Xzero is a Swedish company that has spent 20 years in R&D for a new technology for process water in the micro- and nanoelectronics industries.
ABSTRACT

Xzero is a Swedish company that has spent 20 years in R&D for a new technology for process water in the micro- and nanoelectronics industries. The basic idea is to recycle the water from waste water into Ultrapure Water. The most recent challenge has been to remove nanoparticles in order to make sure these are not spread in the environment and not enter the Ultrapure Water used in cleaning of the nanoelectronics.

Third party tests done by The Royal Institute of Technology and Swedish Environmental Research Institute (Sweden), Clarkson University (US), Manta Inc (US) and Anton Paar (Austria) have confirmed that Xzero technology is more efficient than existing technologies in removing nanoparticles from water.

In January 2015, Xzero started to industrialize the technology in co-operation with researchers at the Royal Institute of technology in Stockholm, Sweden and at the leading European organization for microelectronics development – imec in Leuven, Belgium.

Testing of the first full scale prototype of the industrialized equipment commenced in August 2016 and final industrialized equipment is slotted to be delivered to imec during the first half of 2017. In order to complement the researchers already working on the project, Xzero has reinforced its staff with three new practically experienced and professional engineers for the industrialization work.

In the commercialization phase, which will start in 2018, Xzero will continue working with imec. Since imec has offices in Belgium, the Netherlands, Taiwan, USA, China, India and Japan and a staff of about 2,400 people including several hundred of industrial residents from leading international nanoelectronics companies, it will be able to influence the largest part of Xzero’s future customers through this network.
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Summary

Plan
Long term plan: To develop zero liquid discharge (ZLD) systems for industrial closed loop recycling of water and materials.

Launch plan: The initial target is the semiconductor industry because it has the highest demands on water purity and pays more for water treatment than any other industry.

Launch steps:

1. Xzero has successfully tested the concentration of difficulty wastes in semiconductor industry together with imec. Successful concentration gives immediate economic rewards in reduced cost for destruction.

2. Xzero has successfully tested the total removal of sub-20 nanoparticles from semiconductor process water together with Swedish Environmental Research Institute (SERI) and Clarkson University (an asset in the Global 450 Consortium (G450C)). There is presently no other technology that can accomplish this. Removal of such particles is an absolute necessity for the commercial success of the next generation of semiconductors with sub-20 line-widths. Therefore this is a good entry point into the semiconductor industry. Efficient removal of nanoparticles is also necessary for recycling of the process water into Ultrapure Water (UPW).

3. Once the market for concentration of wastes and the market for removing nanoparticles is established. These two functions can be merged into one system - a closed system where water and contaminant are separated and both can be recycled. This is part of the planned Zero Liquid Discharge (ZLD)

Final launch: Once the system is established in the semiconductor industry other industries will be targeted with then proven ZLD- systems.

By using the pressing need for improved removal of sub-20 nanoparticles in the rich and resourceful semiconductor industry as leverage, Xzero will also be able to introduce polygeneration and ZLD in other industries to save energy and reduce CO2 emissions.

Execution
At the moment there is no alternative to Xzero's technology to remove small (sub-20) nanoparticles from water. The semiconductor industry needs to have sub-20 nanoparticles removed from UPW they use in the manufacturing process to be able to manufacture coming generations of semiconductors in a profitable way.

State-of-the-art equipment will remove many of the nanoparticles, but some of them will be left. These are called “killer particles” in the industry. Here is a graph showing how efficient present best technology is to remove nanoparticles. Until now – 24 nm – it has been acceptable. But then the risk for “killer particles” increases as does the risk for defects and dwindling yield rates.
Xzero has co-operated with leading industrial companies and consultants in the R&D stage of the technology and the company's approximately 1,500 shareholders have invested more than 10 M€ in this development stage. The research institutes Xzero works with will promote the technology as part of their own general dissemination mission. The marketing will be performed in co-operation with the large industrial integrators that install the large (ten million liters per day or more) UPW-systems.

After successful R&D and testing, Xzero now needs tools and facilities to ramp up to commercial production. The time frame for industrialization and ramp-up is two years and the cost has been calculated to approximately 3 M€.

**Unique selling proposition**

Xzero has developed and tested unique proprietary technology that can efficiently remove sub-20 nm “killer” particles from UPW.

“The importance of managing the particle challenge to the UPW final filters is growing as the killer particles size approaches the limits of the best available technology.” *Ultrapure Water for Advanced Semiconductor Manufacturing: Challenges and Opportunities*, Slava Libman, Balazs NanoAnalysis, Daniel Wilcox, Samsung Austin Semiconductor, Bernard Zerfas, IBM Microelectronics, 2015 ECS - The Electrochemical Society, Oct 12, 2015. (Mr Zerfas is now with Globalfoundries in Malta, N.Y.)

“Our measurements clearly show that your water is much cleaner (about 2x when it comes to the number of particles and smaller ones as well) than Milli-Q obtained through standard units of Millipore devices like Simplicity UV equipped with 10 kDalton or 0.2 um final filters. You can use our measurements as the reference. Our detection limit is about 10^4 particles/mL and for Milli-Q we observe typically about 2-3x10^6 particles/mL with the sizes below 200 nm, the most of them between 100 and 150 nm diameters.

We are so happy with your product that we would like you to be our supplier of water that we use for diluting samples that we test internally or that are being tested for our customers... We noticed that even when stored for several weeks, the water that your provide does not contain increasing number of nanoparticles while Milli-Q if not produced under sterile conditions contains those in few days at increasing quantities. What terms of delivery of your clean water can we get? We’d rather prefer this water to be in smaller bottles, like 0.5 liter or even 0.25 liter,
which is the amount that we use during one experiment.” Kuba Tatarkiewicz, of MANTA Inc 2016-04-07

By removing the threat of killer particles Xzero will facilitate the semiconductor industry to **continue developments of reducing line-widths** and at the same time enable the semiconductor industry to **start recycling of the waste water** into process water.

**Unique marketing position**

Because of the great need for new technology in this area Xzero has already been able to sign written NDAs with two major semiconductor manufacturers and has started testing with two major research institutes, Clarkson for Global 450 Consortium and imec for the European 450 consortium.

The cost of a new Xzero UPW system will be negligible compared to its impact on yield rates and to the profitability of the customer.

Our offer of new technology is just in time since there are reports from the industry that the first 7nm test semiconductors have been demonstrated recently. It will take some time before complete ramp-up of 7nm nodes. At that time Xzero will have commercialized its technology.

**Present status**

During 2015, Xzero has proven, by several tests in Sweden (KTH Royal Institute of Technology and Swedish Environmental Research Institute) and US (Clarkson University and Manta Inc), that Xzero's new proprietary technology is more efficient in removing nanoparticles from water than state-of-the-art equipment.

The tests were conducted on specially designed lab equipment. In the beginning of 2016 Xzero also made tests with difficult nanoelectronics waste water for imec with lab equipment. In April 2016 Xzero also delivered full scale test equipment to imec and in August 2016 a pre-industrial prototype, also to imec. At present Xzero has entered a program for industrial series production of equipment and plans to deliver the first fully commercial equipment for testing at imec or a semiconductor manufacturer during the first half of 2017.

**Competition**

Because of the great profits from increasing yield rates by removing all “killer particles” there will surely appear competitors to Xzero employing similar or entirely different technologies for the purpose.

Xzero presently has a lead in development and relies heavily on research co-operation with leading customers and relevant research institutes to keep the lead in technological know-how and to develop manufacturing agility.

**Manufacture, recycle and recover**

Xzero technology is presently being tested for three main tasks.

To **remove nanoparticles** in the manufacture of UPW in order to reduce defects and thus increase yield rates in production.

To **recycle water** in the process in order to save water and stop pollution by effluents with increasingly toxic substances. **Recycle is not possible if nanoparticles are not efficiently removed.**

To facilitate **recovery of valuable materials** by concentrating the effluents in a ZLD process.
Market potential
A large semiconductor factory may use up to 15 million litres of feed water per day. The total present annual market for water treatment equipment in the semiconductor industry is 2 B€ and is expected to grow. Xzero will be able to win large market shares because of a lead in development and co-operation with strong partners. As a next step, not as advanced but much larger markets for industrial water recycling will be targeted.

Main benefit for European industrial development
Through co-operation with imec, Xzero will join a growing group of presently export oriented European suppliers to the international semiconductor industry. This will lay a strong foundation for the future semiconductor manufacturing industry in Europe and will be crucial for Europe’s industrial growth and thereby important for income and employment.

![European Electronic Equipment Production](image)

Source: DECISION

Electronics is an important industry in Europe and manufacture of semiconductors in Europe would secure and increase that industry. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.

Europe is definitely lagging behind in semiconductor manufacture and needs to pick up.
This graph depicts the competitive situation in the industry. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.

This is a good illustration of the employment effects of one single nanoelectronics development project. € 3.5 was invested in 2013 in research and manufacturing in the area. € 600 million from the national government, € 400 million from the EU and € 100 million from local authorities. The program is led by STMicroelectronics and includes CEA-Leti, IBM and
around 100 small and medium-sized companies from across the supply chain. STMicroelectronics alone will invest €1.3 billion to double the production capacity of its 300mm fab in Crolles to around 7,000 silicon wafers a week. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.

**Added benefit for European industrial development**
The tests at imec have shown that Xzero’s technology may also be efficient in purifying/concentrating semiconductor industry waste water, which today because of its contents of acids, bases and toxic minerals is a major environmental issue.

Recycling will substantially reduce water consumption in the industry. At the same time it will decrease pollution and facilitate recovery of valuable metals.

**Verification**
Xzero has presented the results from third party testing of its technology to some of the absolute leaders in semiconductor research and in semiconductor manufacture. They agree that Xzero addresses an important concern for the profitable manufacture by increasing yield rates and are willing to assist in the commercialization process.

**Unique technology and unique position on the market**
Xzero’s technology is unique and proprietary. In partnering with imec, imec will supply designs, equipment and personnel for the testing and also analyze the risk factors in the proposed processes.

The information of the new system will then be certified and channeled to the imec network. Xzero will therefor also have a strong position in its direct contacts with already interested parties in order to offer them to buy test units of the commercialized equipment for industrial in situ demonstrations. Among these will be

- end users: TSMC in Taiwan, Intel in the US and Global Foundries in the US
- and integrators: M + W Group of Germany, Christ of Holland (Ovivo group), Veolia of France, Organo, Sumitomo and Hitachi in Japan, Entegris of the US

**Strong team**
Because of the complicated and complex nature of semiconductor technology and the difficulty in measuring particles on the sub-20 nano level, Xzero has been required to cooperate with the leading suppliers and research institutes in the industry and will continue doing so. For the industrialization phase Xzero has already expanded its core technical team to five practically experienced and professional engineers. In the market launch phase additional people will have to be employed.

**Finance for commercial launch**
The commercialization of the new technology will be a costly undertaking. Through the cooperation with selected research institutes and manufacturers, information about the technology will be well spread in the industry. The strong need for the solution will result in a pull from the market that will enable necessary finance both from the existing approximately 1,500 share-holders and new investors. The latter may be financial investors or present partners or future customers.
**Expected outcome of the proposed project**

The purpose of the proposed project is to commercialize Xzero technology for the manufacture and recycle of UPW.

The main criteria for the success of the project is that there are one or several commercial orders for Xzero equipment from the international semiconductor industry. A secondary criteria is that Xzero is firmly integrated into the European effort to build advanced industry for the future.

As the first units of commercial equipment are sold, the 1 500 share-holders in Xzero, as well as other investors, will realize that Xzero has moved from the pure R&D phase to a commercial phase. This will lay a strong foundation for further finance needed for a full international launch of Xzero’s technology.

Considering the value of each single order Xzero will rapidly move from spending money on R&D to earning money from commercial orders and is expected to reach sales of over 100 M€ within a few years. Net profits calculated as 30 % of sales will be 20 M€ in 2019 growing to over 200 M€ in 2024. The employment of both engineers and sales people will start to grow with a few already during the industrialisation/implementation/market launch phase of the project and thereafter with several hundred people during commercialisation.

**Business case**

Xzero will manufacture and sell proprietary components for the manufacture and recycle of UPW to end users in the nanoelectronics industry such as Global Foundries and Intel and to integrators such as MW Group and Veolia.

