainability. To reach this purpose, alternative higher-value uses for bio-refinery waste and co-products, such as the sludge, aqueous concentrates coming from the wastewater treatment and, as already mentioned, the lignin separated by ethanol stream achieved after hydrolysis and fermentation of the lignocellulosic biomass.

The conversion of lignin into chemicals is considered a valuable solution with respect to the energetic valorisation. Valuable work has been carried out to find potential applications for lignin in various fields. At laboratory and at pilot scale, preliminary tests were carried out in order to use lignin in bioplastics, paints, bricks and cement industries, and others, with encouraging results.

Valorisation and energy recovery of wastes, reducing also the disposal cost for the companies, is a key topic. For this purpose, further research focuses on the inventory of wastes, the identification of the critical points of the process and their optimization. The analysis of disposal cost, the scouting of technologies will all be activities necessary for minimizing the wastes and for increasing the best use of wastes in the agriculture sector.

Further, enzyme development is an ongoing progress in cooperation with the key partners, aiming for a reduced enzyme consumption and a possible higher sugar content.

Similarly, improved process development in the fermentation area will be also pursued, aimed at improving yeast growth and possibly reducing fermentation time.

Steam and residual heat from process are further points of interest. Any possible recovery of this energy source could be used to optimize entire system.

3.4 Health and safety

Health and safety issues constitute an area where each event is also a lesson learned to prevent it. Table 4 summarises some of these accidents and near misses involving employees.

ACCIDENT / NEAR MISS	LESSONS LEARNED
Foot failure due to distraction	New training sessions have been offered
Injury due to a heavy piece removed by one person only.	New procedure for removal and handling of a metal carter
Injury due to a fall in a manhole which protective grid had been removed	Establishment of a checklist to be verified before starting work.
Injury during use of the forklift	Training session
Injury during maintenance of knife systems	New procedure for intervention
Near fall due to slippery road	Preventive salt spraying to avoid ice
Near injury during repair work	Training session
Near eye injury during test of grinding machine with wrong Pressure Sensitive Adhesive (PSA) sanding discs.	New procedure replacing normal glasses with goggle glasses.

Table 4: Summary of accidents and near misses involving employees.

In some cases, the whole process underwent accidents and near misses. The following have been reported.

During tests concerning a new technology for the conditioning of raw feedstock, high temperatures were reached in the gearings, causing even glowing spots in the feedstock

Lesson learned 1:Be aware of not properly greased bearings and always ensure proper greasing of the bearing

In a CO2 separation unit, during a scheduled shut down in the mid of the year. the adsorption column was opened and after purging the column with air a temperature increase happened within the packaging which was partially destructed by this temperature increase. It was cooled down with water and the old damaged packaging was removed and new one installed. The root cause of this oxidization within the packaging is not yet clear. Current working hypothesis is that a very thin organic layer on top of the packaging had a catalytic reaction with air and the metal of the packaging, resulting in an oxidization of this material. This reaction increased the temperature within the packaging and resulted in a loss of the mechanical properties of the very thin packaging layer.

Lesson learned 2: Be aware of the risk of oxidization in the packaging of the CO2 separation unit under contact with air.

A mobile top grinding machine to grind the feedstock was tested. This machine was manually operated and produced enormous amounts of dust particles because it had no air suction system after the grinding. Based on these dust amounts, the test was stopped.

Lesson learned 3: Always install a proper suction system for top grinding machines in a separated area to significantly reduce this issue.

Some plants also implement dedicated safety procedures. A detail of such procedure can be found in Table 5.

SAFETY SYSTEM PROCEDURES	
TITLE	**MAIN CONTENTS**
FACILITY ACCESS CONTROL AND MANAGEMENT OF CONTRACTORS	• Verification of contractors documents • Control and documentation management of the works carried out by contractors
PERIODIC INSPECTION AND MANAGEMENT OF FIRE FIGHTING EQUIPMENT	• Terms and internal plans for periodic testing for fire-fighting systems
USE OF FIRST AID SETS	• Use, contents of first aid boxes and periodic verifications
CORROSIVE EXHAUST	• Type of exhaust corrosive substances • Personal protective equipment (PPE) to be used • Check list for verifying the suitability of the load
ETHANOL LOAD	• Type of load • Personal Protective Equipment to be used • Check list for verifying the suitability of the load
COMPANY SECURITY PLAN	• Provisions for the protection of company assets • Procedures to be followed in the event of an emergency related to intrusion of strangers on the site
AUTHORIZATION FOR NEW CHEMICALS	• Request procedures for the introduction of new chemicals in the site
CONFINED SPACES	• Assessment of the suitability of contractors to work in confined spaces
DISTILLATION PLANT START AND STOP	• Safety procedures for starting and stopping the distillation plant
FORKLIFTS MAINTENANCE	• Type and frequency of maintenance for forklifts
HYDROGEN SULFIDE CONCENTRATION CONTROL	• Mode and frequency of hydrogen sulphide concentration control in Waste Water Treatment Plant (WWTP)
ROOT CAUSE ANALYSIS	• Accident analysis method

