GA-No. 283018
(FP7- Collaborative project-2012)
June 2012 – May 2016
www.rewagen.eu

REWAGEN - Electrochemical WAter treatment system in the dairy industry with hydroGEN REcovery and electricity production

Executive summary

The aim of the REWAGEN project was the development of an eco-efficient wastewater and whey treatment system in the dairy industry for the total abatement of contaminants based on electrochemical technologies, enabling water reuse and separated waste valorisation.

The energy needed for the treatment will be partially recovered from the hydrogen produced during the electrochemical treatments, thus improving process sustainability. The process includes a pre-treatment (Pulsed Electric Field, PEF), an electrocoagulation (EC) and electro oxidation (EO) step and a final conductivity reduction process by capacitive deionization (CDI).

Moreover the REWAGEN concept considers the separation of metals from the electrocoagulation sludge with the target to separate organic sludge and valorise it for energetic or fertiliser purposes. The key novelty of the process includes a hydrogen recovery process where this by-product produced during the electro-oxidation step is purified and burned into a fuel cell enabling energy recovery for the sustainment of the water treatment process.

The concept addresses the wastewater management as a whole, understood as an industrial process directly linked with the production performance. The idea was to develop a wastewater treatment system aiming at closing the water cycle, by integrating energy and water management, where the electricity generated through the hydrogen conversion is used to keep the system working and the extracted residues from the waste water treatment are reused inside the food and dairy production process to cover different needs. Therefore, the project developed a system with technologies that had not been jointly developed together with hydrogen recovery. The hydrogen generation from EO systems for electricity production was completely used to feed the wastewater system.

Started in summer 2012, the REWAGEN project has made significant progress, both in terms of the single wastewater treatment technologies applied and in terms integration

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of different technologies into one plant. Experiments have started at the laboratory scale, processes have been developed and reactors have been designed. The trials showed a reduction of the energy consumption for the wastewater treatment processes and a reduction in water consumption by recycling. The consortium proved that electrocoalescence (Pulsed electric field) is efficient to remove oils and fats from wastewater streams without any addition of chemicals, that the developed electrocoagulation technology reduces the turbidity that the high organic load can be decomposed by electro-oxidation, and that capacitive deionization can decrease the salinity to a drinking-water compatible level. The collected hydrogen from the electro-oxidation processes could be collected, upgraded and used in a fuel cell.

In summary, by 2016, REWAGEN has developed an environmentally-friendly treatment system pilot plant including internal energy recovery for dairy wastewater and whey. The purified water can be reused in the dairy process.

The project has a huge economic potential that will contribute to the growth of the global market for environmental technology and services, the competitiveness of the EU economy while increasing the creation of jobs with these new technologies. The food and beverage sector is one of the largest industrial sectors in Europe in terms of turnover. Environmental issues in the food processing industry are diverse, but one of the main issues is wastewater prevention and treatment. Through improving the environmental and economic sustainability of wastewater treatment in this sector, REWAGEN has the potential to open up new business opportunities for the consortium as well as for the industry. It is worth considering that water and wastewater services provide close to 600 000 jobs in Europe, with an overall investment of more than €33 billion annually and a turnover of around €72 billion annually. Therefore, the development of new wastewater and whey treatment technologies could open commercial opportunities in an attractive market.

There is also potential for job creation in the development and manufacturing of technology necessary to produce energy from hydrogen. Companies are looking to invest in technologies to treat emissions with the lowest operative costs possible. This project can therefore stimulate the production of fuel cells or alternative systems capable of converting hydrogen into electrical energy.

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Summary description of the project context and the main objectives

From a global perspective, the dairy industry has shown steady growth the past five years despite an only slowly recovering economy. The European Union, India and the U.S. were the largest milk producers in 2010 and are expected to remain so in 2020 [1]. In the EU, the food and drink industry is the largest manufacturing sector in terms of turnover (14.6%) and value added (12.5%) [2]. It generates 11% of total EU employment and 6% of the EU Gross Domestic Product (GDP). As of 2013 there were 286,000 companies in food and drink industry [3].

In 2018, the European dairy market is forecasted to have a value of $184,618.4 million which represents an increase of 12.8% since 2013 [4, 5]. In Germany, France, UK, the Netherlands, Poland, Ireland, Austria, Denmark and Belgium milk production has increased in the last 10 years [6] and the forecasts to 2024 are generally positive. Most of the EU milk output is processed as cheese, butter or skimmed milk powder, as well as a wide variety of yoghurts, creams, ice creams and other value-added products [7].

These figures clearly show the relevance of the dairy market, but can also give a first impression about the immense amounts of wastewater generated in the sector day by day. For the project context, it is therefore important to know, that the dairy industry is a growing industry that generates about 2–10 liters of effluent per liter of milk (sludge) although it is possible to optimize this consumption using advanced equipment and proper management. The sludge can only be spread directly on agricultural land or treated in an on-site or local mixed wastewater treatment plant.

These are often not cost efficient solutions due to high economic costs for freshwater and for the process of spreading the sludge on the land that most of the SME dairy producers cannot afford, and are not in accordance with environmental considerations due to the presence of nitrogen in dairy effluent that may contaminate ground water with nitrate.

There are existing processes for the treatment of waters from the dairy industry on the market already. However, these treatments still have limitations in terms of removal of pollutants or water recovery, which REWAGEN aimed to overcome.