**Added value of the innovation**

**Technological, economic and environmental comparison to state-of-the-art.**

<table>
<thead>
<tr>
<th>Parameters / Features</th>
<th>Veolia Water (France)</th>
<th>Ovivo (Canada)</th>
<th>GE Infra. (US)</th>
<th>Hitachi (Japan)</th>
<th>Kurita (Japan)</th>
<th>Entegris (US)</th>
<th>XZERO ULTRAWAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of nanoparticles</td>
<td>&gt; 20 nm</td>
<td>&gt; 20 nm</td>
<td>&gt; 20 nm</td>
<td>&gt; 20 nm</td>
<td>&gt; 20 nm</td>
<td>&lt; 20 nm</td>
<td></td>
</tr>
<tr>
<td>Retention of contaminants</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>ultra high</td>
</tr>
<tr>
<td>Recovery of rare materials</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Contamination from purification equipment to UPW</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Fixed instal</td>
<td>Fixed instal</td>
<td>Fixed instal</td>
<td>Fixed instal</td>
<td>Fixed instal</td>
<td>Fixed instal</td>
<td>Modular</td>
</tr>
<tr>
<td>Treatment steps</td>
<td>~20</td>
<td>~20</td>
<td>~20</td>
<td>~20</td>
<td>~20</td>
<td>~20</td>
<td>~20</td>
</tr>
<tr>
<td>Process electricity consumption</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>50% reduction</td>
</tr>
<tr>
<td>Process water use</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>recycle</td>
</tr>
<tr>
<td>Chemical treatment steps</td>
<td>several</td>
<td>several</td>
<td>several</td>
<td>several</td>
<td>several</td>
<td>several</td>
<td>none</td>
</tr>
<tr>
<td>Zero liquid discharge all valuables recovered</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Cost of hardware</td>
<td>40k$/gpm</td>
<td>40k$/gpm</td>
<td>40k$/gpm</td>
<td>40k$/gpm</td>
<td>40k$/gpm</td>
<td>40k$/gpm</td>
<td>30k$/gpm</td>
</tr>
<tr>
<td>O&amp;M costs</td>
<td>05$/kilo-gallon</td>
<td>05$/kilo-gallon</td>
<td>05$/kilo-gallon</td>
<td>05$/kilo-gallon</td>
<td>05$/kilo-gallon</td>
<td>05$/kilo-gallon</td>
<td>05$/kilo-gallon</td>
</tr>
<tr>
<td>Closed loop</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Harmful minerals &amp; chemicals collected and reused</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Chemicals used in the purification process</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sustainable growth decoupled from an increased resource consumption</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Concepts used

Nanoelectronics
Nanoelectronics industry is the new name for what recently was called Microelectronics industry. It is a similar concept as Semiconductor industry but is a bit wider.

Ultrapure water (UPW)
UPW is highly purified water, presently in three grades. The highest grade is for the semiconductor industry (Type 1), the second grade is for the pharmaceutical industry (Type 2) and the third grade is for the power industry, as boiler feed water (Type 3). Also other uses exist, i.e. lab water. Type 1 water has a Resistivity of 18.2 MegOhm and a Conductivity of 0.054 MicroSiemens.

A nanoelectronics manufacturer may use several millions of liter per day as rinse water to clean the components after each stage in manufacture.

Semiconductor
We use semiconductor in a general sense about microelectronics devices, such as processors, memories, application specific integrated circuits (ASICs), photovoltaic cells among many other.

The semiconductors consist of transistors (switches) that are built into integrated circuits. A large number of distinct integrated circuits are manufactured on the basis of a wafer (generally a thin dish of silicon) where each distinct unit is called a die. After it has been cut out from the wafer it is often called a chip or microchip. The chips are provided with connections (interconnect) and packaged into functional devices.

There are 1400 dies on a 300 mm wafer (300 mm in diameter) which until now was the most advanced and there are 3400 dies on a 450 mm wafer. The dies on a wafer are all built at the same time in more than one hundred consecutive steps which explains the possible savings in going from 300 to 450.

Line width
With line width we mean the distance over the switches in an integrated circuit. The shorter the distance, the quicker and more compact will be the device. Although not entirely interchangeable, line width may also be called gate length or node. Present best commercial line widths are above 20 nm. Advanced production has started at 14 nm line widths and research is done on linewidths down to 5 nm.

The names and figures the industry uses for feature size, nodes, line widths and gate lengths do not always match. So for instance Intel’s 14nm node has a 20nm gate length according to analysts and a guess about 5nm is therefore that it will have 10 to 12 nm gate length. These differences may have practical consequences for what would be considered “killer” particles (see below). However, the need for complete removal of nanoparticles remains.

Nanometer – nm
One nanometer is one billionth of a meter which is also one millionth of a millimeter.
**Killer particles**

Particles that are large enough to cause short circuit at a certain line width. So, in general terms, a particle larger than 14 nm may cause short circuit at 14 nm line width. However, several smaller particles may also combine into causing a short circuit. A short circuit anywhere in the microchip will mean that the finished microchip will be discarded in the final test of the product. High failure rate causes a low yield rate which may influence the economy of the production considerably. To increase yield rates is a target for nanoelectronics manufacturers.

**Yield rates**

Yield rate is the percentage of approved products in the final testing. At first runs of a new semiconductor plant, the yield rate can be as low as 3-4%. After a while it can be 30 – 70% and then go up in the 90ies when the process has been adjusted properly.

Defects are due to three major causes: a few percent from defects in materials, some 10% from remaining processing errors, including photolithography and mask defects. The rest is from contamination by unwanted particles.

A one percent reduction in defects, i.e. a one percent increase in yield at a new 450 mm facility may create an additional € 418 million in annual profits. The investment in Xzero system to achieve this reduction in defects is estimated at €42 million. The cost of a new Xzero UPW system will thus be negligible compared to its potential impact on yield rates.

**Reuse of water**

*Recycle* in this document is taken to mean to treat the waste water from a process in such a way that it can be reused in the same process (in a closed loop). *Recover* would then mean to treat the effluent in such a way that it can be used in other – less exacting – processes in the same plant. *Reclaim* would mean to clean the effluent in a way that it can be beneficially used for other purposes outside of the plant. Without removal of nanoparticles, the semiconductor industry cannot recycle its water. This is Xzero’s second marketing argument.

**Recovery of materials**

In the manufacture of semiconductors and other nano devices many expensive materials are used such as gold and silver and especially rare earth metals which are only found in specific locations and in limited quantities. To be able to recover these in a simple way will be extremely profitable.

Some other materials, such as arsenic and cadmium, must be recovered to avoid danger to the environment. This may not be profitable to the individual industry but nonetheless very desirable.

**Polygeneration**

Polygeneration is taken to mean a distributed energy system that reuses local waste energy and tops up with renewable energy resources to supply all types of local energy demands, such as electricity, space heating and cooling, hot water, process cooling, and in our case, also recycling of process water and recovery of materials in an integrated way. The system will reduce operating cost and contribute significantly to CO₂ emission reduction. The main purification process in Xzero’s system is driven by low temperature ambient pressure heat.
that can be derived from waste heat in the process itself. This will avoid some of the demand for electricity that is typical for state-of-the-art separation technologies and thereby also reduces carbon emissions.

Zero liquid discharge

Zero Liquid Discharge (ZLD) means that no waste stream leaves the factory. All waste streams are processed into reusable water and solids. The solid residue can be recovered. In any water purification process, clean water is separated from contaminants. In ZLD the contaminants are concentrated until they become a sludge and then further into solids. In Xzero systems all the water extracted in the concentration process can not only be reused, but also recycled as UPW.

