PROJECT FINAL REPORT

Publishable summary

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Project acronym: CapWa

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1 FINAL PUBLISHABLE SUMMARY

1.1 An executive summary

One of the major challenges of this century is the provision of water for a growing population and industry. A hidden source of water is the evaporated water present in many industrial processes. In these processes water is either produced and/or liberated and escapes as "waste" water to the atmosphere. Up until now little development has taken place in capturing this water in an economically profitable way.

One option to recover the evaporated water, is using gas separation membranes. With a sufficiently selective membrane purified water can be produced in a single process step. The objective within CapWa is to have commercially available membrane modular systems suitable for industrial applications in 2015. The produced demin water from this system is competitive with existing demin water technologies.

The advantages of the proposed process compared to traditional molecular separations are:

- High energy efficiency: no phase change is required to achieve separation
- Temperature neutral to the source: making heat recirculation in industrial processes very interesting
- High reliability: no moving parts
- Small foot print: it generally easily fits in existing spaces, factories etc.
- Environmentally friendly: no use of chemicals, no waste streams
- Energy savings: aside from recirculation, reheating of the flue gases is no longer necessary and the latent heat can be reused in the process.
- Corrosion benefits: removal of water vapour from flue gas streams helps mitigate corrosion

In three years the consortium fulfilled the following ambitious objectives of the CapWa project:

- Gained global media coverage – estimated audience 500 million persons
- Applied (commercially available) selective materials for water vapour removal
- Shown promising results from fundamental research for a different water recovery approach
- Proved that the membranes and modules can be manufactured from a pre-industrial line
- Successfully completed pilot tests in a coal fired plant and paper mill – results coincide with lab
- Proved that an industrial sized pilot is successful and confirming computer modelling estimates
- The quality of the water retained can easily fulfil the drinking water standards

The conducted two pilots show performances that coincide with laboratory findings. One large pilot conducted at the Rutenberg coal fired power station in Israel is a capable of producing ~100 kg water per hour. This unit had about 30 m^2 of semi-industrial made membrane modules integrated with industrial equipment. A smaller unit (~2 kg/hr) was installed in a bypass of the exhaust of the paper hood of a Dutch mill.

In the paper industry the CapWa process can reduce the energy and water consumption in the dryer section, significantly. Energy savings alone in the European paper sector can result in yearly savings of EUR 1 billion. The process is therefore promising for this industry irrespective of the scarcity of water. The technology has previously been tested in waste to energy plants and cement kilns, hence it is likely applicable in a wide range of industries. The consortium intends to finish pilot testing with the large test unit at the gas fired plant in Madrid, although the project officially ended.

An alternative track using hydrophobic membranes will be tested for application in a cooling tower (on top of geothermal well) in Tunisia. These alternative membranes show promising results in the laboratory and can be particularly interesting for cooling towers and thermal distillation processes.

1.2 A summary description of project context and objectives

One of the major challenges of this century is the provision of water for a growing population and industry. The shortage of water resources in arid areas requires the availability of more efficient and cheaper water production processes. A hidden source of water is the evaporated water present in many industrial processes. In these processes water is either produced and/or liberated and escapes as "waste" water to the atmosphere. Up till now little development has taken place in capturing this water, with a good quality, in an economically profitable way. The CapWa project aims to do so by using gas separation membranes to recover the water. With a sufficiently selective membrane it should be possible to produce purified water in a single process step.

The project aims are to optimize and scale up production of a smart membrane (system) towards a breakthrough in reclamation of evaporated water. The concept of this membrane is based on a gas separating composite membrane capable of capturing evaporated "waste" water. The membrane consists of a porous hollow fibre coated with a water-selective material. Application of vacuum as a driving force will start the process and the concomitant condensation of the water yields high water purity. In other words a ΔP is needed to create the driving force necessary for separation. The produced water quality is close to that of demineralized water, and no microorganisms are present.

The objective within this project is to transfer the technology from lab scale to industrial scale (figure 1). The starting point will be the water vapour selective composite membranes that are developed in the proof of principle project. At the same time fundamental research will also be done on other alternative water selective membranes. The aim is to have commercially available membrane modules suitable for industrial applications which are competitive with existing technologies at the end of the project. Within this project commercial newly developed membrane modules will be placed in the flue gas duct (bypass) of a gas fired, a coal-fired power plant, in the outlet of a cooling tower, geothermal well and in the hood outlet of a paper or board factory. To achieve this goal the selective membranes must be thermal/chemically stable under the existing environmental conditions (50-150 °C) and resistant to fouling.

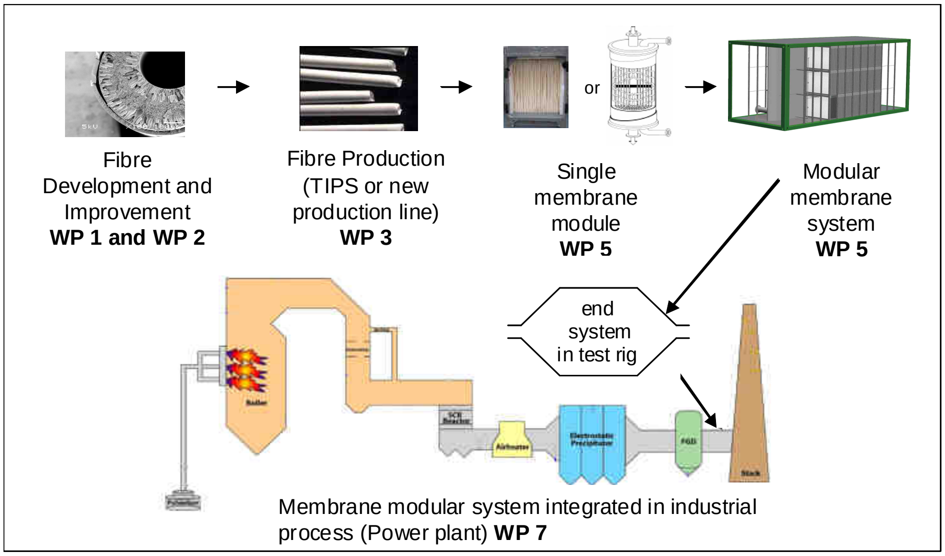

Figure 1 From fibre research to industrial process diagram

Principle of water vapour capture by a membrane

Water transport through dense polymers occurs via the so-called solution diffusion mechanism. Water molecules need to "*dissolve*" in the membrane and they have to subsequently diffuse through the membrane. Then the permeated water is collected via a condensation step. Co-permeation of gases affects the vacuum and will finally stop the process. For this reason not only the water permeability of a membrane is important but also the selectivity for water over gases. Permeability values and the corresponding values for the water vapour over N_2 selectivity of several polymers are presented in Figure 2. Materials interesting for flue gas dehydration are located at the upper right corner of Figure 2, as indicated by the shaded area.