The aim of the REWAGEN project has been the development of a pilot plant for a water treatment system for the dairy industry – based on the sequential combination of three technologies: electrocoagulation, electro oxidation and a technology for the recovery of generated hydrogen for energy saving and the reutilisation of the resulting regenerated water for different applications – more efficient in terms of wastewater treatment and self-sustaining in terms of energy needs.

The REWAGEN project aimed to treat dairy effluents composed by wastewater and whey by means of electrochemical processes in order to achieve the desired water quality to its reuse; recover the hydrogen generated during treatment as a by-product in a secondary power generator feeding the main wastewater treatment technologies; reduce the amount of sludge generated during the electrochemical treatments and valorise the remaining generated sludge, if this is economically feasible.

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REWAGEN had the following ambitious objectives:

- Treatment of target dairy effluents (wastewater and whey) through coupling EC and EO upgrading systems
- Reduction of water consumption at dairy site through treated water reuse
- Having high conductivity related to sweet and acid whey reduced, this allows water reutilization
- Hydrogen recovery and purification from EC and EO processes
- Energy recovery through hydrogen combustion in a fuel cell system
- Study of waste management through electro generated sludge valorisation
- Reduction of chemicals consumption

In summary, the main goal of the project has been finding a general and sustainable solution for the wastewater and whey treatment of the dairy industry. This could be constituted by the combination of several technologies that can be valorised both as a whole processes, and as single technologies in various applications. Also modular combinations of only some of the technologies are thinkable for special applications and will be further developed after project end.

References:

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Description of the main S & T results/ foregrounds

The aim of the REWAGEN project was the development of an eco-efficient wastewater and whey treatment system in the dairy industry for the total abatement of contaminants based on electrochemical technologies, enabling water reuse and separated waste valorization. The energy needed for the treatment could be partially recovered from the hydrogen produced during the electrochemical treatments, thus improving process sustainability. The process includes a pre-treatment, an electrocoagulation (EC) and electro oxidation (EO) step and a final conductivity reduction process. The key novelty of the process includes a hydrogen recovery and valorization process where this by-product produced during the electrochemical steps is purified and burned into a fuel cell enabling energy recovery for the sustainment of the water treatment process.

The concept addresses the wastewater management as a whole, understood as an industrial process directly linked with the production performance. The result is the development of a wastewater treatment system aiming at closing the water cycle, by integrating energy and water management, where the electricity generated through the hydrogen conversion is used to keep the system working and the extracted residues from the waste water treatment are reused inside the food and dairy production process to cover different needs. Therefore, the project developed a system with technologies that were not integrated together before and joined them with hydrogen recovery process. The hydrogen generation from the electrochemical treatment system for electricity production is completely used to feed the wastewater system.

The first necessary step is based on the elimination of fats and oils in order not to interfere in further processes. Afterwards, electrocoagulation and electro oxidation as Electrochemical Advanced Oxidation Processes (EAOP) is coupled and upgraded in order to remove/reduce suspended solids, colour and turbidity. Post-treatment based on Capacitive Deionization Technology (CDI) was developed to obtain appropriate conductivity level for water reutilization.

- **Pulsed Electric Field (PEF):**

The aim of the technology development of pulsed electric fields for the separation of oil/fats from watery media was the improvement of an eco-efficient wastewater and whey treatment system in the dairy industry for the removal of contaminants based on electrostatic and gravimetric technologies, enabling water reuse and separated waste valorization. Conventional technologies for pretreatment process are based on chemical addition. The energy needed for the treatment is low and no chemicals will be needed. This also means that no chemicals have to be stored, transported and handled. This will next to environmental issues bring more safety for the operation.

During REWAGEN a new technology based on a pulsed electric field system that generates high electric pulses (up to 70kV) with very low currents (in the mA range) was developed. Colloidal systems like different types of emulsions and suspensions are stable due to surface charges and adsorbed ions. To split these emulsions, conventional technologies usually add chemicals to change the surface charge.

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However, according to the DLVO-theory also energy can be used for this: if the oil drops in the emulsion can coalescence and form bigger agglomerates they float and can be removed easily. In the REWAGEN we took advantage of this base and developed a coalescent process based on electrical application and paying special attention on the materials, electric components and process technology.

In the REWAGEN project Aqon and its partners could show that a sustainable splitting of the dairy emulsions is possible with an energy demand of less than 2.5 kWh/m³. Reduction rates of the turbidity which was taken as the main parameter is between 87% and 96%. Inlet values from more than 700 NTU could be reduced to 35 NTU and lower. This means that the reduction of turbidity is successful according to the objectives. The separation of fats/oils works continuously and does not need any support while running. The agglomerated oils/fats where separated by a gravity separator with special designed installations.

The pulsed electric field technology and the special designed separator are patented by Aqon and can be used in different applications and fields. This novel technology could be use and have an important impact in different fields like in the food processing industry (e.g. dairy waste water), in the metal processing industry, in the petrochemical industry.

This technology has got a high score in technology maturity and benefits of the invention following the assessment of the technology during the project. However the overall score was low due to it has been considered at a pre-commercial stage and there are still tests to be carried out.

In any case the project gave the opportunity to validate the technology against organic fats in dairy industry with promising results.