Crystallization

Crystallisation is an alternative to evaporation in the ZLD process. In crystallisation (some) solids can be separated already in the concentration process. If there are only salts and minerals in the water that is concentrated, the water can be concentrated while the solids precipitate without leaving a sludge.
This glossary is by no means complete. It probably appears much too simplified for the expert and not didactic enough for the lay-person. However, we hope it will simplify for both categories. The semiconductor industry is very complicated and of many concepts are used slightly differently by different parties.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>III-V technologies</td>
<td>Integrating III-V materials (for instance GalliumArsenide) into CMOS enables higher performance at lower power density, allowing for an extension to power/performance scaling to meet the demands of cloud computing and big data systems.</td>
</tr>
<tr>
<td>ALD</td>
<td>Atomic Layer Deposition (advanced deposition process)</td>
</tr>
<tr>
<td>APC</td>
<td>Advanced Process Control</td>
</tr>
<tr>
<td>ASP</td>
<td>Average Selling Price</td>
</tr>
<tr>
<td>Back-end Production</td>
<td>Assembly and Test of devices</td>
</tr>
<tr>
<td>CAM</td>
<td>Computer Aided Manufacturing System</td>
</tr>
<tr>
<td>Carbon Nanotubes</td>
<td>Carbon nanotubes are single atomic sheets of carbon rolled up into a tube. A carbon nanotube may form the core of a transistor device that will work in a fashion similar to the current silicon transistor and could possibly replace silicon beyond the 7 nm node.</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access - refers to the US mobile communication standard</td>
</tr>
<tr>
<td>Chip</td>
<td>“Chip” is short for microchip, i.e. the incredibly complex yet tiny modules which store computer memory or which provide logic circuitry for microprocessors.</td>
</tr>
<tr>
<td>Crystallization</td>
<td>Technologies where sea-water or waste water is concentrated until solids precipitate. It is thus the final step in a zero liquid discharge process. An alternative to evaporation.</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary metal-oxide–semiconductor is a field-effect transistor that has a metal gate electrode placed on top of an oxide insulator, which in turn is on top of a semiconductor material. It is now the dominant technology for constructing integrated circuits.</td>
</tr>
<tr>
<td>Post-CMOS</td>
<td>Post-CMOS refers to the expected transition to new forms of integrated circuits based on carbon structures, etc. which are expected to develop below the 7nm node.</td>
</tr>
<tr>
<td>CMP</td>
<td>Chemical Mechanical Planarization - used to smooth the surface of a Silicon wafer with the combination of chemical and mechanical forces</td>
</tr>
<tr>
<td>CVD</td>
<td>Chemical Vapor Deposition – one of the processes in building a die</td>
</tr>
<tr>
<td>Die</td>
<td>Refers to the chip itself. Hundreds of dies are being processed in parallel on the same semiconductor wafer.</td>
</tr>
<tr>
<td>DRAM</td>
<td>Dynamic Random Access Memory</td>
</tr>
<tr>
<td>E-beam</td>
<td>Electron-beam lithography - refers to one of the next generation lithography technologies possible under development for advanced technology nodes (also called mask-less lithography)</td>
</tr>
<tr>
<td>EDA</td>
<td>Electronic Design Automation - software used in the semiconductor design flow</td>
</tr>
<tr>
<td>EDI (Electrodeionization)</td>
<td>Most recent complementary technology in UPW systems.</td>
</tr>
<tr>
<td>EEMI450</td>
<td>European 450mm Equipment &amp; Materials Initiative</td>
</tr>
<tr>
<td>ESIA</td>
<td>European Semiconductor Industry Association</td>
</tr>
<tr>
<td>EUV</td>
<td>Extreme Ultra Violet - refers to one of the next generation lithography technologies that will be necessary to produce sub-22nm</td>
</tr>
<tr>
<td>Fab</td>
<td>Semiconductor manufacturing unit, from “fabrication”.</td>
</tr>
<tr>
<td>Fabless</td>
<td>Company that designs nanodevices but has no manufacturing of its own</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>FET</td>
<td>A field-effect transistor uses an electric field to control charge in a semiconductor by switching on and off with changes in the electric field over a gate.</td>
</tr>
<tr>
<td>Fin</td>
<td>A fin can be added to the traditionally flat microchip in order to improve performance.</td>
</tr>
<tr>
<td>FinFET</td>
<td>Fin-based multi gate transistors architectures used at the most advanced technological nodes.</td>
</tr>
<tr>
<td>Flash</td>
<td>Flash memory is a non-volatile storage that can be erased and reprogrammed.</td>
</tr>
<tr>
<td>FOSB</td>
<td>Front Opening Shipping Box - used to ship processed wafers to other location (back-end facilities)</td>
</tr>
<tr>
<td>Foundry</td>
<td>Company that manufactures designs made by others</td>
</tr>
<tr>
<td>FOUP</td>
<td>Front Opening Universal Pod - used to convey wafers throughout the different process steps within the fab</td>
</tr>
<tr>
<td>Front end production</td>
<td>Initial fabrication of the wafer</td>
</tr>
<tr>
<td>G450C</td>
<td>Global 450 Consortium - based in Albany (New York State) funded by Intel, TSMC, Samsung, IBM and Global Foundries in order to speed-up and coordinate the development of 450mm equipment and materials</td>
</tr>
<tr>
<td>Gate</td>
<td>A devise that stops and opens the signal in a transistor</td>
</tr>
<tr>
<td>Gate length</td>
<td>The distance between the source of a signal and the destination (drain). Similar to but not identically used as the concepts line width and node.</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GDS-II</td>
<td>Database file format which is the industry standard for data exchange of integrated circuit or IC layout artwork</td>
</tr>
<tr>
<td>Giga-Fab</td>
<td>Refers to TSMC's concept of duplicating and interconnecting fab modules to create very large manufacturing infrastructure with capacities above 100k wafers per month</td>
</tr>
<tr>
<td>Graphene</td>
<td>Graphene is pure carbon in the form of a one atomic layer thick sheet. It is an excellent conductor of heat and electricity, and it is also remarkably strong and flexible. Electrons can move in graphene about ten times faster than in commonly used semiconductor materials such as silicon and silicon germanium. This opens a possibility to build faster switching transistors than are possible with conventional semiconductors</td>
</tr>
<tr>
<td>Hi-k metal</td>
<td>Refers to materials used in advanced transistor designs in order to improve</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
<tr>
<td>IDMs</td>
<td>Integrated Device Manufacturers with both design and manufacturing capabilities (as opposed to fabless and foundries pure-play business models)</td>
</tr>
<tr>
<td>IE (Ion Exchange)</td>
<td>Earlier dominant technology for UPW, still included in all present systems.</td>
</tr>
<tr>
<td>Imprint</td>
<td>A stamp is replicated into a material by mechanical contact and three dimensional material displacement</td>
</tr>
<tr>
<td>Integrated circuit</td>
<td>An integrated circuit (IC), sometimes called a chip or microchip, is a semiconductor wafer on which thousands or millions of tiny resistors, capacitors, and transistors are fabricated. An IC can function as an amplifier, oscillator, timer, counter, computer memory, or microprocessor. A particular IC is categorized as either linear (analog) or digital, depending on its intended application.</td>
</tr>
<tr>
<td>Integrators</td>
<td>Large infrastructure companies which build whole plants or parts of plants on the basis of a contract with the owner.</td>
</tr>
<tr>
<td>IP</td>
<td>Intellectual Property</td>
</tr>
<tr>
<td>ISMI</td>
<td>International Sematech Manufacturing Initiative</td>
</tr>
<tr>
<td>ITRS</td>
<td>The International Technology Roadmap for Semiconductors working group is a gathering of leading experts from the semiconductor industry intended for the assessment of common non-competitive technology needs.</td>
</tr>
<tr>
<td>KET</td>
<td>Key Enabling Technology</td>
</tr>
<tr>
<td>Killer particles</td>
<td>Those particles of minimum size which can cause a significant effect on the yield of semiconductor manufacturing.</td>
</tr>
<tr>
<td><strong>KTH (Kungliga Tekniska Högskolan)</strong></td>
<td>Royal Institute for Technology (Stockholm, Sweden), Xzero's main partner in energy research.</td>
</tr>
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<td>--------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Line width</strong></td>
<td>Measure of dimension in a microchip with reference to what the lithography can accomplish in the masking, beam etching process. Corresponds in magnitude to what is referred to as gate width and node.</td>
</tr>
<tr>
<td><strong>MCU/MPU</strong></td>
<td>Microcontroller / Microprocessor</td>
</tr>
<tr>
<td><strong>MD</strong></td>
<td>Membrane Distillation.</td>
</tr>
<tr>
<td><strong>MEMs</strong></td>
<td>Micro-ElectroMechanical systems - refers to specialty manufacturing processes enabling the use of silicon or other semiconductor substrates to design micro-sensors, actuators, etc. and possibly integrate signal processing/control(interface) onto the same chip</td>
</tr>
<tr>
<td><strong>MES</strong></td>
<td>Manufacturing Execution System - software used to optimize and control the manufacturing operations within a semiconductor plant</td>
</tr>
<tr>
<td><strong>Microchip</strong></td>
<td>A microchip (sometimes just called a &quot;chip&quot;) is a unit of packaged computer circuitry (usually called an integrated circuit) which is manufactured from a material such as silicon. Microchips are made for program logic (logic or microprocessor chips) and for computer memory (memory or RAM chips). Microchips are also made which include both logic and memory and which are intended for special purposes, such as analog-to-digital conversion, bit slicing and gateways.</td>
</tr>
<tr>
<td><strong>MM</strong></td>
<td>More Moore - referring to the most advanced (miniaturized) SC manufacturing processes, at present below 65nm</td>
</tr>
<tr>
<td><strong>MtM</strong></td>
<td>More than Moore - referring to complementary integration techniques and SC processes like sensors, analog, heterogeneous modules (System in Package), etc.</td>
</tr>
<tr>
<td><strong>NAND</strong></td>
<td>(negative-AND) gate is a gate which produces an output which is false only if all its inputs are true.</td>
</tr>
<tr>
<td><strong>Neurosynaptic Computing</strong></td>
<td>A novel technology that may allow for computing systems that emulate the brain’s computing efficiency, size and power usage. IBM, for instance works on a program to build a neurosynaptic system with ten billion neurons and a hundred trillion synapses, all while consuming only one kilowatt of power and occupying less than two liters of volume.</td>
</tr>
<tr>
<td><strong>Nano</strong></td>
<td>One millionth of a millimetre</td>
</tr>
<tr>
<td><strong>Nanophotonics</strong></td>
<td>Plan to develop transceivers that use light to transmit data between different components in a computing system at high data rates, low cost, and in an energetically efficient manner. Silicon nanophotonics uses pulses of light for communication rather than traditional interconnects based on copper wiring. The vision is to move terabytes of data via pulses of light through optical fibers.</td>
</tr>
<tr>
<td><strong>NIL</strong></td>
<td>Nanoimprint lithography is a patterning method in which a surface pattern of a stamp is replicated into a material by mechanical contact and three dimensional material displacement</td>
</tr>
<tr>
<td><strong>Node</strong></td>
<td>The point at which electronic pathways intersect. It is used to characterize the level of size of the manufacture. It is a general description encompassing the size of the sizes of the transistor gates in the products and the line width in the manufacturing process.</td>
</tr>
<tr>
<td><strong>OEM</strong></td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td><strong>PA</strong></td>
<td>Public Authority</td>
</tr>
<tr>
<td><strong>POU (Point of Use)</strong></td>
<td>Present UPW supply facilities consist of large central purification units where water is purified to an exceptionally high degree of purity. The purified water is kept circulating in polishing loops until it is used in the clean-rooms. At the same time it is polished to the final UPW standard of purity. In a POU system, the water would instead be brought to UPW quality (and possibly recycled) locally in the clean-room.</td>
</tr>
<tr>
<td><strong>PV</strong></td>
<td>Photo-Voltaic</td>
</tr>
<tr>
<td><strong>PVD</strong></td>
<td>Plasma Vapor Deposition – one of the processes in building a die</td>
</tr>
<tr>
<td><strong>Quantum Computing</strong></td>
<td>Quantum computers can weed through millions of solutions all at once, while an ordinary computer would have to consider them one at a time. Superconducting qubits are typical building block for one type of quantum computer.</td>
</tr>
<tr>
<td><strong>RO</strong></td>
<td>Workhorse of State-of-the-art UPW technology, included in all present UPW systems.</td>
</tr>
</tbody>
</table>
### Semiconductor
A semiconductor is a substance, usually a solid chemical element or compound, which can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current. Its conductance varies depending on the current or voltage applied to a control electrode, or on the intensity of irradiation by infrared light (IR), visible light, ultraviolet (UV), or X rays. Also a general name of the IC industry.

### SiGe
Silicon-Germanium - new base material for semiconductor wafers with improved performances compared to Silicon albeit higher cost.

### Silica
Silicon dioxide, a chemical compound that is an oxide of silicon with the chemical formula SiO2.

### Silicon
Silicon is a chemical element with symbol Si and atomic number 14. It is a tetravalent metalloid, more reactive than germanium, the metalloid directly below it in the table. In wafer manufacturing, thin films of silica grow spontaneously on silicon wafers via thermal oxidation to a very shallow layer (approximately 1 nm) of so-called native oxide.

### SIP
System in Package - refers to the integration of different chips in a single package in order to provide a complete system.

### SoC
System on Chip - refers to the integration of different elements of a functional system into a single silicon chip (e.g. memory + processors + wireless interfaces etc.)

### SOI
Silicon On Insulator - refers to a specific substrate manufacturing techniques providing higher transistor performance and lower energy consumption compared to bulk Silicon wafers (at identical transistor design).

### SRAM
Static Random Access Memory

### Steep slope device
A switch under development that work on lower voltage than FETs and therefore may reduce the leakage of power in the transistor.

### TFET
In the tunnel field effect transistors the quantum-mechanical effect of band-to-band tunneling is used to drive the current flow through the transistor. TFETs could possibly achieve a 100-fold power reduction over complementary CMOS transistors.

### Transistor
A device used to switch electronic signals. In a semiconductor product, transistors are combined into integrated circuits (IC). One microchip may today contain billions of transistors.

### TSV
Through Silicon Via - technology used to interconnect several dies vertically (3D modules).

### UPW (Ultrapure Water) for the semiconductor industry
There are several grades of UPW. The UPW used in semiconductor processing has the highest demands on quality. It should have the resistivity of 18.3 MegOhm and no more conductivity than 0.054 MicroSiemens.

### UTB (FD-SOI)
Ultra Thin Body (Fully Depleted Silicon On Insulator) - refers to a competing transistor architecture to FinFET based on SOI wafers.

### Wafer
Round slabs of silicon on which a thin film of silica (silicon dioxide) grows spontaneously via thermal oxidation to a very shallow layer (approximately 1 nm) of so-called native oxide. The wafer is the substrate of further processing by masking, etching, deposition, polishing and cleaning into transistors and finally cut into hundreds of individual pieces (dies) which each make up semiconductor products (microchips).

### Wpm
Wafer out per month - refer to the output capacity of a semiconductor wafer fab (front-end)

### ZLD (Zero Liquid Discharge)
No waste stream leaves the factory. All water is reused. Only solid residue is removed from the factory. This solid residue can also be recovered.
1 Project

Plan
Long term plan: To develop zero liquid discharge (ZLD) systems for industrial closed loop recycling of water and materials.

Launch plan: The initial target is the semiconductor industry because it has the highest demands on water purity and pays more for water treatment than any other industry.

Launch steps:
Xzero has successfully tested the concentration of difficulty wastes in semiconductor industry together with imec. Successful concentration gives immediate economic rewards in reduced cost for destruction.

Xzero has successfully tested the total removal of sub-20 nanoparticles from semiconductor process water together with Swedish Environmental Research Institute (SERI) and Clarkson University (an asset in the Global 450 Consortium (G450C). There is presently no other technology that can accomplish this. Removal of such particles is an absolute necessity for the commercial success of the next generation of semiconductors with sub-20 line-widths. Therefore this is a good entry point into the semiconductor industry.

Once the market for concentration of wastes and the market for removing nanoparticles is established. These two functions can be merged into one system - a closed system where water and contaminant are separated and can be recycled. (ZLD)

Final launch: Once the system is established in the semiconductor industry other industries will be targeted with then proven ZLD- systems.

Unique selling proposition
Xzero provides completely pure process water for the nanoelectronics industry

Employment
A technical team of three people have worked at Xzero from the start. A very large number of ad hoc tasks have been ordered continuously from research institutes and industrial consultants. For the industrialization work an extra team of three industrial consultants have been employed on a continuous basis. This technical team will also continue to be engaged once the commercial phase starts and will be complemented, mainly by technical sales people, when full scale manufacturing starts and sales pick up. Within a few years it is envisaged that the company will have employed around 200 professionals and the administrative staff necessary to support these people. It will have created much more employment among suppliers and integrators.

Research
During the first ten years Xzero co-operated with several Chemical departments at Swedish universities to develop and test the basic technology. During the last ten years Xzero has co-operated with the Department of Energy Technology in order to test, evaluate and improve specific applications of the technology. A large number of Masters Studies have been
performed for this purpose as well as three doctoral studies. At present one Postdoc and three PhD students are actively investigating different aspects of the applications.

**Xzero’s project has the following aims**

- To contribute to the profitability of the semiconductor industry by reducing defects in manufacture
- To reduce water use and pollution in the semiconductor industry by recycling
- To reduce water use and pollution and to recover materials in all industries by zero liquid discharge
- To support European industrial ambitions for innovation and employment.
- To lay the foundation for a European company with initial sales of 100 M€ within five years

**Xzero’s business case**

Normal line-widths in nanoelectronics devices are today 20 – 32 nanometres and there is research on designs down to 5 nanometres. Particles larger than the actual line-width can cause short circuits which will cause the whole device to be scrapped.

Each discarded product reduces the profits of the factory and, historically, nanoelectrics companies have been bankrupted because of what is called "low yield", i.e. high rejection because of faults.

To be able to ensure that there are no nanoparticles in the process water promises substantial profits for a semiconductor manufacturer. This is where Xzero’s market entry is. By removing the nanoparticles Xzero will also enable recycling of the process water.

**Xzero’s technology is in line with the requirements of the European 450 program**

The quotes below are from: *The Move to the next Silicon Wafer Size: A White Paper from the European Equipment and Materials 450mm Initiative (EEMI450) – 2013.*

**New technology needed**

“So the equipment of the 450mm generation will have to meet currently unknown high yield manufacturing ramp rates, challenging levels of defect free operation, and extreme reliability performance.

Therefore, a series of research and development efforts will have to be invested into equipment improvements and innovations.”

**Opportunity**

“For newcomers in the market, a wafer transition is a unique opportunity to enter the market and gain new customers.