Table 5: Example of Safety System Procedures found in bioenergy plants.

4 Aggregated knowledge – Wind energy section

4.1 Technical set-up and performance

Due to specific operating conditions (onshore, offshore, specific climatic conditions), there is a diversity among the projects and the solutions adopted.

The offshore projects are made of 54 to 67 wind turbines installed 45 to 115 km from the coast. The wind turbines are of commercial type (Senvion, Siemens) in the range of 6 MW with rotor diameters of 126 to 154 m and water depths of 28 and 39 m. All benefit from the latest available technology.

The innovative aspects of the projects are the installation of the monopiles at sea and the connections to dispatch the produced electricity. But, also, the solutions established in order to reduce downtime is part of their innovation.

The onshore projects are set up in mountainous surroundings facing severe, even artic, climate conditions. The number of wind turbines varies from 13 at an altitude of 1800 m above sea level to 90 at an altitude of about 700m above sea level with artic conditions.

The wind turbines are of commercial type (Nordex, DF, Enercon). The power of the wind turbines is in the range 2.5 to 3.0 MW The rotor diameters are about 80 to 100 m. Nevertheless, the turbines had to be adapted to the harsh working conditions being, for example, equipped with specific de-icing systems. Innovative solutions were necessary to adapt the commercial turbines to these extreme conditions.

All projects share two specific phases: the construction phase and the running phase of the installation. Each of these phases has its own challenges that are different for the onshore and the offshore projects.

Concerning the offshore projects, the technologies used remain classical. The turbines are either equipped with direct drive or gearbox. Nevertheless, it seems that direct drive, when available, is preferred over gearbox. The support structures are composed of monopile (MP) foundations with an attached transition piece (TP). An effort was made to have the turbines assembled on land and then transported to sea. Innovative solutions, like dedicated vessels for the transport and installation, needed to be developed. Both projects use an Offshore Sub-Station (OSS) as transformer platform and an Inter-Array Cable (IAC) system to connect the Wind turbines.

Offshore and onshore installations are controlled remotely with dedicated installations and software. Especially, SCADA (Supervisory Control And Data Acquisition), a computer system for gathering and analysing real time data, is used to monitor and control the installation together with CMS (Content Management System) Software. The CMS and SCADA systems create big amounts of data that can barely be handled by standard wind IT equipment (including windfarm management systems/ Enterprise Resource Planning (ERP) systems). Future development in that area could contribute to enable the projects to improve preventive maintenance.

Aluminium cables with two different diameters have been used and proven to be suitable in one project. Despite one cable incident, where the minimum bending radius of a cable was violated (and the cable required exchange), the installation and commissioning of the cables went without major disruptions. For future projects, even with bigger diameters, it can be assumed that aluminium is equally suitable. Given smaller bending tolerances of aluminium compared to copper, attention needs to be paid to installation and routing into and within the turbines.

During operation, some elements, like the blades or the bearings showed defects that had to be corrected.

An important aspect is the corrosion protection of metallic parts, which can passive (paint) or active (cathodic currents). Nevertheless, despite these protection systems, one project saw some metallic parts failing. After the detection of a missing nut, complementary inspections revealed a total of 56 failed nuts on 17 different locations (See Figure 2). A detailed investigation concluded that hydrogen embrittlement was the mode of failure, resulting from a very susceptible material being exposed to corrosive electrolytes. This resulted in the dissolution of the zinc layer on the bolts, which freed up diffusible hydrogen that could easily ingress into the ungalvanized thread of the nuts and trigger fracture built-up.