- **Electro coagulation (EC)**

Electrocoagulation is an electrochemical process used as alternative to conventional coagulation/flotation processes. In this advanced technology, coagulum agents are *in situ* generated through electrochemical oxidation of sacrificial metallic anodes (*e.g*. iron or aluminium) (Equation 1). Obtained Fe(II)/Fe(III) (Equation 2) or Al(III) precipitate with hydroxide ions (Equations 3 and 4) generating coagulum particles which destabilize and adsorb water pollutants by surface complexation or electrostatic attraction. Pollutants are removed by sedimentation or electro-flotation owing to bubbles of hydrogen gas generated at cathode surface (Equation 5).

Between others, some of the main involved reactions during EC process, when iron anode is used, are the following ones:

$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$ (E^0 = -0.44V vs SHE) (Equation 1)

$Fe^{2+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + 1e^-$ (E^0 = 0.771 vs SHE) (Equation 2)

$Fe^{2+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_{2(s)}$ (Equation 3)

$Fe^{3+}_{(aq)} + 3OH^-_{(aq)} \rightarrow Fe(OH)_{3(s)}$ (Equation 4)

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$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$ (E^0 = -0.83 vs SHE) (Equation 5)

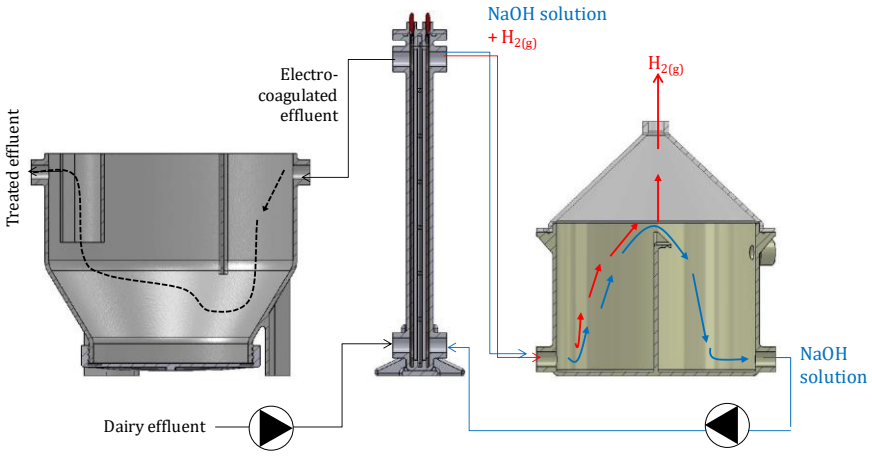
Comparatively with conventional wastewater treatment processes, EC mainly offers low investment and operational costs, efficient removal of contaminants (organic compounds, suspended solids or turbidity, fats and oils, metals, nutrients, salts), no chemicals addition and a minimum level of residual and dense sludge. EC bench scale system was designed in Leitat Technological Centre and it was composed by three main modules:

- An **electrochemical bi-compartment cell (or divided EC cell)**, where anode and cathode compartment were separated by an anionic exchange membrane. Hydrogen was recovered from cathode compartment and dairy effluent was treated in anode compartment.

- A sealed tank for hydrogen recovery and catholyte (NaOH solution) recirculation.

- A settle tank where electro-generated coagulants are removed from the treated effluent coming from anode compartment.

The figure below shows a section view of the **continuous EC system at bench scale** used for dairy effluent treatment and simultaneous recovery of hydrogen. The electrochemical cell is a one-compartment filter-press cell used as electrolytic reactor, composed of several components in order to allow water treatment and simultaneous hydrogen recovery.



Section view of bench scale EC unit.

Dairy effluent could be effectively treated by advanced REWAGEN EC continuous system.

With the optimal operational conditions, turbidity removal was of 95%, COD removal of 33% and the H_2 purity would be around 90%. The EC pilot scale unit was constructed by Fraunhofer in cooperation with Leitat.

The EC pilot scale unit was re-design in order to ensure reliable and energy efficient operation, however the hydrogen production in optimal conditions was not appreciable. For the overall energy efficiency was then decided to avoid generation of Hydrogen in the EC process.

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The main innovation is that no chemicals need to be added due to the electrochemical production of hydroxide flocs. Floc generation occurs even at low feed pH value, and energy efficiency due to floc blanket. Also other important factors, such as reducing electrode fouling was considered and improved from actual equipment.

Exploitable Foreground

Its purpose:

Leitat as Technological Centre has the purpose of transferring know-how acquired within this technology development to the interested stakeholders. Our added value is our expertise and knowledge acquired on the technology.

How the foreground might be exploited, when and by whom:

Know how transfer ready to be exploited to the interested stakeholders.

IPR exploitable measures taken or intended:

Lab scale electrocoagulation cell design may be patented referring to the H2 recovery. Actually under study.

Further research necessary, if any:

Further research may be needed to have a wider portfolio on specific applications for specific sectors. Technology has been tested for the dairy industry but other sectors such as pharmaceutical, leachate treatment, etc. may have interest and some adjustments and validation may be needed for the technology. In addition, the technology could be further improved in terms of energy efficiency.

Potential/expected impact (quantify where possible):

Electrocoagulation is a commercial technology but not very extended in the market. The H2 recovery is an added value to the potentiality of this technology in the future since electrocoagulation offers clear improvements compared to conventional wastewater treatment processes such as low investment and operational costs with an efficient removal of contaminants, no chemicals addition and a minimum level of residual sludge.