It is therefore extremely important to be at the forefront of developments to enable introduction of equipment to new customers at an early stage in order to profit from a possible change in vendor policy from 450mm customers with an attractive offering”
Necessity to remove nanoparticles

The next major transition in the semiconductor industry is called the 450-program. It entails both moving to smaller line widths – 14, 10, 8 and 5 nanometers - and a larger wafer – from 300 to 450 millimeters in diameter.

In this transition the semiconductor industry needs to change everything from what is well-tried and proven today. One worry is that semiconductors may be destroyed by small particles in the process water that cannot be removed by state-of-the-art equipment. Therefore there is a need for a technology that removes these particles. The same particles must also be removed from the waste water. Otherwise the water cannot be recycled. And it will need to be recycled in the future in order to save on water resources, recover valuable metals from the manufacture that is rinsed from the semiconductors and to prevent pollution of recipients. State-of-the-art technology cannot remove small nanoparticles. However Xzero’s new technology does and will thus enable both manufacture on the sub-20 nano scale and the recycling of process water.

“Currently, the most difficult UPW quality challenge is the control of particles. The “killer” particle has shrunk to 10nm in size in the most advanced semiconductor processes. This is smaller than the detection capability of the most advanced UPW metrology. Furthermore, the most advanced filtration technology becomes marginal in its ability to completely remove particles at this size. Eliosov et al. (2014) demonstrated that only ~99% removal efficiency was achieved for 10nm particles by the best available final filters (ultra-filters) used in the most advanced semiconductor facilities (see Figure below). This removal efficiency (filter retention) drops significantly for particles <10nm in size...Particles in UPW are viewed as a high risk parameter due to the high probability of their occurrence, the insufficient ability to detect them, and the high potential of device impact. Other contaminants, such as organics and hydrogen peroxide, are being investigated for their impact on yield.” (Libman et.al. 2015)

To avoid short circuits all contaminants must be removed from the wafer and no contaminants may be added from the water that is used to clean or from the materials in the cleaning equipment or in the water supplied for cleaning.

For instance, the wafer is cleaned from residual materials and debris after each manufacturing step. The water used in the cleaning process must in itself be free from contaminants. It is called Ultrapure water (UPW). Contaminants that can cause short circuits are called “killer particles”. If a “killer particle” is left imbedded in the semiconductor after a certain process step it cannot later be removed. It will cause a fault which will not be discovered until final testing and the particular device must be discarded.

If too many devices are discarded the manufacture becomes uneconomical. What is called “the yield rate” becomes too low. High yield rates means high profits. Low yield rates may lead to bankruptcy. UPW is thus an inconspicuous detail in the manufacturing process, but has a crucial role. Just as the washing of hands in an operating theatre.

As line widths in semiconductor designs become narrower, the size of what can be a “killer particle” also becomes smaller. A particle twice the size of the line width is definitely a killer. A particle of the same size as the line with might be as well and several smaller particles together can also cause a short circuit.
Actually, the smaller the particles are, the more numerous they are.

It is the reduction in line-width that has driven the fantastic development of electronics and it will do so also in the future. As line widths become lower than 20 nanometer it will become absolutely necessary to remove all particles larger than 20 nanometers and it will be necessary to remove also smaller particles. Ideally, of course, all particles should be removed.

"The importance of managing the particle challenge to the UPW final filters is growing as the killer particles size approaches the limits of the best available technology." Ultrapure Water for Advance Semiconductor Manufacturing: Challenges and Opportunities, Slava Libman, Balazs NanoAnalysis, Daniel Wilcox, Samsung Austin Semiconductor, Bernard Zerfas, IBM Microelectronics, 2015 ECS - The Electrochemical Society Oct 12, 2015. (Mr Zerfas is now with Globalfoundries in Malta, N.Y.)

"There are several possible particle sources in UPW. Stainless steel particles are believed to originate from the high sheer stress in stainless steel polish pumps, whereas a majority of carbon particles are believed to originate from polymer materials used in the UPW treatment process. Recent studies conducted by a SEMI task force confirmed that new (virgin) ion exchange resin can produce as many as 1E+7 particles/mL 10nm or larger even after extensive resin rinse..." (Libman et.al. 2015)

Today there is no technology available for guaranteed removal of the smallest nanoparticles. Naturally, water treatment suppliers are racing to develop such technology. It has however proven difficult to improve state-of-the-art equipment to also remove the smallest nanoparticles. If that were not the case, it would have already been done.
Business plan

In 1996, Xzero started R&D on technology for improving the purity of UPW and is now ready to commercialize innovative technology for removal of sub-20 nanoparticles. Xzero has already presented the technology to some of the most advanced semiconductor manufacturers and made technical adaptations to their expressed needs. The final step of commercialization and market launch will be taken in co-operation with imec.

In 2015, Xzero wrote Non-Disclosure Agreements with two leading semiconductor manufacturers in the Global 450 Consortium and started testing activities in co-operation with one of the research members of the Global 450 Consortium, Clarkson University in Potsdam, New York and with imec in Leuven, Belgium, the leading research institute in the European 450 consortium. The agreements with these four leading players testify to the importance of the Xzero technology.

During 2015, Xzero has also made industrial designs for full scale equipment with the help of several engineering companies. The first full scale prototype was sent for testing to imec in April 2016 and was replaced by an improved prototype in August 2016. A final commercial prototype made with real tools will be sent to imec in early 2017. A first patent protecting the new design has been approved in 2015 and others will follow.

Once these full scale prototypes have been tested and verified and turned into commercially viable products, Xzero will start commercial marketing. Initially smaller systems for specialized uses, for instance treatment of specific waste streams or for polishing to remove nanoparticles. These smaller systems will be followed by larger full systems for UPW for advanced nonmanufacturing. Finally, the company will graduate into all-purpose ZLD-systems for recycling of water and recovery of materials.

Through the participation in both the International and the European 450 program, Xzero will be able to reach most if not all major customers in the nanoelectronics industry. Successful tests in the programs, and especially at imec, will be convincing sales support.

The use of water in the industry

Nanoelectronics are in the hearts and brains of all new electronics and IT industry, indeed, all modern industry. The main reason for the amazing development of electronics and IT during the last decades is the increase in semiconductor performance. This increase is mainly driven by the miniaturization of the semiconductors, the decrease in line width. As the line widths have become lower, the specifications for the cleaning water, Ultrapure Water (UPW), have become increasingly stringent.

After each of 150 or so intricate steps over what can be a six to twelve week production cycle, it is necessary to remove all residual materials and debris from the wafer. This is done with UPW. UPW accounts for less than 6% of capital costs and even less of operating costs but can have a serious impact on yield rates and thus chip viability. Those who supply water plants perform a modest but essential role in the manufacture.

An average 450 fab will require approximately 60 million litres of UPW per day and the water system will cost up to € 60 million.
European position

Although there were initially many leading microelectronics manufacturers in EU countries, EU has continuously lost competitiveness in this sector for decades. In the nineties the US dominated the processor manufacturing and Japan dominated the memory manufacturing. Today Korea and Taiwan have joined the leaders, Japan has fallen back somewhat and PR China is a runner up. Also, the Emirates have bought one of the present leaders in the industry, GLOBALFOUNDRIES. India will soon also be a contestant.

To survive in a competitive business world, EU must re-enter the semiconductor industry and again become a leader in development of innovative microelectronics – now better called nanoelectronics. One building block is already there, the microlithography equipment (EUV) manufacturer ASML of the Netherlands which ranks as the world’s leading supplier of semiconductor manufacturing equipment. Other strong EU companies in the sector are for instance Carl Zeiss SMT in optics and photo masks and MW Group in facilities.

To achieve further reductions in feature size, EUV appears to be the lithography technology of choice. Sub-14 nano EUV is critical to achieve the cost, performance, and power improvements needed to meet the industry’s anticipated demands in cloud computing, Big Data, mobile devices, and other emerging technologies. Imec assists industry to understand when and how to insert this technology and Xzero is already co-operating with imec.

To build semiconductor industry in Europe

Europe needs to re-establish and enhance advanced electronics industry.

Electronic components determine ability of countries to compete in high value markets, including those for: automobiles; aeronautics; communications; defence; medical devices; power generation; computers; railways; audio; engineering; financial services and many others. These are all key sectors in Europe.

The global electronics sector, is valued in trillions of dollars and, according to KPMG, accounts for more than 10% of global GDP.

Global market values

- **products**
  - 9.1 trillion €

- **components**
  - 3.4 trillion €

- **semiconductors**
  - 333 billion €

Europe is a major user of nanoelectronics devices such as semiconductors. However, it has been falling behind other producers of semiconductors, accounting for less than 10% of global production. Despite a global market lead in many applications, the process has left
Europe dependent on imported semiconductors. Being dependent on imported semiconductors on which a vital electronics industry rests is not considered healthy. The European Commission is therefore charged with developing European fabrication of semiconductors.

In May 2013, former EU Commission Vice-President Neelie Kroes, charged with enhancing the EU’s competitiveness in IT and telecommunications, outlined a plan to use €10 billion in public and private funding to kick-start investment of €100 billion into the industry. The plan will use a multi-pronged approach: boosting cross-border cooperation; allowing easier access to capital financing through loans; simplifying European state-aid rules; aligning EU, national, and financial resources to enable larger-scale projects; and creating and maintaining a highly skilled workforce. It is called the 10/100/20 because it is hoped that a €10 billion investment from EU will motivate another €100 billion of investments from the industry, which is hoped to increase the European production of semiconductors to 20 percent of the global from approximately 15 percent today.

Foreign companies are not excluded from the 10/100/20 program, which is aimed at all companies interested in investing in manufacturing in Europe. According to market research firm IC Insights, 71 percent of all new semiconductor capacity needs between 2014 and 2020 would have to be located in Europe in order to meet the 20 percent goal. It is an ambitious effort, but the strengthened semiconductor industry would do much to underpin the major electronics industry that depends on it.

The 10/100/20 strategy will facilitate industry investments of €100 billion and help create 250,000 jobs in Europe up to 2020. The objective is to reverse the decline of Europe’s share of the supply of micro and nanoelectronics and ensure in a decade from now a level of production in the EU that is more in line with the size of its economy. The proposed strategy in consonance with the Key Enabling Technologies (KETs) initiative approach.

Global competition in the nanoelectronics sector

Ownership of the industry has changed over the last decades. The leading producers being owned in different countries: Intel in USA; GLOBALFOUNDRIES in UAE; TSMC in Taiwan; and Samsung in Korea.

Just as Gulf Arab capital in the Middle East was used to consolidate a number of producers into GLOBALFOUNDRIES, China and India have allocated substantial funds to promote development in the two countries. Changes in ownership do not alter the need to produce more in consuming markets. GLOBALFOUNDRIES did not alter the geographical focus of its production base even though ownership changed. Perhaps the most important development that impacts on this is the growth of electronic industries in China and India.

The German market is Europe’s biggest, and the fifth largest worldwide with around €106 billion annual market volume. Although semiconductor manufacturing in Europe has waned in more than 20 years, investment in production has now started to return. In the way of illustration, STMICROELECTRONICS is extending the life of its Crolles fab, Grenoble, France and GLOBALFOUNDRIES has decided to increase production at its Dresden, Germany, facility, providing a potential new impetus to leading-edge production on the continent.

The two leading semiconductor companies that Xzero has written NDA’s with have production facilities in Europe. Europe is an important market and has the skilled manpower that the industry needs. It also is an important supplier of semiconductor manufacturing equipment.
Xzero will join a growing group of presently export oriented European suppliers to the international semiconductor industry. This will lay a strong foundation for the future semiconductor manufacturing industry in Europe. The development will be crucial for Europe’s industrial growth and thus for income and employment.

The activities suggested in the present proposal would therefore strengthen the EU cluster for semiconductor manufacturing by strengthening Xzero’s bid to become a leading equipment manufacturer for nanoelectronics manufacturing.

**Timeline for EU (Global) Activity**

Although the overall progress in the timeline is somewhat delayed, Xzero has finished the testing stage in 2015 and is entering the full pilot stage in 2016.

**Synergy with other EU-projects**

In the EU’s Key Enabling Technologies (KET) program with a budget of more than 6 B€ there are about a dozen semiconductor projects and pilot lines that could benefit from using water without nanoparticles. Xzero will seek co-operation with several of these projects.

**New water treatment technology needed**

The next generation of semiconductors – the sub-20 nanometres – will need purer water than what state-of-the-art technology can supply. Xzero is preparing to launch such technology.
Industry stands for approximately 40% of water abstractions in Europe\(^1\). At the same time, it is a major water polluter. EUROSTAT’s statistics currently show that only up to 60% of industrial wastewater receives treatment before being disposed into the environment. Recognizing this problem, the EC calls for more sustainable water use through its Water Framework Directive (2000/60/EC). The implementation of new technologies in those sectors has potential not only to cut water use and pollution, but also to reduce energy use and achieve more efficient chemical use.

Manufacturing of semiconductors consumes an estimated 400 billion litres of water per annum and results in poisonous effluents such as strong acids and bases, cadmium and arsenic and contains many valuable and even rare metals that are important to recover.