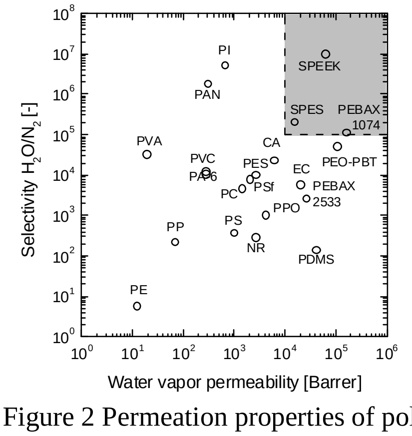

Figure 2 Permeation properties of polymers

sPEEK combines an extremely high water vapour permeability with an extremely high water vapour/N_2 selectivity. sPEEK also shows a high chemical and thermal stability. sPEEK is stable up to 260 °C[2], which makes it especially suitable in high temperature applications such as the treatment of flue gas streams. PEBAX is an alternative which is also fabricated through dip coating. PEBAX

[2] Jiang, R. et al., Investigation of membrane property and fuel cell behavior with sulfonated poly(ether ether ketone) electrolyte: Temperature and relative humidity effects, Journal of Power Source 150 (2005) p.120-128.

selectivity can be increased by utilizing dendrimers. Thermal stability with PEBAX remains however an issue. Both sPEEK and PEBAX have as property to separate CO_2 selectively as well. For sPEEK the selectivity for CO_2 is higher than for PEBAX. The selectivity to SO_2, NO_x and other contaminants in the flue gases is very low. Traces of SO_2 have been measured in pilot experiments.
Microporous membranes have a poor selectivity and therefore are less suitable for large amounts of flue gas streams. However this material might be suitable for other applications.

Alternative approach – water condensation
An alternative approach and completely different driving force is the use of microporous hydrophobic membranes. Here the ΔT and a slight Δp over the feed flue gas flow which allow the condensation of the water with its consequent removal in the retentate side and the simultaneous transfer of the other gases across the membrane will be developed. Here development of both flat-sheet and hollow fibres membranes will be done with materials like PVDF, PEEK-WC and Hyflon.

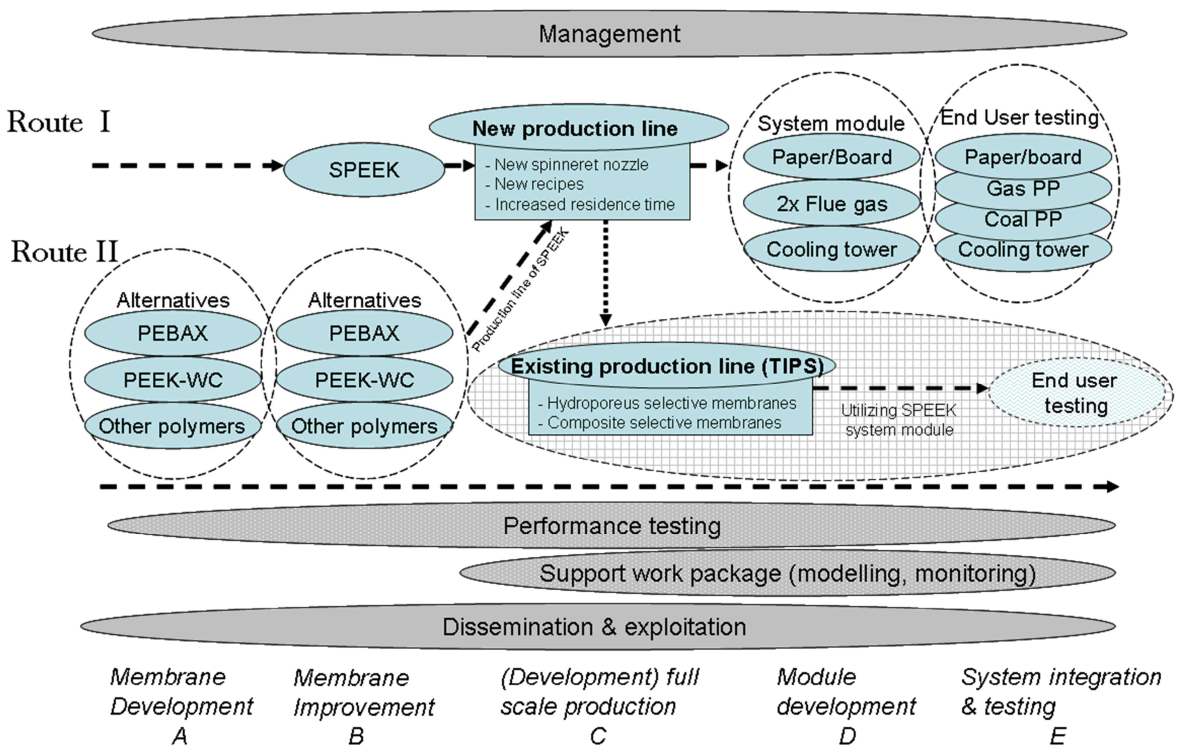

Figure 3.1 Initial Implementation scheme of CapWa project showing: route I sPEEK; route II alternatives