- **Electro oxidation (EO)**

Electro-oxidation (EO) is widely used in waste water treatment processes. The novelty that this technology offers is the use of silicon or niobium based anodes coated with boron doped diamond (BDD), which allows reduction of chemicals usage for wastewater treatment, the size of the installations and the possibility of program the operations processes, high energy efficiency of the system due to the hydrogen recovery and reduction of waste water.

The electro-oxidation (EO) system design at laboratory scale for the REWAGEN project has been carried out selecting the most appropriated system design for simultaneous effluent treatment and hydrogen production. The best materials for the

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electrochemical cell as well as the different types of electrode materials to be used in the designed electrochemical cell have been as well selected.

The performance of the electrochemical cell in the EO system for the high organic matter oxidation has been thoroughly evaluated through the time. Nonetheless, additional experiments for the optimal conditions using the designed laboratory scale cell with real wastewater together with the hydrogen recovery and quantification will need to be carried out in order to be able to scale up into the pilot plant.

The EO system is based on a divided electrochemical cell, which consists of an anode/membrane/cathode assembly. The anode side is separated from the cathode side by an ion exchange membrane. The EO pilot system has two stages Oxidation Process to assure oxidation requirements. EO system has received high score in the internal assessment due to its evident benefits in comparison with traditional electro-oxidation process: Reduce of chemicals usage, the size of the installations and the possibility of programing/scheduling the operations processes, high energy efficiency of the system due to the hydrogen recovery and reduction of waste water.

The innovation consists in the development of a complexed treatment system for a difficult waste water type from diary industry which is characterized by changing composition, high organic load and also changing salinity. It is a new application for BDD electrodes in waste water treatment, but not a new process in general - AOP processes are well described in the literature, the point are the special requirements of the used waste water type, especially concerning materials (membranes, electrodes), process parameters and potential production of harmful substances in EO.

This system can be use in every industrial field which produces high load of recalcitrant organic pollutants in its waters and wastewaters. Challenging wastewaters hardly degradable can be addressed and oxidized with this technology.

Exploitable Foreground

Its purpose:

Electrooxidation using BDD anodes in REWAGEN project was developed as a two-stage oxidation for continuous run. This technology has good prospects in wastewater treatment for water with a high COD load (“biological decontamination”). Besides the wastewater of dairy industry, which cause in Germany only partial problems exist a number of similar wastewater streams to be treated: from biogas production plants, cutting and cooling emulsions, pulp and paper industry, food industry. For all these applications EO using BDD electrodes can be adapted. Due to the high price of the BDD electrodes and the energy demand EO can be a quite expensive process, Therefore it must be well designed and adjusted to the different applications. EO is one of the best methods for the final stage of COD reduction (range 8.000 -200 mg/l). When the COD load of the waste water is higher, a combination of methods like PEF+EO or PEF+EC+EO will be the better solution. For better economics EO can be designed without membranes. They were necessary in REWAGEN project for hydrogen separation and reuse, but for small and middle size EO plants hydrogen recovery make no sense.

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How the foreground might be exploited, when and by whom:

EUT is in intensive contact with Aqon (PEF), Fraunhofer (EC) and Idropan (CDI) to test the combination of methods for several types of wastewater. Actually wastewater from the food industry is in test for the combination PEF+EO. In preparation are tests for pulp and paper ww. EUT together with producer of BDD electrodes plan to introduce the EO technology in an adapted form to the Chinese market in autumn 2016.

IPR exploitable measures taken or intended

Dairy industry: update of the market study for Germany, especially for Bavaria and Schleswig-Holstein starting 09/2016

For cutting and cooling emulsions: market introduction study in progress (by Fraunhofer)

Food industry: trials for combination PEF+ EO started, additional EC possible

COD reduction in industrial waste water in China (EUT + partner): pilot trials planned for 10/2016

Further research necessary, if any

Yes, for adaption of EO to the different ww types and to make the technology more economical. We expect additional 1.5 – 2 years R&D , design and pilot test work, before the technology will be ready for industrial scale processes for wastewater different from dairy ww.

Potential/expected impact (quantify where possible)

Too early to quantify. Only the Chinese market is huge, probably the production of EO equipment will be organized on license base in China, so that the income from the license fee can grow up to 1.5 -2.0 Mio € within 5 years.

- **Capacitive deionization (CDI)**

CDI is a technology for the reduction of conductivity, desalination and demineralization, which has found during the progress of the REWAGEN project its maturity in terms of optimization and enhancement of the process. Several aspects and parts of the process have developed to help the overall process to be reliable and increase its capacity. From the most remarkable improvements are: the development of FIFO tanks and their inclusion into the overall process for the product water as well as the regeneration water, the evolution of two new generations of PSU boards (AI11 & AI13) for increasing PSU capability to feed the CDI cell, the development of a controller & firmware for the automatic operation and the test and validation of the new concept for desalination of higher conductivity water.

The following table summarizes the evolution of the CDI concept due to the REWAGEN project.

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Parameter	Before REWAGEN	After REWAGEN
Conductivity	2000 uS/cm	7000 uS/cm
Cell capacity	100% (reference)	250% or more
Water recovery @ 3000 uS/cm	40-50%	>80%
Max current from single PSU	80 A	300 A
FIFO tanks in product water	NO	YES
FIFO tanks in regeneration water	NO	YES

• FIFO tanks

• Up to 7 mS/cm conductivity

CDI has got a high score in the internal assessment in benefits of the invention, sector of application and relevance of protection and it presents a high level of innovation due to it can be considered as emerging technology.