Different industries require differing degrees of purity of water and the latter determines costs. The semiconductor industry requirements for water purity are the highest and the semiconductor industry pays more for their water purification systems than any other industry. It also has a lead in introducing new technologies.

Standards of purity are rising in semiconductor manufacturing - in particular the need to remove nanoparticles. At the same time water consumption is rising and there is no way in the foreseeable future of lowering the volumes required.

Xzero has developed technology that can

- remove nanoparticles
- recycle water
- recover materials

With this in mind, Xzero applied for funding in the Horizon 2020 framework to undertake a feasibility study as phase one of assistance. Funding for the study was granted by Vinnova in Sweden and the study has been implemented. Funding is now required for the market launch of the system.

There is a need for purer water in the processing of the next generation of semiconductors.

“Improving manufacturing yields on silicon wafers and microprocessor devices is the foremost goal of every chip manufacturer. Improving yields will increase operating efficiencies and profitability.” Christopher Eric Brannon, Texas Instruments, Inc, Dallas, TX (in Automatic wafer inspection systems replaces eyeballs with cameras, Solid State Technology | Volume 56 | Issue 2 | February | 2013)

A quick overview of the fervent development in the industry can be found in What to Expect in 2016 in the Chipworld, Dick James, Senior Technology Analyst, Chipworks, Solid State Technology, January 11, 2016

“As to line width the following is predicted: 2016 will be a relatively quiet year when it comes to the leading-edge processes, since we do not expect to see a high-volume of 10 nm products this year. There has been a fair bit of comment that the upcoming Apple A10 processor might be on 10 nm this autumn, but to me it seems a real stretch to expect a full node advance barely 18 months after the introduction of a 14 nm product from Samsung, and a 16 nm product from TSMC, especially in the volume that Apple would require.”

We do expect to see the second generation 14/16 nm processes, FinFET Plus (16FF+) from TSMC and 14LPP from Samsung and possibly their co-supplier GLOBALFOUNDRIES. The second-tier foundries such as UMC and SMIC will be ramping up their 28 nm high-k metal gate (HKMG) product, so we will be monitoring those as we get them. It appears that UMC will be skipping 20 nm and going straight to 14 nm, but that will not likely appear until 2017.

Also: Intel has a parallel “Embedded Multi-die Interconnect Bridge” (EMIB) technology (to TSMC’s InFO), and given the completed Altera deal, we may finally see a 14 nm field-programmable gate array (FPGA) product with EMIB this year.”

From the present most advanced 22 nm node, the step was taken to the first commercial products with 14/16/20 nm line width in 2015. It is about two years later than plan and also the plans for the next steps will be delayed. However research is already under way for the coming nodes 10, 7 and 5 nm. Also, some manufacture at the 7 nm node has been reported in 2016.

Main technical justification for the Xzero system - removal of nanoparticles

In the tests below, no extra purification equipment has been used. No degassing, no chemicals, no pretreatment, only a one-step Xzero module. Feed was added to the feed tank. The unit was turned on and permeate collected. All tests performed by third parties.

**Ag+ nanoparticles:**
Liquid containing 3100ug/l Ag+, 5nm and larger. After Xzero no detection in three consecutive tests. Analysis with Atom absorption spectroscopy (AAS). Detection limit was <2ug/l.

**Ag+ and Au+ nanoparticles:**
1. Tap water spiked with Ag+ nanoparticles - 140mg/l with 80% 0,24nm particles and 20% 1-24nm particles. Result <0,1ug/l
2. Tap water spiked with 100% 2nm particles at a concentration of 37mg/l Au+ nanoparticles. Result < 0,1ug/l

Test by Swedish Environmental Research Institute in June 2014 with HPLC. The results for nanoparticles have later in the year been verified by tests done with equipment with even more stringent detection levels.
Test with Xzero’s equipment for removal of sub-10 nanoparticles by Swedish Environmental Research Institute. The graph shows distribution in size for the Ag nanoparticles removed. As seen, even particles below the sizes of “killer particles” are removed.

Nano tests in 2017
Since these first test was made several tests have been made in co-operation with KTH, ALS Global, Manta Instruments, Clarkson University and Anton Paar. All tests have verified excellent results. The tests have been done with silver and gold nanoparticles to verify the technology and improve the practical implementation. A program is underway in 2017 for testing of other types of nanoparticles such as polystyrene sphere nanoparticles, silica nanoparticles and other nanoparticles that are of interest in the industry. Since the method is not selective in regard to material or charge, it is expected that all nanoparticles will be removed in the same efficient way.

Economic justification for Xzero technology
To reach acceptable yields in the manufacture semiconductors with sub-20 nanometre line widths it is necessary to remove all nanoparticles from the process water to avoid faults in production. This is what Xzero does.

The manufacture of a wafer containing hundreds of micro (nano) chips may take about four months of consecutive operations. It involves around one thousand steps. Each step has to be absolutely perfect. If the first step is wrong, it may take four months before it is found out in the final test of the individual microchip which then has to be discarded. All the long and expensive work will have been of no use.

The next generation of nanochips will have line widths that are less than 10 nanometres, i.e. ten billions of a meter. One human hair has a diameter of 200 000 nanometre, i.e. the line width in the semiconductor is 20 000 times thinner than a human hair. Even the smallest particle will cause short-circuit in the chip.

The wafer is cleaned at least 100 times during the manufacturing process. If the cleaning water is not absolutely clean at any of these cleaning steps, one or several or all chips may have to be discarded and the whole sophisticated manufacturing process has been in vain.

Xzero’s water treatment technology ensures that all particles are removed from the cleaning water.

Every 1% rate of rejection would amount to a loss of € 418 million per annum in a 450 fab, € 130 million in a 300 mm fab. Most of that figure would be a direct reduction in profits. Historically, semiconductor companies have been bankrupted because of what is called “low yield”, i.e. high rejection because of faults.

When a new generation of semiconductors is launched, the first step requires getting processing right. At first run, production of new semiconductors is so besotted with problems that yield rate can be as low as 3-4%. Once the processing mechanics are burnt in and working well, yield rates rise but may still be only 67% at the probe stage and are known to have been as low as 30%. Defective wafers are binned early, defective chips are eliminated before they are packaged after which, yields are claimed to be as high as 94-99%.

Defects in dies (chips) are historically due to three major sources: (a) 2% from defects in materials, including the wafer itself, (b) 8% from processing errors, including
photolithography and mask defects, (c) 90% from contamination (Richard P. Rumelt, UCLA). Contamination means unwanted particles adhering to the water or mask, causing defects to be etched or deposited onto the patterns of a wafer. Contamination can be from air particles, human presence, equipment and processing. To avoid contamination on wafers, rinse water plays a crucial role.

The International Technology Roadmap for Semiconductors (ITRS) has identified nanoparticles as a major threat to further progress in semiconductor manufacturing. Today, particles that are 20 nm can cause damage to the semiconductors. However, industrial predictions and calculations indicate that 10 nm particles or even 5 nm particles will soon be considered as “killer particles” that pose threat to the semiconductors.

The number of contaminants is inversely proportional to their size. The smaller the particles, the more of them there is. Currently, there is no efficient technology for the removal of the smallest nanoparticles from UPW. By removing all nanoparticles, Xzero will contribute to raising yield rates and thereby substantially increase the profit for the manufacturer.

Improvements in yield rates are several times more profitable than reduction in cost of water. As a new technology, it is very likely that Xzero equipment would initially be added as a step in current state-of-the-art systems with some other steps being phased out over time. For the 450 fab, as an example, even a temporary doubling of water system capital costs would be justified even if there were only a 0.25 % increase in yield rates.

Yield rates become increasingly important. Every one percentage point of rejection would amount to a loss of € 418 million per annum in the new type of fab (450) while it amounted to € 130 million in a 300 mm fab.

Development plan for recycling

While the main motive for Xzero technology is to remove nano particles to enable manufacturers to make more advanced components, an equally valid, although not as economically pressing, argument is to reduce environmental pollution and minimize water use. Tests at imec already show promise in this respect, but careful planning is needed to pursue this important market aspect.

1. Semiconductor manufacturing facilities (fabs) have a number of waste streams in the process of production of varying degrees of contamination and toxicity. These waste
streams take place at different points in the process. End-users often have their own priorities as to which waste streams need to be tackled earliest. Xzero must discuss with end-users and those developing systems on their behalf the above range and target those concerns of greatest interest.

2. There are parameters within which tests must take place. Waste streams have different Ph levels, TOC etc that may affect equipment. There is a need to co-ordinate tests that validate integrity of Xzero technology in the face of such disruptive contaminants.

3. Waste streams also differ in the volume and timing of their discharge. There needs to be co-ordination on the ideal capacity of equipment to treat particular streams. Often, a flush capacity is required on an intermittent basis and there is scope for linking storage with treatment.

4. Product water that ensues needs to be re-introduced into the UPW cycle. Tests must determine as to which part of the cycle the water is fed back to out of the various stages such as make-up water and the polishing loop.

5. The points of the fab where waste streams are discharged should be examined to see if there is waste heat that could be married to the Xzero system to reduce costs. We know there is surplus waste heat in a fab, this step is in order to see if there is easily accessible waste heat that can be used.

6. Particular contaminants may foul the membranes of the equipment such as scaling, if so counter measures must be developed.

7. The testing schedule is interactive and there will be a continuous need for dialogue between Xzero, industry end-users and their contractors. This dialogue has to start with the design stage and continue until the technology is implemented.
## Time Schedule

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Year(s)</th>
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</thead>
<tbody>
<tr>
<td>General R&amp;D</td>
<td>1996 -</td>
</tr>
<tr>
<td>Application testing of experimental units with KTH</td>
<td>2006 -</td>
</tr>
<tr>
<td>First full scale commercial test unit running</td>
<td>2012</td>
</tr>
<tr>
<td>Application testing with KTH and others on full scale units</td>
<td>2012 -</td>
</tr>
<tr>
<td>Input from other customers testing</td>
<td>2012 - 2013</td>
</tr>
<tr>
<td>Design of an improved module starts</td>
<td>2013</td>
</tr>
<tr>
<td>Tests of the new module – internal and customers</td>
<td>2013 - 2015</td>
</tr>
<tr>
<td>Removal of nanoparticles verified by several third parties</td>
<td>2014 - 2015</td>
</tr>
<tr>
<td>Prototypes of new module built and tested</td>
<td>2016</td>
</tr>
<tr>
<td>Tests of concentration of difficult wastes start at imec</td>
<td>2016</td>
</tr>
<tr>
<td>First commercial full scale of new module (alum tools)</td>
<td>2017</td>
</tr>
<tr>
<td>Imec and other third party tests of new commercial modules</td>
<td>2017</td>
</tr>
<tr>
<td>Design optimization of new modules</td>
<td>2017</td>
</tr>
<tr>
<td>Manufacture of commercial equipment (steel tools)</td>
<td>2018</td>
</tr>
<tr>
<td>Imec and other third party tests of final commercial equipment</td>
<td>2018</td>
</tr>
<tr>
<td>Commercial launch of equipment for waste treatment</td>
<td>2019</td>
</tr>
<tr>
<td>Commercial launch of equipment for removal of nanoparticles</td>
<td>2019</td>
</tr>
<tr>
<td>Commercial launch of equipment for manufacture of UPW</td>
<td>2020</td>
</tr>
<tr>
<td>Commercial launch if recycling and ZLD – “from waste to UPW”</td>
<td>2021</td>
</tr>
</tbody>
</table>
2 The needs of the industry

We have established contacts in and made a special study of the semiconductor industry because they have the highest demand on purity and also probably the most poisonous waste water. Both these aspects create problems for the industry. Solving these problems is urgent and therefore this particular industry is a good market entry for Xzero technology.

However, the need to treat poisonous waste water and to make pure water applies to all of the nanoelectronics industry and, indeed, to many other industries as well, such as for instance the pharmaceutical and the chemical. The need to make pure water and to save on water use and to conserve materials is general and a target for later development of ZLD technology.

The semiconductor industry
The semiconductor industry's historic cost reductions have enabled the mobile and interconnected society we live in.

Dale Ford, IHS Technology, 2015 (see Appendixes)

The main reason for the reduction of costs for processing power has been the astounding increase in numbers of transistors (switches between 0 and 1, between off and on) on each semiconductor. It has grown from initially tens, to hundreds, to thousands and now to billions. This explosive growth was predicted by Moore’s (one of the co-founders of Intel) law
already 50 years ago which states that the number of transistors on a semiconductor will double every 18 to 24 months without increase in cost. And it has.

This can be depicted as the minimisation of semiconductors by compaction enabled by increasingly smaller transistors by a constant reduction in line width between the conductive parts in the transistor, between off and on.

The main explanation to the advances in computational speed and power is therefore that the continuous decrease in line-widths has reduced the distance that a signal has to travel and vastly increased the number of signals in a given volume of hard-ware.