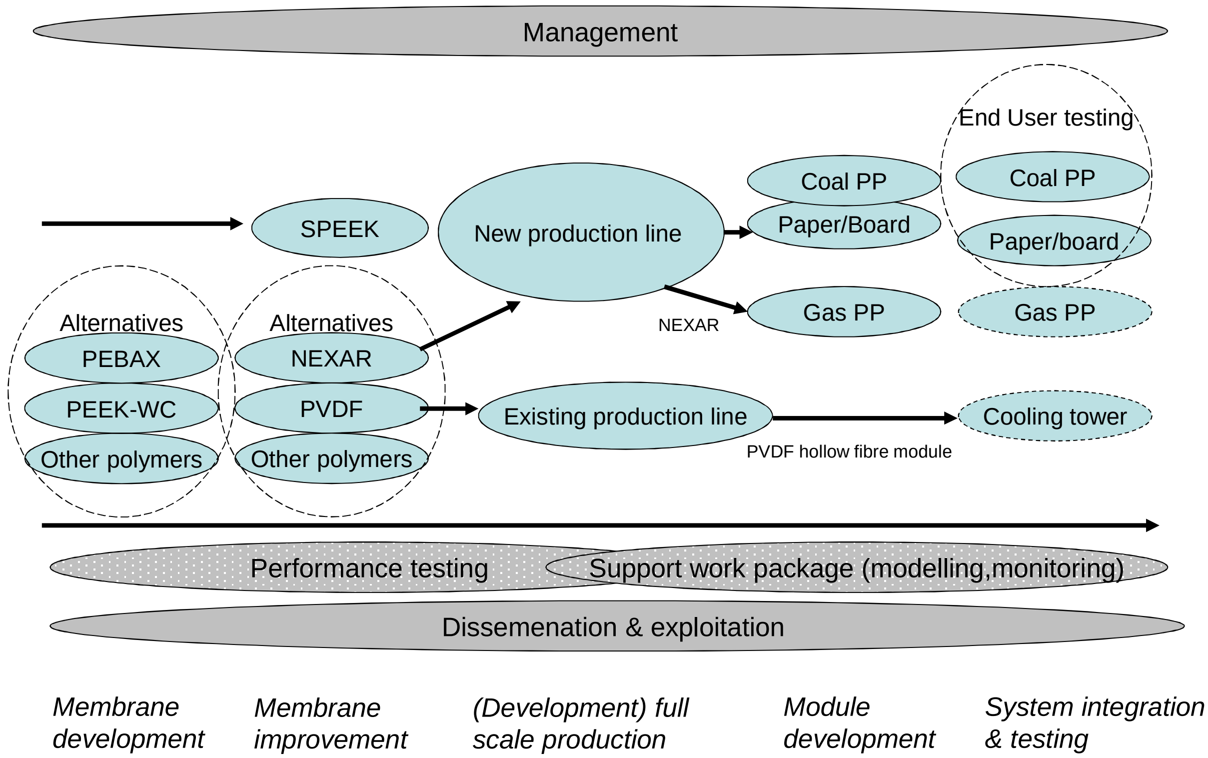

Figure 4.2 CapWa project showing the followed routes

The objectives and implementation scheme are schematically presented in figure 3 and amplified below.

A. Membrane development

The aim is to develop and improve membranes, using microporous hydrophobic membranes and microporous hydrophobic composite membranes. A total of 3 to 5 of the most promising membranes have been researched – ECTFE, PVDF and PEBAX (similar to sPEEK). The performance of these new membranes will lead to the selection of the two most promising ones for (field) testing: PVDF and alternative selective material.

B. Membrane improvement

The main goal is to improve the novel membrane sPEEK in order to reach all the parameters required for the different CapWa process applications. Special attention will be paid to the improvement of selectivity, thermal, mechanical and chemical stability (fouling) of the membrane in harsh environments.

C. Development full scale production

The production speed of membrane fibre needs to be boosted to reach an industrial standard and make the production viable. Two main alternatives will be studied, one of them using the existing Membrana line (support material) and the other one developed in a new pilot line intended for coating sPEEK and PeBAX. The other alternative membrane PVDF is a commercially available product.

D. Module development

The goal is to design and construct at least one modular end system suitable for flue gasses from a power plant (gas or coal fired). This system will be able to produce approximately 0.1 m^3/h demin water from evaporated water in a user friendly way in order to also determine energy, material use and durability. Also a smaller unit will be constructed that is suitable for a paper mill and a cooling tower (or geothermal well). The end users will design the test rig (skid) to house the end user system.

E. System integration & testing

The ultimate objective of the CapWa project is to install complete systems to be subsequently tested in industrial applications. At least one membrane system module has been tested in a flue gas application, the other is planned after the project period. Also a small membrane system pilot has been applied in the paper/board industry. For the cooling tower application a pilot is planned after the project period.

1.3 A description of the main S&T results/foregrounds

1.3.1 Membrane development: field and larger scale lab experiments

In this paragraph an overview is given of the different field (and larger scale lab) experiments that have been conducted with relevance to the power industry.

The durability testing of the potting material and the adhesion of this material to the housing and an alternative membrane in a coal fired plant lasted more than 3 months. In this durability test the materials were exposed behind a reheater of a 400 MW coal fired plant with FGD. The membrane material had a small decolouration and seemed intact. Of the 8 potting materials tested several seemed suitable for use in power plant operation. Also the adhesion did not seem to be effected due to the conditions. The sPEEK material was previously exposed to over 1700 hours of real flue gas operation and showed good durability.

Performance testing of 1 m^2 sPEEK and alternative selective membrane material showed that the sPEEK material had a better water flux. There is reasonable linear trend of the water flux as function of the delta p for the sPEEK membranes. This is so far not been witnessed for the alternative material. Mimicking a coal fired power plant flue gas the water production was around 2 l/m^2.hr for sPEEK. Since there were conflicting results for the alternative material (no lineair trend) values of 2.5 as well as 0.75 l/m^2.hr have been recorded under these conditions. The non-condensable flux of the alternative material was a factor four / five lower than that of sPEEK. The higher the non-condensable flux the more compression is needed for the vacuum pump and hence a higher energy demand.

The sPEEK material showed stress and little to no water production under flue gases mimicking a natural gas power plant. The alternative material showed water production a slight improvement in water production value’s but they do not coincide with what has been found in EMI’s laboratory. Recommendations are made to determine effects on performance under gasfired conditions as well as conditioning of the membrane.

Multiple sPEEK modules were placed behind each other and the performance was determined. The water flux values were on average lower than expected; this was caused by a too low dimension of the pilot setup in the lab. An estimation was thus made if all six (6) modules would have been installed. This would amount to 1.55 $l/m^2.hr$ for a single train of 6 modules and this could be the average flux of the test unit to be placed in Israel. Performance improvements of 50% were recorded when improving the module configuration. This is in line with Computational Fluid Dynamic findings.

1.3.2 Fouling

In the field of membrane technology fouling of is a very well-known topic. Therefore attention needs to be paid, in any membrane application, to prevent or minimize the fouling and/or to remove fouling. Also the membranes which will recover water from wet gasses could be subject to fouling. The type of possible fouling will be discussed, together with options to remove this fouling and recover the performance of the membranes. In these experiments not only the type of fouling will be verified, but most of all prevention or mitigation of fouling will be investigated.

Based upon experience in laboratory experiments fouling is not likely in gas fired power plants. However this needs to be confirmed during testing at GN in Spain.