A consequence of this bolt failure induced the implementation of following design changes:

- ➔ Exchange of all nuts, bolts and washer of the MP/TP connection with higher quality material (of the nuts only)
- ➔ Improvement of the outer sealing concept to avoid salt water penetration from the outside
- ➔ Control of the environmental conditions (low humidity) primarily around the MP/TP flanged connection
- ➔ Extension of the condition monitoring system to track additional data, e.g. on humidity and moisture development at the flange connection level.

These measures resulted in an additional investment of 30 MEUR.

Figure 2: Cracked nut.

Water penetration problems have also been identified and generated corrective measures like the reinforcement of outer seals or the retrofitting of inflatable seals. Further, It appears that the airtight platform (which is a platform shielding the turbine generator internal climate from the water at the bottom of the monopile) should be placed below the bolted connection to avoid moisture and condensation to access sensitive metals and structurally critical components. Furthermore, mould has built up in areas of high humidity which also causes hazards for working personnel.

Finally, ventilation under the airtight deck needs to be thoroughly thought through at the design stage, especially when applying active corrosion protection. With the risk of hydrogen and chloride gases to build up in the process of active corrosion protection, there appears to be few options to active ventilation below the airtight platform. But, nevertheless, redundant ventilation for elimination of related risk shall be considered even above the platform.

Preventive maintenance appears to be fundamental to reduce downtime for all installations. The main causes of downtime were the turbine itself (rotor, pitch, blades, converter, generator, gearbox, etc.) but also the loss of the grid, scheduled maintenance and external conditions, like low wind. An option adopted by several projects was to have a full-service maintenance contract with the supplier of the turbine. By doing so, the availability of the wind turbine was guaranteed. A strong quality insurance policy has also a positive effect on reducing the turbine downtime.

Some innovative features developed during the projects have meanwhile been deployed on other projects, especially what concerns big monopiles. For other features, like the innovative bolted connection with short skirt and innovative sealing, there is certainly room for improvement and the industry is aware that additional research is required there. The main problems to be solved are:

- ➔ How to reduce steel for the TP-skirt while keeping the bolted connection away from salt water?
- ➔ How to enable smooth installation while keeping the airtight deck below the bolted connection? It seems that the installation of a monopile with airtight deck is not feasible; so, easy-to-connect solutions for the airtight deck are required.

4.1.1 Future developments

How to determine the correct soil conditions for an optimized monopile design. The measured eigenfrequencies were slightly higher than calculated because of conservative assumptions for soil conditions. More advanced methods could have saved weight in the MP design. Future developments

The installation of the onshore project faced challenges of another type in the sense that is was the first time wind turbines were installed in such harsh climatic conditions. As a consequence, the construction phase had to take into account the meteorological conditions. Therefore, the simple transport of the turbine elements could become an obstacle for the realisation of the project.

The specific meteorological conditions encountered were the driver for innovative solutions. However, additional progress needs to be made in the fields of:

- ➔ Special turbine control systems for areas with unusual wind flow distortions and sea level above 1600 m;
- ➔ Integrated optimisation systems for rough weather conditions (e.g. windstorms);
- ➔ Concept for a network of icing sensors and de-icing System for each wind turbines. The used sensors are very effective concerning ice detection and reliable in operation. Future development of the sensors and optimisation of their use could lead to less sensors per blade, which would decrease costs;
- ➔ Sufficiently large heating areas to make sure that the turbine can restart after a downtime during icy conditions;
- ➔ Lightning protection systems to protect the heating system of the blades;

- ➔ Efficient and adapted maintenance procedures (for example for blade replacement) during icy conditions;
- ➔ Control algorithms for ice prevention systems. The available algorithms often give significantly longer blade heating time than necessary to make sure the heating is active during icing events. The facility consumption could thus be significantly reduced with a more efficient control algorithm;
- ➔ Reliable techniques for ice detection on rotor blades. Ice sensors giving in-data to ice prevention systems are often mounted on the hub or nacelle roof. However, the icing conditions at the tip of a moving rotor blade are very different compared to at the hub or nacelle roof due to the difference in height and effective wind speed. There are existing techniques for ice detection on rotor blades, for example by measuring the eigenfrequency, but the reliability needs to be improved;
- ➔ Techniques for reparation of heating foil ice prevention systems. Preferably less dependent on weather conditions, less time consuming and causing minimal changes to the current density distribution of the foil;
- ➔ Techniques for blade inspection and thermography. Blades with heating foil need to be inspected yearly for damage and hotspots, which possibly can be done with less expensive alternatives to rope inspection. Inspection by drones is a viable technique, but needs improved reliability. Camera inspection from the ground is also viable, but the resolution of the images gives limitations in detectability;
- ➔ Nacelle anemometers with improved reliability under extreme icing conditions to avoid unnecessary downtime;
- ➔ Separate heating for the rotor blades compared to switching off heating on all blades when the upper temperature limit is reached for one sensor at a single blade;
- ➔ Technical solutions, which allows activation of blade heating and pitch motors simultaneously without compromising safety.