- Hydrogen recovery and energy production

The technology allows upgrading and purification of hydrogen by means of adsorption and pressure swing adsorption (PSA) to fuel cell quality. The hydrogen (H_2) generated in the electro-oxidation processes is used in fuel cell stacks in order to produce energy.

The Hydrogen Processing Unit consists of coalescing filters, a gas heater /cooler, several adsorption guard beds, a deoxidizer and gas upgrading section. It was demonstrated that it is possible to capture and purify and recover hydrogen for energy production in the waste water field using electrochemical processes. This technology could be transferred to different industrial or manufacturing processes where production of hydrogen is a consequence or by product of the main industrial streams.

Hydrogen recovery and Fuel cell has received a high score in the internal assessment in terms of technology maturity, technology readiness level and industrial feasibility. In fact, this technology is already in a commercial stage, but the main novelty of the REWAGEN technology is that it offers the application to a water treatment system with integrated hydrogen recovery.

One of the innovative aspects within Rewagen is the use of vacuum swing adsorption. Regular high pressure PSA is normally used to purify hydrogen containing gas streams to high purity H_2. As a consequence the H_2 yield is only moderate while compression energy for current application is high. The high purity H_2 is fed to a Fuel Cell (FC) and is converted to electricity.

Current technology makes use of vacuum pressure swing adsorption (VSA) to yield H_2 of moderate purity (only nitrogen remains as impurity, while all detrimental compounds are still removed) at high H_2 yield. The moderate purity H_2 is fed to a FC. To improve the efficiency the non-converted low purity H_2 is recycled back to the inlet of the FC. The use of VSA technology is expected to reduce the electrical consumption of the process. The combination of VSA technology, moderate purity H_2 and FC H_2 gas recirculation is expected to yield a higher overall efficiency compared to conventional PSA and FC utilization technology.

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Exploitable Foreground:

Its purpose

Idropan uses Plimmer CDI as an alternative to RO for desalination. In Rewagen IDD goal was to increase operational range of CDI toward higher salinity. CDI is a salt removal technology opposed to RO that is a water removing technology. This means that CDI is more efficient for lower salinity than RO and requires far less energy. Normally CDI is upward limited to a salinity of 1500/2000 µS/cm because his capacity to accumulate ions on electrodes is limited.

How the foreground might be exploited, when and by whom

Plimmer CDI in the post REWAGEN state is a very viable RO competitor. Worldwide market is very big and not limited to Europe. IDD has already contacts worldwide:

- India
- Australia
- South Europe

Production will be performed in Europe.

Post Rewagen Plimmer CDI is a very strong competitor because:

- In this application there is not a problem of income salinity but instead a need to reduce as much as possible waste.
- Using FIFO tank as a regeneration tank wastage can be reduced to an absolute minimum of only 1-2% of treated water
- With a well-designed chain of countercurrent rinses it is possible to directly reuse in plating bath salts and metals without further treatment
- Lowest possible operating cost
- Use only electricity for salt removal
- Easy operation

Further research necessary, if any

Further research will be done in order to translate this technology platform into a market-ready system for high-volume production.

Potential/expected impact

Water market had total global revenue of €5.6 billion and a projected CAGR of 5.9 % until 2025. Europe is 15 % of the market worth €800 million. Projected market size for January 2019 could be €7 billion global and €1.05 billion for Europe. Drivers for stable market growth are user awareness of the cost of water to their businesses and growth

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of application sectors e.g. food, general heat exchange, and commercial property management.

Despite the drawback of high energy and water consumption, currently for want of a cost-effective alternative, the dominant desalination technologies are RO and NF.

Our Plimmer CDI approach follows this market trend towards chemical-free technologies and overcomes the limitations inherent in RO and nano filtration (NF) regarding low water efficiency (especially RO), high energy consumption and high capital costs (especially NF). Market entry of new approaches typically faces barriers as the market is dominated by large key players. But taking the new Plimmer CDI post Rewagen approach into the market independent from these large companies the marketing possibilities will be great.

- **Hydrogen Recovery and Fuel cell**

In the REWAGEN project, it was shown that hydrogen gas evolved by the EO can be collected and burned in a fuel cell stack for internal energy recovery within the complete wastewater treatment process. This achievement reduces the total energy consumption and makes the concept economically and ecologically attractive.

Exploitable Foreground

Its purpose:

This technology allows the upgrading and purification of hydrogen by means of adsorption and pressure swing adsorption (PSA) to fuel cell quality. The hydrogen (H2) generated in the electrooxidation processes is used in fuel cell stacks in order to produce energy. The hydrogen to be used in the fuel cell need to fulfill strict requirement on purity and impurities such as carbon dioxide (CO2), hydrogen sulfide (H2S), ammonia (NH3) and chlorine (Cl2). For this reason it needs to be upgraded. The energy obtained in the fuel cell is recirculated to the system in order to decrease the use of energy and consequently decrease the carbon foot print.

How the foreground might be exploited, when and by whom:

HyGear will exploit the patent in interested markets through licensing of their patent EP 2803656A1.

IPR exploitable measures taken or intended

Patented: EP 2803656A1.