In coal fired power plants fouling is, under certain circumstances, a known possibility. This has been witnessed during several tests in the past. To combat this fouling a Cleaning in Place system was successfully installed at those test locations. During the large scale test in Israel it was decided not to take any measures to prevent fouling to see what effect of possible fouling could have on a larger system. The test results show that it is likely that due to the construction of the end system condensed water being formed in the inlet header was washing away any contaminants/fouling on the membranes. And thus little gypsum particles was found on some of the membranes, a majority of the membranes did experience gypsum fouling. Also blisters where found containing a lead oxide likely originating from paint (which is not supposed to be present in the flue gas stream).

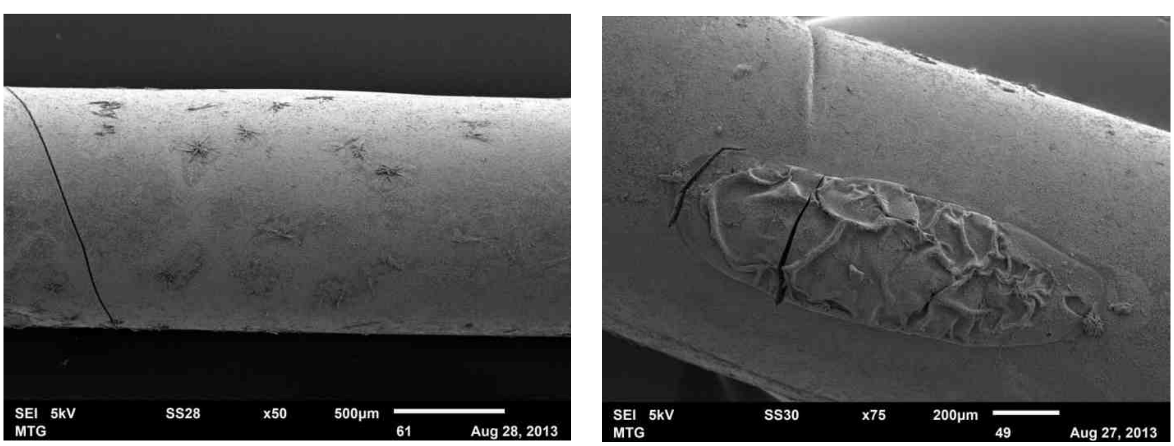

Figure 5 Microscopic enlargements of fibers exposed at coal fired power plant in Israel, left no gypsum crystals, right a blister.

Not much was known about the fouling possibilities at a paper mill. Without taking any measures fouling occurred. This fouling affected the performance of the membranes. Extensive research was done to find the source of the fouling, to prevent the fouling from settling and to remove the fouling so that the membranes would keep their performance. A few simple measures were taken, including a cleaning in place (CIP) by spraying a liquid on the first rows and shut down procedures during a web break. These actions assured a good performance of the membrane modules over a longer period of time.

Figure 6 Brown coloured deposits

In the applications where fouling is witnessed and considered to affect to performance of the membranes a simple Cleaning in Place system (CIP), seems to be effective. In the large demonstration in Israel limited fouling was witnessed, at least not at a level which influenced the water flux performance of the membranes. This could be related to the design of the test rig where the flow over the membranes was top down. This would allow any condense water formed in the pipework before the modules to clean some of the membranes.

1.3.3 **Development full scale production**

The membranes being used for the CapWa-Project are coated in a dip-coating process. The capillary is led through a coating bath consisting of the selective polymer sPEEK dissolved in methanol. Being pulled out of the bath, the membrane carries a liquid film of coating solution on its outside. By drying under certain conditions, the methanol is evaporated while a solid layer of sPEEK remains on the membrane's outer surface.

In the first half of the CapWa-Project, the coating process has been executed with a lab scale coating machine at the University of Twente. To fulfill the amounts for the demo testing at Israel Electric Company (Ashkelon, Israel) and Gas Natural Fenosa (Madrid, Spain) a scale up of the coating process was necessary.

The machine, designed and constructed by Membrana, consists of four parts being the unwinding-, coating-, tension control- and winding-section (figure 6). Three membrane spools are mounted onto the unwinding unit where they are uncoiled by an electric drive. The membranes enter the coating section where they are led into the first coating bath containing sPEEK dissolved in methanol. Coming out of the bath, the membranes enter the first drying stack where the methanol is evaporated and exhausted leaving the dry coating layer behind. In order to achieve thicker layers, three coating steps are possible. After being coated, the dried membranes are coiled with controlled tension on to three spools again.

Membrana did put a lot of efforts into the realization and optimization of the equipment. All necessary safety issues have been considered so the exposure of operators is reduced to a minimum but also explosion safety can be guaranteed. The machine allows to process three capillaries in parallel having a constant quality and the process runs very stable and does not require a lot of attention when running. Essentially for this outcome is the exact preparation of the coating solution.

Operating this machine will help provide necessary information to design even larger industrial membrane coating machines. This machine can easily be upgraded to produce membranes at an industrial scale.

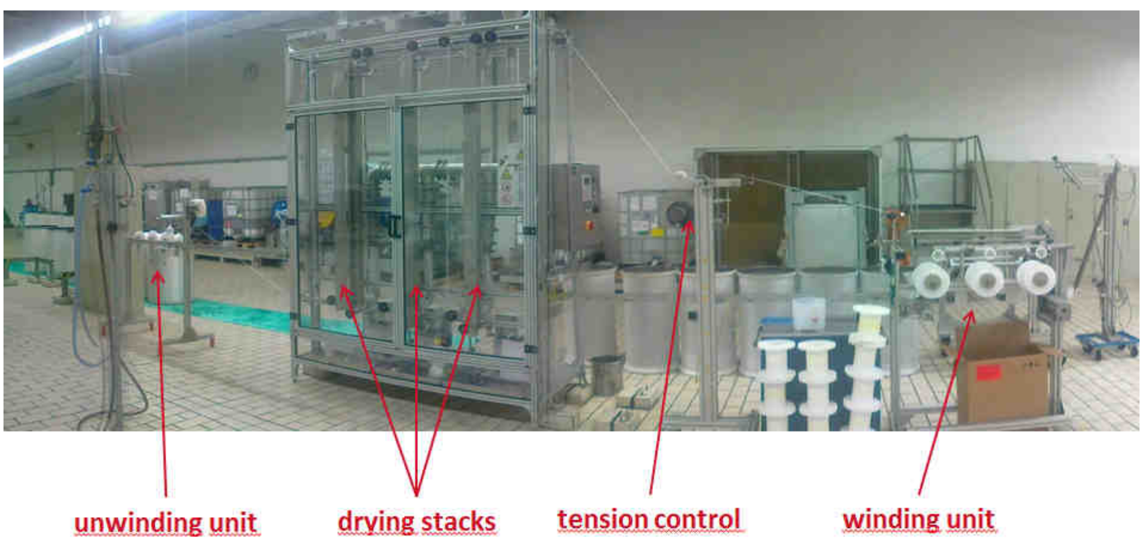

Figure 7 CapWa coating line at Membrana's R&D facility

1.3.4 Production of Modules for the pilot tests

The membranes for the pilot tests were manufactured in an industrial setting utilizing UltraPES as support material which was coated two times with Sulphonated polyether ether ketone (sPEEK). The sPEEK was provided by a commercial supplier and dissolved in a methanol solution using the coating line shown in figure 6.