It is clear that de-icing is a main concern for the operation of wind turbines in cold severe meteorological conditions.

In follow-up of onshore wind projects, following research topics should also be considered:

- ➔ Related to grid equipment: grid support, phase shift, controlled transformers, reactive power supply in the grid;
- ➔ Related to the turbine: acoustic emissions, large wings including vortex tips and ice detection systems, new generators, larger turbines in alpine regions;
- ➔ Related to plant control: data and energy management (bird and bat migration, weather forecast);

➔ Related to energy use: e-mobility fast charging stations directly fed with wind energy, storage systems.

4.2 Project Management

Concerning the communication strategy, each project has developed its own.

One project focuses on innovative ways of sharing resources, for example, by instigating and implementing a new helicopter emergency rescue service with a number of other wind farms in the area, undertaking regulatory requirements with other projects e.g. through a joint noise campaign. Some even install communications equipment on their OSS and encourage suppliers/contractors to share resources (e.g. vessels), optimising fuel and other materials.

For another project, one important ambition has been to establish good communications with especially local residents and the autochthone population. The annual public viewing had been much appreciated and there were more than 100 visitors at every event.

Because the wind farm is situated far from big cities, like the capital or Brussels, having national and European politicians visiting the sites becomes a challenge.

Concerning the consortium management, one project points out that specific rules for management, shareholders, and lenders have been set out, aimed at covering the majority of potential decisions during the operational phase of the wind farm.

During the construction phase, the project adhered to these management limits, thereby avoiding any potential defaults with lenders, as well as any conflict situations with shareholders. This has given the Project a good solid, tried and tested governance model for the operational phase.

The project continues to hold regular steering committee meetings with all shareholders and the Project team. During these meetings, current progress is presented, and major decisions discussed and agreed. This high level of involvement from shareholders provides a constant communication channel between all parties, enabling smooth decision making, information equilibrium, and built-in governance.

Another project notices that inspection and certification of safety critical elements did not go well; many ladders, lifts and other safety critical elements were not (re) inspected in due time, resulting in impeded access to the wind turbines. To avoid such situation, only one dedicated person should be in charge of the inspection of safety critical elements to have it carried out on time. Further, they notice also that the as-built documentation has not been clearly defined at the time of contract signature. This led to a lot of discussion with the OEM on what documentation has to be submitted. They propose to define the as-built (fabrication) documentation under the contract in more detail; at least minimum packages should be defined. It could also be an option to define a date in time when the as-built documentation has to be agreed in content. This could be payment related so that the Contractor is keeping the deadline.

For another project, the Environmental Impact Assessment for the wind park was carried quickly due to optimised management and intensive negotiation with the authority based on extensive experience from other projects. Therefore, the process of planning and obtaining permission is already carried out on a very high level by the project sponsor. Depending on public attention and local site characteristics, other strategies could be more appropriate for a successful implementation of up-coming wind energy projects.

In general in the consortium, both the owners and the suppliers have a natural interest for a successful project. The owner wants turbines that have as high performance as possible during the all year, regardless of climate conditions. The target of high delivery capabilities will give the owners as much as possible return from their investment and allow turbine suppliers to develop new systems.

Concerning the finances, the main observation is that the risk is the highest at the beginning of the project and decreases continuously and significantly, once the project is running. It is noted that projects mainly opt for conservative features to avoid market risk. The Finance Documentation requires that the Project Company holds a Debt Service Reserve Account (DSRA). The purpose of the DSRA is to protect lenders against unexpected volatility, or interruption, in the cash flow available to service interest and debt repayments. The DSRA is semi-annually adjusted to the size of the following 6 months of debt service (interest + repayment). The reserve account was funded as part of the construction budget, and has not been drawn upon.