Further research necessary, if any

This is the current status on the technology development and the improvements required:

- Handling WWTP gases for energy recovery feasible

- PSA and FC technology mature

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- System efficiency: 95% H2 efficiency, 50% electrical efficiency (will improve for larger systems)

Potential/expected impact

The system can be utilized for upgrading gases from H2-containing low pressure gases from other sources. Part of PSA development strategy at HyGear

- **Integrated control and monitoring system**

Apart from the control systems for the single units an overall control and monitoring system was realized. This allowed not only control of the complete pilot plant but also monitoring of water and energy flows. This was essential for operation of the single units at optimized conditions and for their efficient interplay.

Exploitable Foreground:

Its purpose

This technology consists in a control and monitoring system developed in the REWAGEN framework. This system is capable of performing both high level control of the distinct facility's water treatment modules and also monitor a fully heterogeneous monitoring network composed of several distinct meters and sensors such as electrical meters, water meters or other sensors integrates at the treatment module level. The meters and sensors integrated in the complete system can communicate through distinct communication protocols such as Modbus, M-Bus, CAN or other. This System, along with the monitoring and control capabilities is also fitted with a two level user interface component (one at the facility level, another at the cloud level), presenting distinct operational functionalities.

How the foreground might be exploited, when and by whom

VPS will considering if they will exploit the results.

VPS is considering how to exploit the results directly. Indirectly part of the achievements were incorporated, and are thus exploited, in the commercial offer of VPS in similar applications.

IPR exploitable measures taken or intended

There are not IP registers at the moment.

Further research necessary, if any

The specified water meters have been revised all through the project until achievement the expected performance of the technology.

The selection of the most appropriate measuring technology for the water meters to achieve the expected performance needs more extensive field testing.

Further research may be useful in the development of specific fault diagnostic and optimization algorithms.

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Potential/expected impact

This technology can have an impact in the following sectors: water treatment plants, food industry and general industry.

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Potential impacts (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results

The REWAGEN project aims to link wastewater treatment to internal energy recovery as an efficient means of managing dairy industry effluents (whey and wastewater). This was accomplished through the production of electricity by recovery and purification of hydrogen generated as a by-product in electrochemical process of electro-oxidation.

The REWAGEN pilot plant therefore acts as an energy efficient water treatment system, where the electricity generated through hydrogen conversion is used to minimize the energy demand and corresponding ecological of the single wastewater treatment units. The pilot unit contained different single units, each optimized for the removal of a specific class of pollutants. This solution allows further applications not only for the dairy industry, but for other sectors as well, such as biodiesel or olive oil production.

Started in summer 2012, the REWAGEN project has made significant progress, both in terms of the single wastewater treatment technologies applied and in terms integration of different technologies into one plant. Experiments have started at the laboratory scale, processes have been developed and reactors have been designed. The trials showed a reduction of the energy consumption for the wastewater treatment processes and a reduction in water consumption by recycling. The consortium proved that electrocoalescence (Pulsed electric field) is efficient to remove oils and fats from wastewater streams without any addition of chemicals, that the developed electrocoagulation technology reduces the turbidity, that the high organic load can be decomposed by electro-oxidation, and that capacitive deionization can decrease the salinity to a drinking-water compatible level. The collected hydrogen from the electro-oxidation processes could be collected, upgraded and used in a fuel cell.

In summary, by 2016, REWAGEN has developed an environmentally-friendly treatment system including internal energy recovery for dairy wastewater and whey. The purified water can be reused in the dairy process.

The project has a huge economic potential that will contribute to the growth of the global market for environmental technology and services, the competitiveness of the EU economy while increasing the creation of jobs with these new technologies. The food and beverage sector is one of the largest industrial sectors in Europe in terms of turnover. Environmental issues in the food processing industry are diverse, but one of the main issues is wastewater prevention and treatment. Through improving the environmental and economic sustainability of wastewater treatment in this sector, REWAGEN has the potential to open up new business opportunities for the consortium as well as for the industry. It is worth considering that water and wastewater services provide close to 600 000 jobs in Europe, with an overall investment of more than €33 billion annually and a turnover of around €72 billion annually. Therefore, the development of new wastewater and whey treatment technologies could open commercial opportunities in an attractive market.

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There is also potential for job creation in the development and manufacturing of technology necessary to produce energy from hydrogen. Companies are looking to invest in technologies to treat emissions with the lowest operative costs possible. Therefore, the project can stimulate an industrial sector related to the fabrication of fuel cells or alternative systems capable of converting hydrogen into electrical energy (engines, turbines, generators, etc.), consequently, there will be specialized personnel needed to design and fabricate the equipment.

The environmental impacts of the REWAGEN project consist in the treatment and recovery of wastewater to be re-used in the manufacturing industrial processes, avoiding the further depletion of the available water resources and reducing the emission of pollutants. The second major positive environmental impact is the capture and usage of the produced hydrogen by the electrochemical processes and turned to energy from the wastewater treatment process, to feed the same wastewater system. This, in turns, allows the reduction of energy consumption and CO_2 emission deriving from normal energy production processes. The third major environmental impact of the REWAGEN Project is represented by the recovery/ reuse of organic compounds, in comparison with the normal organic compounds extraction and displacement processes.

Despite huge investment in better wastewater treatment eutrophication caused by large inputs of nutrients, mainly nitrogen and phosphorous, is still a major environmental problem across Europe, affecting all types of waters.