The support fibre had an outer diameter of 1.2 x10^{-3} m and the coated layer was 5 to 10 x 10^{-6} m thick. More than 20 km of sPEEK membranes were produced during the project and about 8.5 km would be effectively used for the 30 modules that each had an effective surface area of 1 m^2 intended for the Rutenberg plant. Each module forms a “curtain-like”, structure through which the flue gas must flow, in that it spans the entire flow area. The construction of this module (with the fibres) was done in a semi-automated way, which also gave information on how a full scale process would look like. The up-scaling factors were:

Up-scaling of membrane manufacturing versus lab method:	>15 x
Up-scaling of module manufacturing versus lab method:	>6 x

For each individual module a leakage test was conducted and where needed broken fibres were removed and open areas were closed with potting material. For the leakage test a 20 mbar pressure was applied on the inside of a module, and a valve was shut and the pressure build up was recorded after a period of 3 minutes. This increase in pressure gives a good indication if modules are leak free.

1.3.5 System integration & testing at Sappi Nijmegen

A small pilot test was performed at a paper mill of Sappi in Nijmegen (The Netherlands). The installation consisted of a small vacuum pump and water cooled condenser in combination with the semi-industrial membrane modules (figure 7, 8). The test lasted over 1250 hours (4 months). The water quality at the paper mill is so high that it easily fulfills drinking water standards. Since the water is so clean, any acidic compound present in the water immediately results in a low pH.

Figure 8 Test location at the dryer exhaust at Sappi Nijmegen

Figure 9 Membranes in stainless steel housing

1.3.6 System integration & testing at Rutenberg Power Station Askelon

To test the pilot installation under real flue gas conditions a bypass was created at the Rutenberg Power Station of Israeli Electric Corporation (IEC). At Rutenburg Power Station four lines are present of which two are equipped with a flue gas desulfurization (FGD) unit. These are unit 3 and 4 each producing 550 MWe and emitting 1.9 million Nm^3/h. Flue gas was taken from behind the FGD of unit 4, guided along the stack to the test location and taken back to unit 3 using PE piping. According to design calculations the lower case flue gas temperature entering the pilot test unit would be 46 °C, based on homogenous flow conditions. In practice this was slightly higher 50 °C.

In general the lay-out of the pilot plant is comparable to the laboratory testing facility. The installation contains a feed side, a module holder with the membrane modules, a retentate pipe and a vacuum system. This vacuum system contains a cooler, a water collection unit and a vacuum pump, **Error! Reference source not found.**. The main differences with the laboratory experiments are that the size is larger, approximately 30 m^2 of membrane surface. Also it's the first time an air cooled condenser is used instead of a water cooled condenser. The unit houses 30 modules divided into 5 trains of 6 modules each. All trains had two common headers, one for the feed flow and one for the retentate as depicted in **Error! Reference source not found.**.

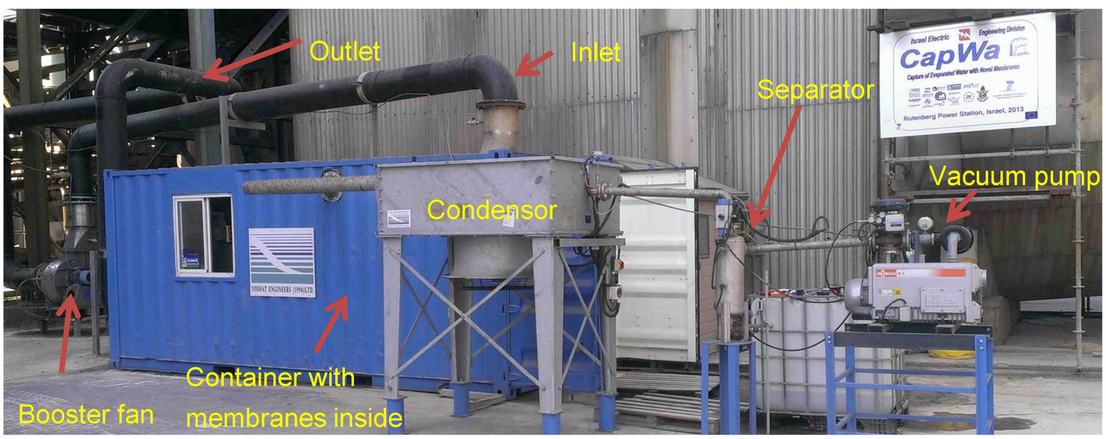

Figure 10 Lay out container

Figure 11 Empty trains including headers and one train filled with six modules

The purpose of the pilot was to:

1. To determine whether the results achieved in the laboratory can be repeated at a larger scale.
2. To determine the effects of industrial conditions on the performance of the pilot system

It can be concluded that a large scale pilot with 30 m^2 of semi-industrially made membrane modules coupled together with an industrial vacuum pump and air cooled condenser is feasible. An important achievement is that the performance of the membrane modules on water production is similar to lab findings namely 1.5 – 1.6 $kg/m^2.h$.

Under real conditions it was shown that the system was well designed and that both the ACC and vacuum pump were able to fulfil the task required. Operational changes caused by the power plant or by ambient conditions were easily absorbed by the pilot. The main parameter influencing the water production was the feed temperature. The latter was effected by ambient conditions.

The test unit was user friendly with easy access to the membrane modules. Also broken fibres in a module can be easily identified and the module can be repaired. The amount of broken fibres amounted to 0.5 ‰ of all fibres. This was not expected but also did not pose a treat for the unit to operate; these findings give confidence for future operational use. A possible cause for the breakage could be turbulence in two of the five trains, and it is recommended to investigate this further.

The water quality easily fulfils drinking water standards (except for pH); however a better water quality can be expected if breakage of fibres can be prevented. Nevertheless for IEC this water quality is acceptable and it is also better than their current raw water source (drinking water) they receive.