**WORLD-LEADING NANOELECTRONICS RESEARCH**

*Extreme miniaturization is the secret of progress in electronics. Published with permission from imec.*

**The 450 program**

*The 450 program is a major step in microelectronics development that will require entirely new manufacturing equipment at all fronts.*
In the next major transition – the 450-program – the semiconductor industry needs to change everything from what is well-tried and proven today. One present worry is that semiconductors may be destroyed by small particles in the process water that cannot be removed by state-of-the-art water treatment equipment.

There is a need for a technology that removes these particles. The same particles must also be removed from the waste water. Otherwise the water cannot be recycled. Recycling will bring many benefits to the 450 program because amounts of water used will grow and the cost of rare material in the effluent will also grow with more and more exotic materials coming into use to meet the requirements of continued miniaturization. Another important aspect is the growing concern for preventing pollution of recipients.

In order to reduce costs per chip, wafer sizes have increased from 125 mm in 1972, 150 in 1983, 200 in 1990 to 300 in 2001 and the next step is 450 mm. Increase in wafer size should each time lead to a 30% reduction in chip manufacturing costs to be commercially viable.

Although no exact calculations are possible, the general view is that the transition to the new standards is costing anything between $ 20 and $ 40 billion and unless a 30% reduction in chip costs can be achieved, the process is not commercially justified. These potential gains cannot be actualised without efficiency of high yield rates.

Five companies have this far joined a consortium to take the next major step in semiconductor development. The consortium is called the Global 450 Consortium (G450C). The members are Intel, GLOBALFOUNDRIES, Samsung, Taiwan Semiconductor Manufacturing Company (TSMC) and IBM.

The purpose of G450C is to develop technology for manufacture of sub-20 nanometre semiconductors on 450 mm wafers.

Semiconductors are first manufactured in quantity on a silicon wafer and then finally cut out and packaged into separate products.

The most common wafer size today is 300 mm. A 300 mm wafer will contain around 1400 separate dies. The 450 will contain around 3400. Because of this scaling effect, the processing becomes more economical it is forecasted that by around 2026 usage of this wafer size will equal that of 300 mm.

This transition will inevitably lead to many opportunities for European suppliers to the semiconductor industry, both in the building of new 450mm fabs and also in improvements to existing 300 mm fabs derived from the same new technologies and techniques.

Wafer size transitions have historically occurred on about a 10–year cycle. Larger wafers are developed for economies of scale required to defray higher costs of more intensive semiconductors.

As pictured in the following chart, the transition to 450 mm wafers late in the decade is already later in relation to previous transitions. The 450 mm wafer ramp up is now expected to be in 2017-2018 for early adopters.
History of wafer capacity for each wafer size transition.

On average, a 30% cost reduction was seen with the implementation of 300 mm wafers from the previous 200 mm cost basis. Some semiconductor manufacturers reported even greater cost benefits. The industry consensus is that the 450 mm wafer can provide similar cost reduction opportunities.

The cost and performance advantage from the manufacturing productivity enabled by the 450 mm transition will allow the semiconductor industry to continue to migrate to advanced technology nodes. This will be a key component of maintaining the continued progress in microelectronics development that is described in Moore's Law.

For the future of the semiconductor industry, not only wafer size and line width are important. Lithography has recently moved from spectrums of several hundred nm using light in the deep ultralight spectrum to the extreme ultraviolet spectrum (EUV) with wavelengths of 13.5 nm and has potential to be tweaked to below 10 nm. In addition there are many other smaller areas that are interconnected with these three major developments:

- **Lithography** – EUV
- **Node architecture** – sub-20 nm
- **Wafer fabrication** – 450

Miniatrurization of semiconductors, which requires new materials and chemicals that are difficult to remove from water, combined with the 450-program (road map taking semiconductors from 40 to 10 nm and wafers from 300 to 450 mm) is expected to increase the environmental impact of this industry even further. The new wafers will consume far larger amounts of water while the architecture of the semiconductors raises further standards of purity required as well as contaminants added during the process that have to be removed.

Cost of fabs is expected to be increased from € 0.9 billion for 300 fabs to € 14 billion for 450 fabs (also with increased capacity) over 20 years and of typical water systems from € 9 million to € 55 million. As each new wafer size was introduced there were more than 30%
savings in semiconductor costs. Real proportionate cost of water purification systems has been and is falling when compared to fab costs.

The fabrication of semiconductors became a viable business around 1960. It has since grown to be the €306 billion industry it is today\(^2\). The semiconductor industry is widely recognized as a key driver for economic growth in its role as enabler for the whole electronics value chain representing 10% of world GDP.

The €306 billion semiconductor industry is undertaking several parallel developments. The industry narrows line width, advances architecture, uses new materials and chemicals, new manufacturing processes and equipment to produce more powerful smaller semiconductors. What is called the 450 program is a major paradigmatic change for the semiconductor industry requiring innovation on all fronts. Earlier developments marked by programs for the 300, 200 and 150 have paved the way for the electronics dominated world today. The 450 offers yet another leap forwards in technology.

The new semiconductors being developed use new materials and architecture to produce semiconductors that are much faster, perform more functions and integrate processes. Accomplished mainly through finer lines, materials and interconnects of higher conductivity, and multi layering. This makes them very desirable and critical to competition in trillions of dollars of electronic products that use them but it also makes them potentially substantially more expensive. That necessitates producing on a larger wafer to avail economies of scale sufficient to reduce costs on a like for like basis. The cycle described takes place at least once every ten years in the past four decades and results in more electronic power for less money.

Changes in the process also have implications for the volume of UPW needed and the way in which it is used, an example being the increased importance of the planarization by CMP (chemical mechanical planarization that prepares wafers after each step for the next layer) steps particularly with increased layering, that use more UPW. Basically, after each step such as deposition, etching or layering, the surface has to be cleaned and levelled and cleaned before the next step can be undertaken.

The economies of larger wafers defray costs of producing more advanced semiconductors. Each 450 fab will produce more semiconductors than fabs working on smaller wafer sizes. In the way of illustration, assuming 45,000 wafer starts per month and 3,400 dies per wafer, at €23 per die, the annual revenues of a 450 mm fab will be €41.8 billion in contrast to the smaller 300 mm fabs which may have an annual revenue of €14.2 billion.

\(^2\) World Semiconductor Trade Statistics Organisation (WSTS)
The launch of 450 is delayed as can be seen from this prediction but according to most experts it is on its way. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16\textsuperscript{th} February 2012.

**Use of water in the manufacture of semiconductors**

“Produced ultrapure water (UPW) is utilized in cleaning and etching processes and to wash and rinse semiconductor parts throughout the manufacturing cycle. Treating raw water to the purity levels required in semiconductor manufacturing demands a robust sequence of advanced processes and water treatment technologies for removing contaminants, minerals, microorganisms, and trace organic and nonorganic chemicals, including other nanoscale particles.”


More than 400 billion litres of water is used annually by the semiconductor industry and most of it must be absolutely free of contaminants.

Semiconductor facilities consume a great deal of water for a variety of purposes that include water for fab rinse, scrubbers, cooling and landscaping. A large portion of the water in semiconductor production is used to produce Ultrapure Water (UPW). Even in the process to produce UPW, the impurities separated from feed water reduce the volume of usable UPW. Between 60 and 75 percent of the feed becomes UPW. The rest is wasted.

This water is employed for rinsing the semiconductors around a hundred times or more during production. The rinse water must be free from contaminants. It needs to be as pure as possible, pure being a relative term, and demand on degree of purity is increasing as the semiconductor architecture gets denser. That is why the Semiconductor Industry is willing to pay substantially more for their water than is paid by
other industries. Costs for semiconductor water are for instance over 30% more than for pharmaceutical water, 0.8 € cents per litre as compared to 0.5 € cents per litre.

![Image of a clean manufacturing facility with people in protective clothing and equipment](image)

*The water must be even cleaner than everything else in the production facility. Here a picture from imec’s manufacturing facility. Published with permission from imec.*

Water consumption in the manufacturing process is estimated to over 400 billion litres annually on a global scale with Europe accounting for roughly 40 billion litres on a pro rata basis. A host of toxic materials and chemicals are used in the fabrication process, ranging from arsenic to harsh acids, which will be present in the effluent.

<table>
<thead>
<tr>
<th>Water consumption for the manufacture of semiconductors</th>
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<tbody>
<tr>
<td>Present 300 mm fab 1 500 000 liters per hour</td>
</tr>
<tr>
<td>UPW use in future 450 mm fabs is estimated to be larger</td>
</tr>
<tr>
<td>Per 300 mm wafer around 10 000 liters total water use</td>
</tr>
<tr>
<td>Per 450 mm wafer around 20 000 is expected</td>
</tr>
<tr>
<td>Per clean per wafer 44 liters of UPW water use</td>
</tr>
<tr>
<td>Continuous supply for one tool is estimated to approximately 2 000 litres per hour</td>
</tr>
</tbody>
</table>
It is established in the industry that a liquid layer remaining on the wafer will deposit all or most particles contained in that layer and potentially cause a defect. Therefore the removal of nanoparticles is the most important task for UPW.

However, recent findings are that also dissolved oxygen (DO2) and hydrogen peroxide (H2O2) can cause defects. To be on the safe side, Xzero therefore also is also testing the removal of DO2 and H2O2 although these are possible to remove with conventional equipment.

Post silicon development

Already now thousands of patents have been filed for technologies that will drive advancements at 7 nm and beyond silicon. These could lead to dramatically smaller, faster and more powerful semiconductor (nanoelectronics) products with technologies such as quantum computing, neurosynaptic computing, silicon photonics, carbon nanotubes, III-V technologies, low power transistors and graphene. As far as can be seen these technologies will not reduce the need for UPW and certainly not the need for absolutely pure UPW, free from all nanoparticles.

The most expensive defect

The most expensive defect is the one that wasn't detected inline. Today there are no reliable ways to detect nanoparticles inline. One percentage point of rejection would amount to a loss of € 418 million per annum in the new type of fab (450).

Defects have always been problematic in the yield ramp for chip designs, but the ability to find them is becoming more difficult and expensive at each node. And it will be especially challenging at 10nm and beyond.
The emergence of 3D NAND and finFETs presents some new and difficult challenges for wafer inspection. “In a planar device, you can see every defect,” said Lior Engel, vice president of strategic marketing for the Process Diagnostics and Control Business unit at Applied Materials. “With 3D devices, the defects are becoming more embedded. You don’t have a line of sight to these defects. In addition, chipmakers also want to put as much stuff on the chip as possible. You may have SRAM, embedded DRAM and dense logic. When you optically hit the device with light and collect it, each one may behave differently. On top of that, you have more and more materials. So you may miss defects.” Finding Defects Is Getting Harder, September 17th, 2015 - By: Mark LaPedus, Semiconductor Engineering

Whether 300mm fabs are retrofitted, new 300mm fabs are built or 450mm are built, the drive for lower line widths will require less nanocontamination and there is a strong market for Xzero equipment. Defects will be lethal in all instances.

**European R&D SWOT**

<table>
<thead>
<tr>
<th>Strengths (strongest first)</th>
<th>Opportunities</th>
</tr>
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<tbody>
<tr>
<td>Lithography – optics and slage</td>
<td>E-beam lithography</td>
</tr>
<tr>
<td>Device physics, Device design</td>
<td>Mask technologies for EUV</td>
</tr>
<tr>
<td>Device variance calculation, Standard cell design</td>
<td>Nano-imprinting</td>
</tr>
<tr>
<td>Bulk &amp; Wafer manufacture, especially SOI</td>
<td>Post-GMOS – carbon based route (US mostly going with silicon based route)</td>
</tr>
<tr>
<td>Deposition/Thermal Treatment, ALD and emerging Deposition techniques</td>
<td>Quantum devices</td>
</tr>
<tr>
<td>High purity Chemicals and Gases</td>
<td>Resist cleaning after implant</td>
</tr>
<tr>
<td>New Materials such as Graphene, Ceramics &amp; Lo-k materials</td>
<td></td>
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<tr>
<td>3D technologies such as TSV</td>
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<tr>
<td>Facility Engineering</td>
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<tr>
<td>Advanced process control</td>
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<tr>
<td>Process Module Development/Integration</td>
<td></td>
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<tr>
<td>Auxiliaries (e.g. vacuum pumps)</td>
<td></td>
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<tr>
<td>Other Consumables</td>
<td></td>
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<tr>
<td>Surface Processing and Cleaning</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th>Current weaknesses (weakest first)</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memristor based technologies (despite EU FP7/ENIAC funded projects)</td>
<td>Lack of consolidated European plan</td>
</tr>
<tr>
<td>Feb Automation</td>
<td>Risk that the G40C in Albany makes CNSE the dominant place in advanced process development</td>
</tr>
<tr>
<td>New generation of M.E.S</td>
<td>EUV lasers don’t meet development timescales</td>
</tr>
<tr>
<td>Atomic Layer Surface Cleaning</td>
<td>Japan government backing for alternative EUV solution</td>
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<tr>
<td>Combined Dry and Wet Cleaning</td>
<td>Lack of suitably qualified engineers in Europe</td>
</tr>
<tr>
<td>Metrology and Analytical Methods</td>
<td>Delay in funding by PAs</td>
</tr>
<tr>
<td>Mask making</td>
<td>Other funding issues as identified by KET</td>
</tr>
</tbody>
</table>

Source: Future Horizons/DECISION

The Swot observes the weakness in cleaning technology that is addressed by Xzero. Without excellence in cleaning, sub-20 nano semiconductor industry will have lower yields than competitors and will definitely succumb to competitors. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.
A summarized explanation of a typical basic semiconductor fabrication process. In reality there are around one hundred distinct steps and between each step debris from many various processes such as coating, etching and depositing has to be cleaned by the use of UPW to avoid faults in the finished semiconductor products. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.