All in all, REWAGEN has developed a pilot plant where individual technologies of six European small and medium sized enterprises could be adapted and validated according to the specificities of the dairy industry. For all of them, the results and lessons learned out of this European collaborative project contributed to advancements in their know-how as well as to new exploitation opportunities.

Based on a Technology Roadmap Analysis that has been carried out for REWAGEN, each individual technology module of the pilot plant has huge potential for exploitation, offering different possible applications. The six evaluated technologies have received high scores in regarding “industrial feasibility”, “sector of applications”, “technology readiness level” and “benefits of the invention”. Actually, three out of the six technologies have received a high score in “sector of applications” given that they can be applied to all water treatment processes and there are many sectors related to this issue.

Building on the insights gained during the project, partners are already thinking on step further, trying to adapt the modular system in a smaller dimension which may be more suitable and affordable for small and medium sized end-users. The partners REWAGEN Eilenburger Elektrolyse- und Umwelttechnik GmbH, Aqon Water Solutions GmbH, Idropan Dell Orto Depuratori SRL and Fraunhofer IGB are envisaging a combination of PEF, EC and CDI technology for several types of wastewater. Furthermore wastewater from the food industry is currently tested for the combination PEF and EO.

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Promising market opportunities for different REWAGEN technology combinations are not only seen in Europe, but also and especially in China, the U.S. and India. In general, these developments not only provide innovative solutions for water treatment applications but also for related fields, such as the hydrogen recovery for energy generation that provides sustainability to the system. Therefore the outcomes of the project have the potential to improve different European sectors and enterprises in terms of business growth, job creation and environmental impacts.

In relation to the Dissemination activities carried out during the project lifetime the consortium has actively disseminated information of the REWAGEN project and its results by participating in events of different kinds such as conferences and exhibitions where partner took the opportunity not only to present and disseminate the project but also to present the materials developed all along the project. Besides that an international workshop was organized by KIM in the frame of the KIM Conference 2015. The opportunity was taken to gather the entire consortium and to disseminate the project and its results among the relevant stakeholders.

During the project lifetime an exploitation strategy has been established in order to transfer REWAGEN'S technologies into the market. To do so, a technology roadmap has been established and updated during all the project lifecycle through a technology assessment carried out by KIM in order to evaluate and categorize the status of the technologies developed by the different partners by close-to-market criteria. The technology roadmap and an exhaustive assessment of the market and its needs are vital in order to develop an appropriate exploitation plan. Therefore and besides the technology assessment, KIM has conducted an in depth research on the current status of the market within the dairy sector which includes the market needs and the sectors of exploitation. A part from this, each partner has put efforts in finding ways of exploitations of their results and some of them are in active conversations to commercialize their technologies or already commercializing it at a worldwide level.

According to the market analysis carried out, there is a clear market need of solutions such as REWAGEN's. During the development of the project, different innovative technologies have emerged. As the REWAGEN solution is a combination of several technologies it is necessary to consider two options of its exploitation. It can be either valorised as a whole process or as a set of technologies addressed to different sectors. At the moment, the first option could be possible but not the main focus given the complexity of the process. For this reason, in order to design a strategy to maximize the transfer of REWAGEN results to the market; this strategy will be focused on the exploitation of individual technologies.

Therefore, in order to carry out the development of the exploitation strategy, a technology assessment of each of the technologies has been carried out. To do so, general close to market indicators such as technology status, intellectual property status and degree of competitiveness have been analysed. Find below the current status of the technologies identified in close to market criteria order.

Position 1 (Electrocoagulation): The main innovation that this solution shows is the hydrogen recovery. The electrocoagulation process is similar to the ones already in the market. But this system recovers the hydrogen produced during the process and sends

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it to a fuel cell in order to produce energy which is used again by the system. It makes the whole system more sustainable and energy efficient.

Position 2 (hydrogen recovery and Fuel cell) has received high score in technology maturity, technology readiness level and industrial feasibility. In fact, this technology is already in a commercial stage, but the only novelty that offers is the application to a water treatment system where the hydrogen has been recovered.

Position 3 (Electrooxidation) has received high score due to this invention provides the next benefits in comparison with the traditional electrooxidation process: Reduce of chemicals usage, the size of the installations and the possibility of program the operations processes, high energy efficiency of the system due to the hydrogen recovery and reduction of waste water.

Position 4 (Integrated heterogeneous control and monitoring system) has got high score in “patent in competition”, “benefits of the invention” and “sectors of applications” due to even though this technology has been designed for operating a dairy water treatment plant, it can be easily adapted to monitor and control any other industrial facility.

Position 5 (Capacitive deionization) has got high score in “benefits of the invention” and “sector of application” and it presents a high level of innovation due to it can be considered as emerging technology. Despite the fact that there are several patent applications related to this technology registered in several countries, the patent that deals with the technology has been patented only in Italy, which reduce the possibilities of commercialization in other countries.

The CDI process can be used for water desalination, demineralization and water reuse; taking into account the capability of treating waters with 7000µS/cm or 4500ppm as TDS, the CDI technology, the target market it expands exponentially giving the process the ability to treat more than 75% of the brackish water sources in the world.