As the membranes can be improved by several factors further improvement of membrane coating and support material are recommended. Also recommended is to further investigate the conditioning of the membranes and (development of) the non-condensable flux.

The measured energy consumption values support previously conducted modelling work. This gives confidence in the determined consumption values and energy saving values. Also the pilot results support the energy savings opportunities like no-reheating of flue gas and pre-heating of the condensate. The savings can lead to a net-energy saving for coal plants that have access to cooling water. For coal plants in dry area's recommendations are to determine the effects of cold night cooling on the energy consumption and to investigate if pre-heating the condensate for coal plants without FGD or dry FGD is feasible.
The system can be further improved if the pressure of the vacuum pump is coupled to the condensing temperature. This value is related to the ambient temperature and the pressure set point from the steam table. In layman terms the effects of night cooling should be investigated.

In the near future a pilot will be conducted at a gas fired power plant in Madrid. This unit will have a different flue gas composition and also the pilot will have different selective membrane material. The occurrence of droplets and dust is unlikely and the acidity of the flue gas will be lower compared to this coal fired plant. The focus in this pilot will be to determine the effects of night and day operation as well as the durability coupled to the performance of the membrane at higher temperatures and low relative humidity's.

Alternatively the PVDF material which utilizes a different approach than the water vapour capture membranes will be tested in the geothermal well in Tunisia.

1.3.7 Conclusions

It can be concluded that:

- The industrial sized pilots were successful (table 1), hence the upscaling of the membrane and module manufacturing was a success. Also the integration with industrial equipment was a success
- The performance of the membranes in the pilots were in accordance with lab findings
- The quality of the water retained from the coal fired power plant could be better but with exception of pH the drinking water standards can be easily fulfilled (see table 2)
- The driving force for implementing the process by the paper and pulp industry, is most likely the potential energy savings
- An alternative track using hydrophobic membranes has been tested in the lab. These alternative membranes show promising results at the laboratory tests and can be particularly interesting for thermal distillation processes. Testing of these membranes in a pilot still has to be done.
- A total of three selective membrane materials (now commercially available) have been identified suitable for water vapour capture/removal

Recommended is to finish the pilot testing in the gas fired application and the geothermal well. The results warrant the next phase namely commercial demonstrations.

Table 1 Summary of the results of the pilot plants at Rutenberg and Sappi in comparison with laboratory tests at DNV KEMA

Description	Large pilot in coal fired power plant Rutenberg	Small pilot in Sappi paper mill	Measured values at DNV KEMA
Amount of membrane area	27 – 30 m^2 6 m^2 in five trains	1 m^2	1 – 2 m^2
Average water production	1.0 – 1.5 l/m^2.hr	1.8 l/m^2.hr	1 m^2 module: 2.0 l/m^2.hr Trains: 1.55 l/m^2.hr
Water production in one day	0.7 – 1.0 m^3	0.050 m^3	-
Water conductivity *	80 – 130 µS/cm	8.2 µS/cm	15 -20 µS/cm
pH of water *	3.6 – 4.9	-	-
Energy consumption **	Condenser: 37 kWh/m^3 Vacuum pump: 58 kWh/m^3 TOTAL: 95 kWh/m^3	-	Condenser: 27 kWh/m^3 Vacuum pump: 81 kWh/m^3 TOTAL: 108 kWh/m^3

* Drinking water pH 6.5 – 8.5 and conductivity is 100 – 1000 µS/cm

** Energy consumption values from DNV KEMA are obtained through modelling

Table 2 Water quality of the pilot in Rutenberg and Sappi versus drinking water limits

Chemical	Rutenberg	Sappi			
	Concentration	Concentration	Duplicate	EPA drinking water limits	Dutch drinking water limits
	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Bromide		<40	<40	-	-
Chloride	30,600	23	90	250,000	150,000
Fluoride	780	<3	<3	2,000	1,000
Phosphate		<12	36		-
Nitrate	12,200	447	490		50,000
Sulfate	32,300	66	69	250,000	150,000

1.4 The potential impact, the main dissemination activities and exploitation of results

1.4.1 Potential impact

The CapWa project started with the view that the captured water is the main driving force to introduce the technique in order to meet the world’s need of clean (drinking) water. Therefor the CapWa process would be especially interesting for arid areas and has to compete with other techniques like desalination. During the project however the insight grew that the overall energy savings that accompany the CapWa process in several industries are a much greater driving force. Based on energy savings the applicability of the process is much larger, basically all over the world. The CapWa process, saving energy and water, fits in perfectly in the pursuit of a sustainable world.

To determine the industry potential of the CapWa technology, first the industries where this technology can be used have to be identified. In a broad sense every industry producing water rich (flue) gases can benefit from the CapWa technology. The main benefits arise from savings on cost for input water, and from savings on energy costs. The latter can be realized by among others:

- Less re-heating to obtain ‘dry’ flue gases to prevent corrosion in the stack
- Removal of reheating units as a corrosion mitigation measure in flue gas streams. The removal of this unit would lead to a pressure drop and hence increase the efficiency of the Induced Draft fans
- Reuse of the latent heat of the captured water vapour in the industrial process
- Less preheating of dry air intended for drying processes
- Compression of the captured water vapour to low pressure steam to be reused in the industrial (drying) process.

The industries with the biggest potential are industries that produce water rich (flue) gases, have a demand for demineralised water, and (most importantly) could utilize the energy savings. For industries in dry areas, that have a water rich flue gas and a high demand for demin water – like the power sector–, the recovered water can be a driving force. On the other hand the energy savings could play such an important role that the demin water (or operational) cost will be easily compensated by the overall energy saving, making the process economically feasible for non-arid areas as well. On the other hand there are industries with a reasonable (limited) water rich gas stream but high potential energy saving, such as open drying process like the food and paper sector. Energy calculations by KCPK, PTS and DNV KEMA have shown that savings can amount to 18% for the paper sector. The CapWa project did focus on the power sector (coal & gas) and paper and cardboard industry. However from a survey the following industries seem promising candidates for introducing CapWa as well: waste processing, biomass fired power plants, lignite fired power plants, steel manufacturing, cement kilns, chemical industry and the glass producing industry. As the CapWa process is more widely used, the price of the system is likely to go down. This can make the process profitable for an even wider range of industries i.e. food industry.