Also the constant increase in number of steps in the manufacturing process increases the risk for defects whereby the economic importance of water treatment increases.
"With increasing process steps, the predicted cumulative yield will drop for advanced design nodes if the per-step yield stays constant at 28nm levels.” Yield and cost challenges at 16nm and beyond, ROBERT CAPPEL and CATHY PERRY-SULLIVAN, KLA-Tencor Corp., Solid State Technology 2016/02

Present development

Extreme purity
The first products with 16/14 nm nodes reached the market in 2015 and planning is well under way for 10 nm. The 16/14 are built with three-dimensional so called finFET (a non-planar (with a fin) field-effect transistor) architecture. The most immediate plan is to continue using the same architecture for the 10, 7 and 5 nodes but also other types of architecture are pursued in the labs.

Originally, 5 nm was planned for launch in 2020 but the launch date has been delayed a few years. However, that 7 nm will be on the market in 2020 is fairly certain. In 2016, there are reports of the first manufactures of 7 nm in trial series.

The reason for the delays are that the R&D for nodes below 14 nm is extremely difficult and costly. It requires large improvements in the finFET architecture or entirely new types of architecture and also entirely new solutions in lithography probably along the line of Extreme Ultraviolet (EUV) and still unknown solutions in interconnect.

Although the gate lengths for each node will be slightly larger than the node number, ramp up of all these nodes 10, 7 and 5 will suffer if there is not an improved technology around to remove the killer particles, i.e. particles 10 nm or smaller.

Xzero is therefore an important part in this enormous investment.

Recycle of Ultrapure water
The race towards 5 nm will also speed up the need to save water by recycling and reuse. The killer particles must be removed from the spent water to make it possible to recycle the water in the process. Otherwise the water can only be recovered for other possible uses if not just cleaned before let out into the recipient. With a complete recycle new fabs are also less dependent on available raw water sources and reduce conflicts with local authorities.

Today many semiconductor plants are situated in areas where water is in short supply.
Recovery of critical materials

The semiconductor industry already uses at least sixty different elements and the new developments will require use of additional elements. Some of these (i.e. Terbium and Holmium) are in the category rare earth elements, some of which are or may become in short supply. With the recycle zero liquid discharge system presently under development by Xzero, minerals and chemicals can be salvaged instead of becoming pollutants.

This makes reuse a profitable, if not necessary, option. Development in this area is followed by the Critical Materials Council for Semiconductor Device Fabricators (http://cmcfabs.org/).

Some of the materials recovered will be critical for the growth of the EU electronic and semiconductor industries. Among these are Gallium, Germanium and Indium. These are essential components in for instance such diverse products as integrated circuits, fiber optics, photovoltaics and light emitting diodes.

The Xzero system will concentrate and transform fab processing waste into a form that is usable by the industry for further refining for use in such advanced components.

Since primary production of Ga, In and Ge is highly controlled by a few countries, mostly outside of Europe, recycling systems to reclaim these materials from primary semiconductor manufacturing waste is needed to secure supply.

EU legislation is already in place to increase recovery. Directive 2008/98/EC establishes the five-step waste hierarchy, in which the most sustainable step is the waste avoidance and the second is recovery by reusing and recycling. This is reflected in many EU programs that could provide input to the development of Xzero’s UltraWat program. Among these are RECLAIM and RECYVAL-NANO.

Xzero is planning to follow up the recovery aspects with Umicore a global European based materials technology and recycling group, with more than 14,000 employees in 38 countries and a turnover of €9.8 billion.
3 Markets in rapid development

Xzero growth potential

The growth potential for the Xzero systems and for the company depends on readiness of commercial products, demonstration in situ and rate of introduction in manufacturing facilities. The market itself is growing and is forecast to keep increasing. A gradual rise in market share has been assumed in the financial analysis but there are determinants that the company cannot control. The latter include the financial analysis by leading industry producers as to impact of nano particles on yield rates.

The urgency that leading producers ascribe to removal of nano particles and, in turn, that depends on their success in developing the next generation of end products, will determine the ease by which Xzero can ramp up production and sales.

If development of new technology is slow it may take some time until yield loss from nano particles become a decisive issue. During that time Xzero will build up sales in the market for treatment of difficult waste water where Xzero has a proven advantage and in removal of nanoparticles where Xzero, at present, has no competition. Once recognized as a leading supplier, Xzero will aim at market shares of the total UPW market by offering systems that make purer and more reliable UPW and also permit recycling of the waste water.

The semiconductor market

The US semiconductor industry is the leading supplier of semiconductors to the world, with a majority of global market share. Semiconductors are the number three of US manufactured export over the last five years and 2014 sales were € 157.2 billion and had 51 percent of the €305.8 billion global market. US sales are estimated to grow seven percent in 2015 and five percent in 2016. Nine out of the top 20 semiconductor companies are from the US. The stiffest competition to US industry currently comes from South Korea and Taiwan. The industries in Japan and the EU were once formidable competitors, but not anymore, at least in the short-term perspective. ³

China represents half of the world market for semiconductors, valued as being over €168 billion; domestic semiconductor production in China only supplies nine percent of the country’s consumption, with imports supplying the balance. The Government of China is determined to alter this imbalance and according to McKinsey is allocating €155 billion to develop the Chinese Semiconductor industry.

The Western Hemisphere is the second largest - €56 billion - end market for semiconductors; followed by Korea at €31.8 billion, Europe at €31.7 billion, Japan at €31.7 billion, and Taiwan at €18.2 billion.

Top markets for US semiconductor sales include China, Japan, Germany, and South Korea. All of these countries exhibit vast amounts of electronics production. China has been called the “factory of the world” when it comes to electronics, and currently has the fastest rate of growth in demand for smartphones and consumer electronics; Japan has plenty of consumer electronics production as well as a very large automobile manufacturing sector; Germany has

³ ITA 2015 Market Report
the largest automobile manufacturing industry in Europe as well as the largest industrial base; and Korea is a powerhouse in consumer electronics manufacturing and has a vibrant automobile manufacturing industry.

The European semiconductor industry is greatly diminished (currently Europe's share of the global semiconductor market is less than 10 percent), as quite a bit of production has moved to Asia, but the European Commission has taken action to counter this trend with the 2013 launch of its “10/100/20” strategy to increase Europe’s share of the global semiconductor market to 20 percent by 2020.

Most industrial countries recognise the key importance of having an advanced semiconductor industry on which a competitive electronics industry can thrive. It is generally accepted as being of strategic importance. That is why newly industrialising countries like China and India are allocating billions of dollars to assist their presence in the market.

### New markets

Apart from the traditional semiconductor companies that traditionally mainly have concentrated on processors and memories, a whole new set of manufacturers of a very varied assortment of semiconductor devise are coming forward on the market.

Also these companies will need the best UPW as their technology develops. According to Solid State Technologies, reduction in the size of electronic devices, growing mobile and consumer electronic markets and high amount of material saving are key drivers for the growth of a new thin wafer market for the manufacture of application such as MEMS (microelectromechanical systems, soon to be called nanoelectromechanical systems - NEMS), CMOS (Complementary metal–oxide–semiconductor) Image Sensors, RF Devices, LEDs and Interposers (new types of interconnect).

Major players in this market are LG Siltronic, Inc. (South Korea), Shin-Etsu Chemical Co. (Japan), Siltronic AG (Germany), Sumco Corporation (Japan), Sunedision Semiconductor Ltd. (U.S.), SUSS Microtec AG (Germany), Lintec Corporation (Japan), Disco Corporation (Japan), 3M (U.S.), Applied Materials, Inc. (U.S.), Nissan Chemical Corporation (Japan), Synova (Switzerland), EV Group (U.S.), Brewer Science, Inc. (U.S.), and Ulvac GmbH (Germany).
M2M (machine to machine) and IoT (internet of Things) are names for clusters of applications in IT that all incorporate semiconductor (IC) technology. For a long time there has been a debate on how significant these developments are and will become. In any case we will see more of both. How much is difficult to say, but new devices in this area are continuously launched.

A development that shows great promise is SoC (System-on-a-Chip) and PSoC (Programmable System-on-Chip), i.e. devices where many different components - digital, analog, mixed-signal, radio-frequency - are integrated into a single chip.

Another area to consider is OTP (one-time programmable non-volatile memory) for driverless vehicles.

Semiconductors technology is migrating from its origins in computers and mobiles to all aspects of consumer and industrial use. This is definitely a strong driver for the market.

![Application Segment By Semiconductor Technology](image)


This table gives a good picture of how the semiconductor industry has diverged from its early manufacture of “processors and memories for computers” to large diversity of applications. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.
Computers now constitute a small part of semiconductor use. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.

This table illustrates that semiconductors are the back-bone of modern industry. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.
The market for water purifying equipment in the semiconductor industry

The world market for semiconductor manufacturing equipment grew from €28.9 to €34.1 billion from 2013 to 2014, and is expected to reach €39.9 (17.1 percent increase) in 2015. After flattening in 2016, the market is expected to enter another cyclical upturn.

A wafer has to be washed at every stage of processing, for example after all depositing, etching and planarization. The wash has to be with as clean water as possible. As line widths narrow, the smaller the particles that must be excluded. Therefore the semiconductor industry uses large amounts of water.

McIlvaine World Markets report that in 2012 there were € 1,274 million in water system sales to the industry. Given a 13% rate of annual growth, in 2015 it is estimated that there are € 1, 656 million of sales of water systems to the industry.

With a 13% rate of growth, introduction of a new wafer and line size will cause a surge in capital investment beyond the projections given below, when the new 450 factories are ready, expected soon after 2018.

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<td>Annual Systems Sales</td>
<td>13%</td>
<td>2,057</td>
<td>2,324</td>
<td>2,627</td>
<td>2,968</td>
<td>3,354</td>
<td>3,790</td>
<td>4,283</td>
<td>4,839</td>
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Recycling of water

Since Xzero removes everything including nanoparticles, the purified water can be recycled as new process (rinse) water. This will reduce water stress. Xzero technology will also enable or increase recovery and reuse of materials.

The target for Xzero is zero liquid discharge (ZLD), which means that the millions of litres per day of water that is used in a semiconductor factory will be handled in a closed loop.

Traditionally some type of evaporation is used as a last step in a ZLD system. However another prospect is crystallization where waste water is concentrated in a recirculation process until solids precipitate. This is a technology which fits better with Xzero technology than evaporation.

While in the past water has been available from utilities at nominal rates, regulations increasingly specify quality for water that is returned after use. The major cost lies in removing contaminants. However, both costs are rising although it cannot yet be quantified by precisely how much.

Extended markets

After introduction in the semiconductor industry, the results can be transferred to many other industries. References from the world leading semiconductor industry will pave the way in marketing and initial sales to the semiconductor industry will bring future prices of Xzero equipment down.

Even though the concentration factor is higher than for other filter technologies, the treatment will ultimately result in sludge. The sludge will have to be de-watered by known technologies, such as filter press, crystallization and evaporation. This way all water – excepting leaks - can be recirculated and the sludge can be used for recovery. Valuable materials that can be extracted to be reused. Toxic materials that cannot be reused can be deposited safely.

This will have a great impact both in restricting environmental pollution and in reducing global water stress.
4 Marketing in co-operation with major stakeholders

Cooperation with imec

The initial project at imec is testing Xzero equipment for treatment of waste water from imec's nanoelectronics manufacturing plant. At present we are testing the most difficult waste water which contains Tetramethylammonium hydroxide (TMAH). TMAH is used in large quantities for etching in the industry and is very difficult to remove by conventional purification methods. Imec therefore sends large quantities of waste water containing TMAH for destruction which is costly.

The first step in this project will be to concentrate the TMAH and 9WTMA waste in order to reduce destruction costs.

The second will be to completely separate components from the waste water and reuse both (all) components. According to imec, however, even just reducing the amount that has to be sent to disposal will entail a big market opportunity for Xzero.

The activity started with imec sending a sample to Xzero in Stockholm. Xzero cleaned the water and sent it back for imec to analyze the results. Imec was pleased with the result and therefore sent one of their staff to Stockholm to make additional test to confirm the results. Also these tests were successful and it was decided to test a pilot plant on site at imec.