One project recommends the early engagement of experienced personnel and/or finance advisor to ensure that lender's requirements are reflected in the technical, commercial, contractual and structural set-up of the wind park and the asset company. Favourable contract setup with conservative programme, properly sized warranty suretyships, low content of variable cost and few interfaces are also suggested.

Concerning the reduction of the risks, It is recommended to have qualified personnel, with skillsets that allow to take over from colleagues in case of absence or short-notice leave. The key processes should be documented and formalized to enable all project participants to understand their roles and what can be expected from their colleagues. Maintenance strategies should be in place to allow fast reaction in case of unexpected occurrences; alternatively, similarly full service contracts with incentivisation/penalization of the contractor should be in place; further, strategic spare parts should be in stock or have easy sourcing with pre-defined terms. Early requirements for standard and back-up communication with (a) the wind park, (b) the direct marketing company and (c) the grid provider should be clarified well in advance. In case of country-linked procedures as it is the case in Germany the process to retrieve curtailment payment from the grid provider should be prepared well in advance. This process is complex and needs proper alignment between the project and the grid provider.

Concerning insurance issues, one project specifies that the construction phase of the project was very successful and completed ahead of time, with an excellent claims record. This means that even though the project experienced some claims, contractors in line with the contractual obligations remedied these and as such, no insurance claims were settled using the insurance policies. This has led to a very positive insurers' perception of the project which enabled the renegotiation of the project's Operational All Risk (OAR) insurance to include a discount depending on certain loss ratios for the duration of the OAR. This re-negotiation of the Insurance terms based on past (construction) performance and its significant contribution to reducing the project's Operating Expense (OPEX) is another key lesson learned for the insurance package.

Another project, issues following recommendations:

- ➔ Define your insurance requirements carefully taking into account lender's requirements (if applicable) and shareholder's risk appetite.
- ➔ Consider insurance requirements and insurance implications (insurability, premium) when designing the wind park, e.g. in discussions on cable strings vs. loops, fire protection, redundancy for key components, spare part strategy.
- ➔ Keep in mind that insurance comes with a deductible and usually does not pay in full. Be prepared to bear cost resulting from insured events and be prepared to

have long negotiations before loss can be recovered from insurance (cash-flow planning).

Concerning the good practices, projects list following issues:

1 Build in Health, Safety & Environment (HSE) thinking into daily operations;
2 Build open and lasting relationships with all relevant regulatory authorities;
3 Build and maintain a strong Lender consortium;
4 Balance the needs of the Project and potential risks when assessing the insurance package;
5 Keep open communication channels between the Project team, Shareholders, Lenders, and Lenders' advisors;
6 Ensure industry best practice is implemented and adhered to;
7 Ensure financing documents, and guidelines are adhered to;
8 Use risk management tools extensively;
9 Actively manage suppliers to deliver as fast and as much as possible, and offer help where it is likely to provide most impact;
10 Ensure the digitalisation of processes;
11 Early involvement of and continuing communication with key stakeholders, including: authorities, financing institutions and advisers, insurance advisers & broker, Direct marketing company, Grid provider/Transmission System Operator (TSO), etc.;
12 Ensure control of technical and contractual interfaces by:
12.1 Engaging experienced personnel for drafting contractual scope;
12.2 Limiting number of contractors as low as possible;
12.3 Defining clear contractual responsibilities for each contractor;
12.4 Deploying penalties and incentive mechanisms in contracts to stay within schedule;
12.5 Paying special attention to innovative/new to market technologies;
12.6 Not underestimating scope of communication and SCADA technologies as this will be crucial for wind park operation and fulfilment of requirements of grid provider and direct marketing company;
12.7 Preparing for curtailment recording and compensation calculation;
12.8 Managing expectations and processes with grid provider;
13 Engagement of experienced team (key personnel with track record in the industry). Find balance between personnel employed short-term and long-term on the project, taking into account that short-term employed personnel might leave without long notice periods;

14 Have adequate processes in place for i) roles in the project, ii) Key project processes like HSE, procurement, iii) Reporting (incl. calendar of deadlines for reporting requirements) and Document storage and management;
15 Have a continuous dialogue with the authorities and stakeholders involved;
16 Inform all parties involved in the project and operation the measures promised in the environmental permit application to minimize deviations that can delay the project;
17 Have a good planning at an early stage in the investigation of several alternative designs of the project is one of the key factors for a successful project;
18 Involve participants in the project early in the planning and risk assessment;
19 Organise the project early with all the skills that may be needed;
20 Ensure that resources are available during the project and that technical specialists are available also during the first years of operation;
21 Work closely with suppliers and ensure that experience from previous project utilized.