Based on a Net Present Value (NPV) calculation for a 600 MWe coal fired power plant, the NPV of the CapWa process (based on 30% water recovery) turns positive in year eight with a CAPEX of about EUR 6 MLN. An NPV calculation was also determined for dry regions, where no cooling water is accessible and air cooling is used. In this case the energy saving is limited to 0.3% instead of 0.5%. The NPV does not turn positive in this case and the value after 10 years is negative. Of course the outcome of the NPV calculation varies based on the specific input parameters like water price, membrane price, membrane life and energy saving. From the calculations it can be concluded that the real driver behind the business case for coal fired power stations is clearly the energy savings. The pilot conducted in Israel in a coal fired power plant gives confidence that the energy consumption and savings calculations conducted by the partners are relatively accurate. However a larger scale demo is needed to confirm OPEX and CAPEX numbers.

With maximum energy savings the NPV for coal fired plants with water cooling turns positive after 3-4 years. This indicates that the technology will be economically profitable for power plants with reheating (energy saving of max. 0.5%). Hence the Netherlands has a small market, due to the fact that most plants have transferred to wet-stack operation and hence no longer need reheating. The rest of Europe looks different. For example in Germany there are a lot of old existing plants but also lignite plants with even more water content then coal plants and high need for low pressure steam for drying lignite. And here many existing plants still utilize reheating. When looking outside Europe in the dry area's i.e. the USA, South Africa and Australia, these could be interesting candidates. By far the largest market with a strongly water stressed area is China. It is difficult to assess how many units are located in dry areas and how many have a dry Flue Gas Desulfurization (FGD).

During the CapWa project a pilot was done at the exhaust of the paper hood of a paper mill in the Netherlands. From the first calculations it was determined that the energy savings would be large for this sector. While the water savings would only be of importance for areas where there is water shortage like in South Africa. For this industry a NPV calculation is performed, based on a likely case. The savings depend on local site factors. It was decided to take the optimal integration and compare the savings to paper mills with common practice with and without heat recovery. With a total investment of the installation of about EUR 1.3 MLN, the NPV value is already positive in the second year.

For the Dutch paper industry energy consumption amounts to about 16 -18% of the total production costs. Current total production costs in Europe is EUR 60 billion a year. At the same time the most energy intensive process is the drying process as shown in the pie diagram below (figure 11). Assuming the 18% saving as assumed in the NPV calculations the total savings for the Paper sector would be EUR 1 billion a year. According to KCPK there about 650 plants in Europe that would be able to utilize the CapWa technology.

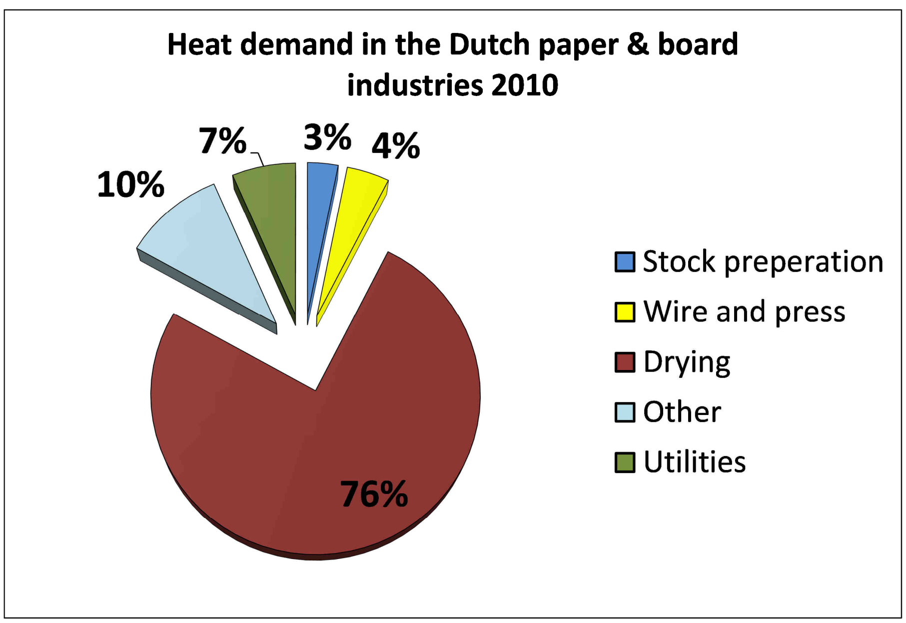

Figure 12 Energy demand of the different processes in the paper and board sector

The returns for the paper industry should be compelling enough for this industry and its system integrators to be involved. As for the power industry the returns are not yet compelling enough for the sector but the results warrant a demonstration. The focus should lay in coal (and lignite) fired power plants. Oil fired plants have not been investigated here. It is recommended to find water suppliers or water system integrators who would have an interest to commercialize the technology. For the returns should be within their acceptable levels.

One aspect which is difficult to assess is the value (and cost) of water in water stressed areas. If the water price is high then this technology can be competitive for coal plants located in these areas. Although uncertainties remain it can be concluded that the CapWa technology produces demineralised water which is competitive to traditional water supplies. In fact some of the industrial sectors earn money when producing water. Thus far identified are the coal fired power plants, waste to energy plants and paper and cardboard mills.

The impact of the technology is simply large and for the relatively small investments made (and still to come), it is recommended to proceed in bringing this technology to the next phase with a large scale system integrator.

Membrane production

EU Paper sector 650 plants	1.1 MLN KM
World Power sector 390 GW	23.8 MLN KM
Dialysis production 2014 estimated	650 MLN KM

Water saved

Paper sector:	45 MLN m3 per year
Power sector:	190 MLN m^3 per year (0.19 km^3)

The water saved is equivalent to 1.96 MLN households based on 120m^3 per household

Current drink water production of Brabant Water is for 2.4 MLN people: 176 MLN m^3 per year

Energy saved

Paper sector:	2.3 PJ per year or 0.08 GW per year
Power sector:	31.6 PJ per year or 1.10 GW per year

The energy saved is equivalent to supplying electricity to about 3 MLN households.

Financials

Market size paper sector (or investments needed):	0.9 BLN EUR
Cumulative returns paper sector after year 10:	3.2 BLN EUR
Market size power sector (or investments needed):	3.8 BLN EUR
Cumulative returns energy sector after year 10:	0.6 BLN EUR

1.5 Main dissemination activities and exploitation results

The project received an incredible amount of global media attention. In particular the first press release in the Netherlands and in China a few months later, likely targeted 500 million persons.