The CDI process has as well the opportunity to compete directly with RO for the desalinization process due to the limitations which this process evidence. Some of the most notable limitations of the RO process are Fouling and scaling. IDROPAN sees this opportunity to become an stronger actor in the world market, therefore it has already agreed a number of strategic partnership with entities in USA, Denmark, Saudi Arabia,Tunisia, India, Russia, Ireland and Australia. Idropan has entered the Indian market through a strategic partnership with Aquasphere Greentech,

Position 7 (Removal of oils and fats wastewater by electrocoalescence) has got high score in technology maturity and benefits of the invention. The main reason that this technology has got low scoring is that it has been considered at a pre-commercial stage and there are still tests to be carried out.

Two main possible sectors of application for REWAGEN have been identified: the Dairy Industry and the Food industry, focusing on big retailers that operate in production of dairy products. These sectors can obtain huge benefits from the results of the project and are considered the target for exploitation of the REWAGEN outputs.

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The food and drink industry is the largest manufacturing sector in the EU in terms of turnover (14.6%) and value added (12.5%). It generates 11 % of total EU employment and 6 % of the EU Gross Domestic Product (GDP). As of 2013 there were 286,000 companies in food and drink industry.

The European dairy market had total revenues of $163,689.6 million in 2013, representing a compound annual growth rate (CAGR) of 2.6 % between 2009 and 20135. In 2018, it is forecast to have a value of $184,618.4 million, an increase of 12.8% since 2013. More recent data confirm the positive trends in 2014, it rose by about 5 % and overall forecasts are positive. In Germany, France, UK, the Netherlands, Poland, Ireland, Austria, Denmark and Belgium milk production has increased in the last 10 years (see figures below) and the forecasts to 2024 are generally positive. Most of the EU milk output is processed as cheese, butter or skimmed milk powder, as well as a wide variety of yoghurts, creams, ice creams and other value-added products.

It should be taken into account that the sectors of exploitation should be limited to EEA countries and Switzerland only. As discussed before, Europe is one of the major producers of dairy products in the world. Many of the large European processors operate globally (e.g. Danone and Nestle). Also due to the European origin of the project and its recognisability by EU companies (the 7th programme framework recognition) the European companies and European Dairy Associations and Government Agencies are more likely to be interested in the REWAGEN technology than the ones based in other parts of the world.

As the REWAGEN solution is a combination of several electrochemical and electrophysical technologies it is necessary to consider two options of its exploitation. It can be either valorized as a whole process or as a set of technologies addressed to different sectors. At the moment the first option could be possible, but not the main focus given the complexity of the process. For this reason, in order to design a strategy to maximize the transfer of REWAGEN results to the market this strategy is focused on the exploitation of individual technologies.

Regarding the introduction into the market of the whole process, two ways have been taken into account:

- Licensing it to a third part, taking into account that, as presented in the previous chapter, the single technologies generated can be used and transferred into the market by the partners interested.
- Acquisition of technologies by an industrial partner that shape the whole process from one of the partners by the other partners in order to exploit it by his own.

Licensing is for the consortium the most suitable strategy for the introduction of the different technologies to the market that can bring more benefits. Taking into account that the partners are already involved in the exploitation of each technology from the project, they could take advantage of the commercialization and dissemination actions carried out for the exploitation of each outputs in order to disseminate and offer the whole process to a third part.

The dairy companies are the prime beneficiaries of REWAGEN solution. The technologies will enable the companies to minimize the use of water, valorize the residues and save energy. The companies could push the providers of wastewater treatment solutions to bring them better, i.e. cheaper and environmentally friendly, technology reusing the hydrogen. In our opinion the companies located in Germany, France, UK, Netherlands, Italy, Poland, Spain, Belgium and Portugal should be reached first. The dairy industry is particularly strong in these countries, either because of the position of the dairy companies in the market or because of the amount of dairy production and its relevance in national market.

For the exploitation of the project, not only large companies will be taken into account, but also small and medium companies, in order to maximize the competitiveness of the entire industry. Small and medium companies will benefit greatly from the results and outputs of RAWAGEN.

Parallel, dairy associations in Europe supporting the dairy industry have been identified. Usually the milk processors associate in national organizations. Few of them, however, are also representing the industry´s interests towards the European Institutions, as well as to the international bodies. There are two major associations representing the interests of dairy industry on European level: European Dairy Association (EDA) and European Whey Products Association (EWPA). EDA associates national dairy associations of EU member states. Hence by reaching EDA with RAWAGEN solution we are reaching national associations and networks and pass information on the REWAGEN to them.

The dairy associations are likely to support the technology because it is not only economical but also environmentally friendly. It creates a new quality in wastewater treatment in dairy industry.

In the exploitation of the results it is being included to contact association and commercial organizations in target countries i.e. Germany, France, UK, Netherlands, Italy, Poland, Spain, Belgium and Portugal.

In the other hand the exploitation strategy can be focused on big retailers in the food industry as well, these retailers cover the all value chain, operate in production of dairy products and have the financial capabilities to acquire and include REWAGEN technology in their supply chain. Even if the large retailers are concentrated in just three countries (Germany, France and UK), it has to be taken into account that they operate all over Europe and that the value of REWAGEN process will be added among the value chain in almost all European countries through these retailers.

As an overall conclusion, REWAGEN technologies have been assessed according to market criteria, the need for such technological innovations in the market has been identified, the sectors of exploitation defined and being the exploitation of individual technologies the most feasible option at the moment, the different options for exploitation of REWAGEN results have been pointed out and partners have already taken actions in this regard.

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