One project focusses on more "practical" good practices

1. Although the turbine manufacturer guarantees a technical availability of up to 97% per year including a clearly defined maintenance factor, it is required to have a separate operator available who also supervises the turbine operation to keep reaction times as well as downtime hours for corrective and preventive maintenance low.

2. Based on the experiences concerning snow fall and corresponding snow heights over the winter season from the years 2012 (wind measurement campaign) to 2017 only a snow plow was provided to keep the roads clear for necessary site inspections. Due to heavy snow fall in 2018 now it is essential to provide a snow groomer together with an associated garage which both will be purchased/constructed in 2019. To get an impression, figure 3 shows the situation in 2018.

Figure 3: Accessing the wind turbine after a snowfall.

4.3 Environmental Impact

Most project minimised their environmental impact and fulfil their legal requirements.

It is stated that the highest environmental impact happened during the construction phase. Projects try to optimise the maintenance end thus reduce the transport of equipment and other material.

Onshore projects underline the improvement in logistics in remote locations, like alpine windpark site, through modular towers. They question also the improvement of construction vessels, which would mean increasing hub height, larger rotor diameter and increasing demands on road works.

It seems that offshore projects see improvement of the technology as a way to reduce the environmental impact

Following improvement have been mentioned:

- ➔ Utilise CMS data to create value in relation to Inter-Array Cable (IAC), Field Operation Unit (FOU) and Wind Turbine Generator (WTG) assets;
- ➔ Develop an end of warranty concept for various individual components such as Blades, Nacelles and towers with a view to discovering anomalies in operational behaviour, initiate claims, extend warranties and evaluate risks;
- ➔ SCADA upgrade: in order to provide more secure and stable software and hardware, implementation of more reliable service provider in order to initiate cost savings by minimising commercial and technical risks;
- ➔ Uninterruptible Power Supply (UPS) Retrofit: the UPS system specific upgrade in 2019 will enable UPS to be accessed remotely in order to reboot system in case of system failure. This will reduce WTG downtime;
- ➔ Use expert inspection service not only to meet regulatory requirements but also to support regular maintenance, lifetime extensions, warranty usage and claims.

4.3.1 Future developments

In the longer term, following innovative projects are proposed:

1. Power output improvement

- ➔ LIght Detection and Ranging (LIDAR): Carry out measuring campaign with LIDAR to harvest maximum energy of the wind available by improving aerodynamics;
- ➔ Pitch and Yaw calibration to minimize technical offset positions.

2. Operation improvement

- ➔ Less unscheduled visits through technical improvement of turbines;
- ➔ Grid Integrity WTG: technical changes to decrease unplanned outages;

- ➔ Power quality measurement on 690V, 33KV and 155KV voltage level to discover further technical risks;
- ➔ Implement overall Operations Management Software.

3. Logistics improvement

- ➔ Sliding access;
- ➔ Increase of Helicopter Operations;
- ➔ Decrease of SOV usage (through vessel sharing, etc);
- ➔ Improvement of Heli Operation Processes;
- ➔ Share logistics with other wind farms.

4. Maintenance improvement

- ➔ Improvement of Risk Based Inspection Approach;
- ➔ Annual Service Campaign improvement Project;
- ➔ Compress annual service campaign.

5. Power marketing:

- ➔ Contractual and technical implementation of domestic facilities;
- ➔ Improvement of Wind Farm power output availability forecasting (new wind data analysis has been undertaken, further data measurement techniques under investigation).

6. Asset Integrity:

- ➔ Lifetime extension;
- ➔ Structure CMS Monitoring;
- ➔ WTG drive train CMS Monitoring.

4.4 Health and safety

The projects experimented a limited number of incidents and near misses

The cause of one incident, a smell of chlorine within a turbine still need to be determined

One projects states, for every incident and near miss, there are lessons learned, but if we should sum our experience from all the incidents that have occurred, it is that no matters how carefully we have been when we have made all our risk assessments, there are always opportunities for improvement on site, where the job is done. It is a joint responsibility in all parts of a project to work safely and make all risk assessments necessary, from planning to implementation.