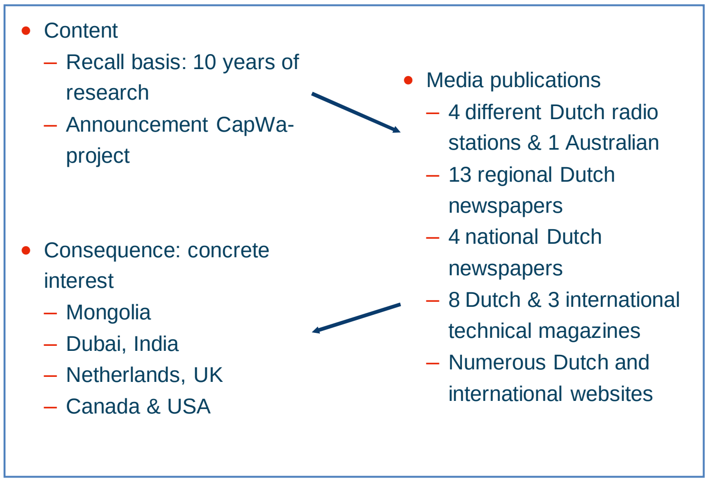

Figure 13 Consequence of media attention on 1st press release February 2010

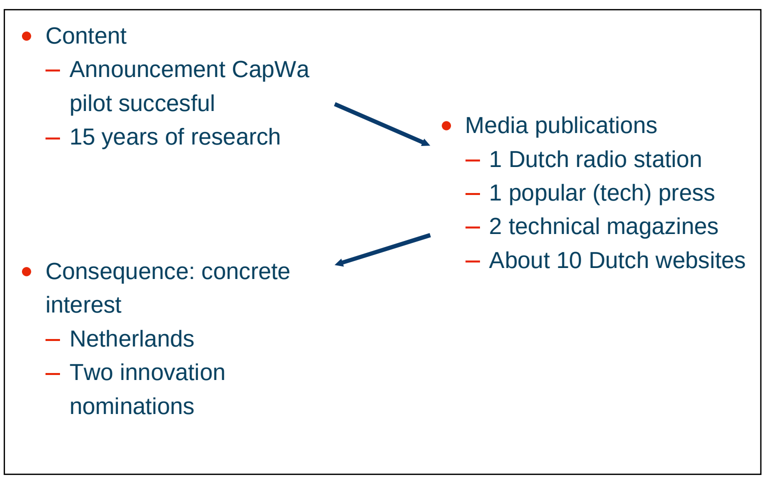

Figure 14 Consequence of media attention on 2nd press release august 2013

Table 3 Quantification of DoW goals for dissemination of knowledge

Type	Initiating partner	Targeted frequency	Type of audience	Targeted audience size	Achieved
Project brochure	Coordinator	M12	Industry	500	>500
Project website	Coordinator	Up and running from >M6	General public	***>25.000 hits after 3 years***	***>120.000 after 1^{st} year***
Project PowerPoint presentation	Coordinator	M12	Industry	500	>500
Conference contribution	WP leaders of WP1-WP7	10 presentations or papers	Scientific	50-250 per conference	>70
Publication	Individual partners	6 publications	Scientific	5000 in total	2 published 3 in review
Additional publications	**coordinator**	**Audience**	**General public & Industry**	**None mentioned in DoW**	**500 MLN**
		Mass media			**>20**
		Websites			**>100**

The *CapWa* project promoted results and approaches through the existing (EU-) networks such as research*eu magazine, NanoMemPro, NanoGlowa, branch organizations, water/energy/paper/board companies and other European networks. An important dissemination event was the combined NanoGLOWA and CapWa meeting held in Germany in 2011. Through CapWa's partners and the website an online questionnaire was distributed in the power and paper industry. The findings were collected and disseminated within the CapWa consortium.

During the CapWa meeting in South Africa it was decided to have an open event and invite the industrial and research community of South Africa. Also in Tunesia an event was organized where CapWa partner ENIT disseminated results. There were several contributions to the conference in South Africa.

The end conference was held in the Netherlands in Den Hague targeting the different embassies in the area. The approach to choose a date and location which would have some symbiotic with another conference / workshop was abandoned due to ending of the project and decision to target embassies.

Over 6000 personal email invitations and 120 letters were sent to embassies. There was a broad public present ranging from the scientific community, industry, embassies and the media. Various countries were represented by embassies and their detachments including China, USA, Venezuela, Ecuador, Great Britain, Dutch Economic affairs and United Arab Emirates. The conference was visited by about 54 persons, which is reasonable. The target was to have 75 participants; the lower attendance was likely due to the vacation period. The conference lasted a full day and the day's host was a board member of DNV KEMA. The conference included a panel discussion and external speakers. The agenda can be found on the following page.

A professional video was made by DNV KEMA and footage material of the pilot site in Israel was provided by IEC. The video can be found on www.watercapture.eu. These activities were funded entirely by the partners (and will not be reimbursed).

Although early in the project, KEMA has commenced investigating the options to exploit the technology through a NewCo. The initial board of KEMA at the time wanted to explore the role as a major shareholder of this NewCo. Due to a merger of DNV (and now with GL), the position of DNV KEMA changed. Here a minority shareholder is considered an option. Preferably the IPR and associated patents at DNV KEMA (and if applicable at some of the University/SME partners) would be sold or licensed to a large system integrator. Support in this process was supplied by Gate2Growth from two other EU projects InnoWater and ProNano and also additional financial support by the (DNV) KEMA board. It is unfortunate that during the exploratory phase one of the beneficiaries of a commercial product decided that it would only support the activities by supplying the membranes needed (on a commercial rate). KEMA was left to approach and convince system integrators at initial meetings alone. Talks with about 20 parties which include 3 financial private equity groups, 13 large power and 2 large water system integrators, have resulted in interest but no real follow up.

The technology in itself should be compelling – being one of the first water technologies to earn itself back within time frames acceptable for water suppliers/water system integrators or the paper sector. Thus far there are some parties identified to take this technology further but this has not evolved to a follow up as yet. At least two spin-offs have been identified:

- Water vapour capture in a cement kiln (England)
- Water and CO_2 capture in a cement kiln (Norway)

Currently spin-off proposals have been submitted for South Africa and the United States.

1.6 Address of the project public website and contact details.

For more information please contact:
Ludwin.Daal@dnvgl.com Coordinator of CapWa
Or visit us at:
www.watercapture.eu
and have a look at the video of the pilot

The CapWa consortium consists of 13 international partners across three continents that come from a wide spectrum of operational, industrial and academic fields. The project is chaired by DNV KEMA Energy & Sustainability (recently changed to: DNV GL Energy Advisory) and funded by the European Commission.