Reducing the number of incidents and near misses is based on intensive yearly trainings and instructions (partially held by the manufacturer). To work safely, every employee has to prove its fitness concerning the supervision of wind turbines as well as lower down on a rope in emergencies; the other condition is the regularly inspection of the used material and tools; this regulation is valid for all employees on site, as well as any other third party

After analysis of the various events, general recommendations were given:

- ➔ All technicians to observe closely weather forecast before undertaking operations;
- ➔ Communication is key;
- ➔ The topic Dropped Objects must be higher on the agenda;
- ➔ The construction department must specify the responsibility for the assembly and disassembly of guiding clamps in contracts;
- ➔ The hoisting position must be part of the acceptance test;
- ➔ Have more technicians on the tag line where possible to maintain maximum control during the lifting operation;
- ➔ Not cutting free hanging cable ties in an area with limited space for turning;
- ➔ Using safety googles when working in these narrow places;
- ➔ Use time to Identify the risk when you work;
- ➔ Take care of all hard parts around your body and pay attention to any movement during working in limited space;
- ➔ Improving safety awareness and increasing safety education.

5 Conclusions

Within the NER300 projects, the two bioenergy projects cumulate now 4 years of operation and the four wind energy projects 8 years. Despite the diversity among the projects, key trends and common approaches emerge that illustrate the lessons learned during this period of time. This report aggregates the available Level 1 and Level 2 knowledge shared by the projects in an anonymised way.

For the bioenergy projects, both are methanesecond-generation bio refineries. Most of the steps of the process are very similar except the fermentation step, which ends with different end-products, either bioethanol or biogas. For the functioning of the plant, some very basic issues seem to have a very important role, like the greasing of the bearings or other mechanical tools used during the pretreatment of the feedstock, like hammer mills, cutting devices, centrifuge screws, etc, that suffer abrasive wear and corrosion and, consequently, need to be properly maintained. Beside these mechanical issue, the process itself is the fundamental issue that needs to be properly fine-tuned. In order to improve it, to make more efficient, thus more cost-effective, a lot of additional research and development is needed. The process that takes place in a biorefenery is complex in the sense that is made of several steps that are all interdependent. Further, as it is a "living process" involving micro organisms during the fermentation step, a high number of parameter characterize the whole process. It is very difficult to control the effect of one parameter without interfering with other parameters. Carrying out experiences with controlled conditions is possible at laboratory scale but does not mean that the results can be extrapolated neither at the scale of a pilot installation, nor at the industrial scale. The projects describe the difficulty and the developments needed to adapt the installation to new feedstocks like rice straw. To achieve such goals, research has to be carried out to fully understand basic processes like the optimization of the enzymatic hydrolysis process or the increase of the yeast tolerance to inhibitors that may be produced during the process. For example, a project started a research collaboration with universities to investigate whether funghi could pre-treat the lignocellulose in a way, which makes it suitable to produce biogas.

From an environmental point of view, the main concern seem to be linked to finding a proper use for the residues. Among these, the use of lignin resulting from the waste water treatment is of particular interest what concerns future research.

For the wind energy projects, water penetration remains a main issue for offshore installations, while onshore installations are to be able to face the harshness of their surrounding environment. Future developments will have to significantly improve their design in order to solve this water penetration problem. Sea water, due to the high sodium chloride concentration, is a very corrosive environment. Research efforts should also be made to improve the corrosion resistant of the material used, either by using corrosion resistant materials or by using surface treatments, like coatings. Further, on-shore environments, like mountainous areas or when severe icing conditions are met, can also be very harsh. The NER300 projects show that very simple issues, such as snow free roads to access the installation, can rapidly become a very complex issue.

Further, this report presents several sets of good practices that have been put forward by the projects in various areas, like technical set-up and performance, project management, environmental impact and health and safety, are listed.

For all projects, that are all demonstration projects, most lessons were learned during downtimes. Then, efforts have to be made to understand the issue and find a suitable solution. By doing so, the whole technology is step-by-step, getting more operational, more efficient and, above all, more reliable. It must be said that some incidents are not yet completely understood which shows, once more, that novel technologies need to undergo extensive periods of testing, corrections and adjustments before full and carefree commercialisation.