In April 2016 Xzero installed a pilot plant at imec. Also the tests with the pilot plant at imec were successful and Xzero delivered a new modified test unit in August 2016. This unit contains prototypes of the modules that Xzero is presently setting up for commercial production. A final commercial unit for the treatment of TMAH and other wastes will be delivered during the first half of 2017. After initial testing, treatment and recovery of semiconductor waste water can start on an experimental basis in the fourth Q of 2017.

At that point, the recovered water is safe for depositing in nature and work will be done to bring it to UPW level. Once that has been achieved there will be a closed water system.

While Xzero builds the equipment, imec will supply designs, equipment and personnel for the testing and also analyze the risk factors in the proposed processes.

The relationship with imec is not a partnership and it is not sub-contracting. Xzero makes the equipment, ships it, installs it and services it. Imec suggests and decides on research targets, tests the equipment and covers all costs for running and testing.

For Xzero it is a great opportunity to get equipment verified and information about the results disseminated.

For imec, the co-operation is part of fulfilling their task to promote European nanoelectronics industry.

The information of Xzero technology will be supplied to the imec network and Xzero will also be in direct contact with already interested parties in order to offer them to buy test units of the commercialized equipment for industrial in situ demonstrations. Among these will be

Among end users: TSMC in Taiwan, Intel in the US and Global Foundries in the US

And among integrators: M + W Group of Germany, Christ of Holland (Ovivo group), Veolia of France, Organo, Sumitomo and Hitachi in Japan, Entegris of the US.
Market entry
The best method of entering the market will be in those functions for which Xzero has the greatest demonstrated advantage. The goal is to introduce use of Xzero based systems in fabrication plants in the same sequence as they are presently being verified in full scale tests. The starting points would be, on one hand, nano particle removal from UPW and, on the other hand, treatment of selected challenging waste streams. In these two areas Xzero would seek to perform tasks that no existing system can and its ability to do so would have been proven in the initial co-operation with imec.

At present the industry pays in average 0.6 €c per litre for UPW at point of use. Xzero can more than meet this criteria and this has long been Xzero’s main target. Under the development work, a new problem has been identified in the need to remove nano particles. A great deal of money is being spent on isolating, measuring and removing nano particles. This step will further increase costs, by how much is unknown, as no existing system is entirely capable for the task. No one knows the precise impact these particles have on yield rates but it is agreed that sooner or later they must harm yield rates and that is why the working on tackling them.

Xzero has been told by an industry leader that they would like any ability to reduce or eliminate particles from UPW to be proven and the proof would be a decisive consideration on use of the system. The cost of doing so is bound to be negligible when compared to anticipated savings from a better yield rate.

At the same time, the industry has recognised that toxic waste removal from spent water is required and disposal takes place at a cost. By concentrating the waste, Xzero can reduce disposal costs and imec, for one, is willing to pay to find a way.

Market research undertaken for Xzero has confirmed a willingness to pay in the above steps. Potential buyers concentrate on solving the problem first and then to minimize what they have to pay for the solution.

In addition, the great increase in nano particles in the waste waters will soon become a problem for industry because of increasingly restrictive regulations. The regulators are already expressing great worry for the consequences of nano particles in waste waters since nano particles have been proven to easily travel through cell membranes in animals and humans. Exactly what the dangers are have not yet been fully researched but that there are serious dangers is obvious.

Market research
From intimate contacts with the industry Xzero has found out the following major requirements from the industry.

To consider changing to a new technology at all, the new technology must offer considerable (disruptive) benefits. In order to be sure to meet this requirement, Xzero has fine-tuned its technology in cooperation with leading suppliers and research institutes in the industry. The disruptive benefits that Xzero offer is total removal of nanoparticles which in turn enables complete recycling of the water and recovery of valuable minerals in a closed loop.

Because of the very high costs involved in the production, any new utility technology must carry minimal risk – no surprises. In order to reduce risks for commercial customers, Xzero has been
running full scale test systems for many years in co-operation with the Royal Institute of Technology and the Swedish Environmental Research institute. 

*The industry will only buy equipment from well-established solid suppliers.* To build trust, Xzero has established co-operation with reputable manufacturers and, more important, well known integrators that have been nominated by leading semiconductor industries.

*The industry requires a net-work of world-wide instant service.* Xzero has decided to entrust all service and maintenance tasks to the integrators that install the systems.

**Present market approach**

*Xzero has already found interest for its technology among trendsetting companies and influential institutes in the industry.*

With state-of-the art technology it is possible to remove a very large percentage of nanoparticles. Fervent activities are also ongoing to improve the removal. However, Xzero technology is a disruptive leap and a technology that can remove nanoparticles to 100 percent. All tests have this far proven that this may also be possible in practical applications. This would mean a noticeable improvement in yield rates. That is why the semiconductor industry, known for its combined risk aversion and reluctance to use unproven technology is interested already at this stage of development.

Xzero has introduced its technology to two of the leading semiconductor manufacturers and signed mutual non-disclosure agreements with them. Both are members of the Global 450 Consortium.

Xzero is already co-operating with imec that has a leading role in the European 450 program. Imec has tested the technology in lab version and is presently testing a full size prototype.

Initially, marketing will be mainly concentrated through the above mentioned channels. Imec is already testing a prototype and will start testing a first commercial unit in 2017. Others will follow.
Imec builds leading 450 facility

Although the European 450 program is delayed just as the international program in Albany, NY, it is on the go and Xzero is part of it. (Appendix 9)

Market opportunity

With present inspection methods, such as optical an e-beam, it is difficult to detect defects at 20 nm and below during the manufacturing process. A small defect may therefore be undetected during the entire manufacturing process which means that the defect is not seen until the functional testing in the end – and even worse – not until the component has been integrated in a product and at that point because of product failure. Discarding components is of course bad but the loss in consumer confidence from failed product is even worse. Whichever, to reduce risk for defects is of greatest importance and Xzero contributes to this task.

Xzero’s proprietary technology for removing nanoparticles from rinse water will bring major benefits to the semiconductor industry by reducing defects in production and thereby increasing yield rates. A one percent reduction in defects, i.e. a one percent increase in yield at a new 450 mm facility may create an additional € 418 million in annual profits. The investment in Xzero system to achieve this reduction in defects is estimated at €42 million.

Yield rate is becoming even more important than before because every one percentage point of rejection would amount to a loss of € 418 million per annum in the new type of fab (450) while it amounted to € 130 million in a 300 mm fab.

Cost of fabs has increased from € 0.9 billion to € 14 billion (also with increased capacity) over 20 years and of typical water systems from € 9 million to € 55 million. As each new wafer size was introduced there were more than 30% savings in semiconductor costs.

The cost of water facilities for the industry is secondary to the impact on fab functioning and most importantly, yield rates. Water engineers aim to providing the best quality water possible and once they are satisfied that the best that technology can offer is being applied,
their remit changes to consistency, no breakdowns and reducing costs. There is remarkable similarity in the UPW systems that different semiconductor companies have adopted. Once an improvement is found it is adopted by all.

The semiconductor industry is prudent when introducing changes in the manufacturing process. Nothing can be allowed to disrupt production as cost of losses are very high. The currently used UPW systems consist of steps including most advanced water purification technologies, added to the UPW system in tandem. Each step was introduced to tackle particular contaminants, but once introduced, the industry is loath to discontinue steps in case there is an adverse reaction in yield rates.

Even if the industry becomes convinced that Xzero could in time substitute some or even many of the current steps, because they must avoid breakdowns, Xzero will begin with being simply added to current systems and to be used for water recovery and reuse.

Reducing pollution and saving water

Except for removal of small nanoparticles, two other ways of introducing the new technology are provided by treatment of used water and niche uses. The semiconductor industry is a major user of utility water and after use has to dispose the contaminated water. Some of the contamination is mild but there are also streams of highly toxic wastes. Treatment of used water divides into recycling, recovery and reuse. Recovery at various levels of purity below UPW can supply need for water for scrubbers and watering grounds or prior to treatment and discharge to the source of the water. Reuse is for some other use at the fab, and recycling is the ideal benchmark since it requires restoring water quality to at least the level of feed water and ideally to the standards of make-up water.

Pressure from utilities to reduce water consumption has led to extensive water recovery, some reuse but negligible recycling. Up to 70% of water is reported as being recovered and used mainly for non fab use in the plants such as in cooling towers, scrubbers and landscape water. The fab spent water which can’t be used is the more highly contaminated water and toxic waste. There is pressure on the semiconductor to clean up this water before its discharge.

Reuse of difficult wastewater streams

“A semiconductor fab at the 450 mm scale requires a tremendous amount of raw water treated to UPW standards, which is very costly,” Till (Ovivo Switzerland) said. “In order to make this more economical, we are looking at ways to reclaim and recycle UPW wastewater, reducing sewerage costs and the amount of raw water needed.”

“Compared to using a city water source, utilizing fab process wastewater to produce UPW may be easier - and more economical - to accomplish, if managed properly”, said David Harris, general manager of the electronics and metals division at Ovivo North America.

“Despite it being very contaminated, you typically know what to expect with segregated UPW wastewater,” Harris said. “In contrast, raw water sources can exhibit variability based on seasonal changes, requiring ongoing adjustments throughout the year. As an example, utility water in farming regions can experience
periodic spikes in fertilizers and urea, which need to be designed for and treated when detected.”

But while considerable opportunity exists for recycling and reuse in future 450 mm facilities, Till said that the wastewater characteristic of today’s newer and more efficient UPW fab processes is also more problematic to treat.

“In 200 mm production, etching and rinsing operations were traditionally conducted in segregated processes with a dedicated drain system for each, producing waste streams that were less complex and easier to manage,” he said. “But in current-day wafer manufacturing using single-wafer tools, processing occurs in a continuous fashion, generating a cocktail of wastewater in one outfall. Formulating an effective solution requires addressing this combination of different contaminants.”

“Understanding the effluent side of semiconductor process tools is becoming more and more important as each step of the semiconductor technology roadmap is achieved,” Peek (Ben Peek, president and CEO of Peek & Associates and a F450C project architect) said. “Today’s state-of-the-art 300 mm fabs use between 2 and 4 million gallons of water per day,” he explained. With the wafer surface area increasing by an order of 2.25 in moving to a 450 mm wafer, water usage could surge to 4.5 to 9 million gallons a day. When dealing with these volumes of water, even small percentage recoveries are important.”

**Ultrapure Water: Transitioning to the 450 mm Wafer Semiconductor Fab, Jeff Gunderson, Industrial WaterWorld, Volume 15, Issue 5, November 2015.**

Xzero is actually testing at imec how to treat the most difficult streams in the fab. Imec has concluded lab tests successfully and installed a prototype unit in April 2016 and an improved one in August 2016.

**Market strategy**

Even though only one of the objectives is necessary for a market launch, Xzero follows three main lines in introducing its technology. The three main objectives are to convince the semiconductor industry:

- That Xzero can remove killer nanoparticles and thus raise yield rates
- That it can recover and re-use fab reject water
- That specific materials can be isolated and either reused or neutralized.

In order to achieve the above objectives, Xzero has to demonstrate its ability, at first at institutions that are recognised by the industry. Since several years we have discussed this matter with imec, and they are presently in early testing of our equipment. Demonstrations at institutions is then to be followed by online demonstrations at fabs. Ongoing demonstrations are directed at removal of hazardous materials, enabling water re-use and removing potentially killer nanoparticles. Because of the complexities in the industry, all the demonstrations must of necessity be undertaken in collaboration with potential customers, system integrators and equipment suppliers including lithography and CMP.

While the technology is being scaled up, it will be introduced to treat water on a smaller scale than an entire fab. There are niche areas in fab water systems that provide entry points for the new technology in the form of especially crucial products with need for exceptional purity or exceptionally toxic or difficult waste streams that need to be taken care of. Introduction is thus likely to be in the form of specific task oriented application.
Xzero marketing strategy is targeted at demonstrating it can remove nanoparticles and is thus worth considering for the UPW commodity water, particularly in development of the narrower width semiconductors.

A second part of the strategy is to target the ability to eliminate specific toxic waste streams, particularly those causing concern to the industry. Equipment has been installed at imec for testing for these purposes. An additional advantage lies in the fact that some of the streams to be tackled have far lower throughput than the massive water consumption of the main plants and Xzero can demonstrate its equipment on a smaller scale.

Recycling spent rinse water from CMP tools offers special opportunities because these rinse waters have higher concentrations of slurry particles than spent rinse water from other fab processes. Compensating for this apparent disadvantage is that the feed water requirements for CMP are not as stringent as for rinse waters fed to the UPW plant. Thus one possibility is to set up a separate water system dedicated to CMP operations in which spent CMP rinse water is treated for particle removal and then used as makeup water for subsequent CMP operations in an independent recycle loop. Xzero has a special advantage in making such dedicated purifying units because it’s technology requires very few components/steps in comparison with the state-of-the art and therefore results in not only in lower cost but also in more manageable footprints.

Information on Xzero’s product is known in the market place and has been presented to the UPW industry as well as quoted in journals. However, the arguments in favour of the technology remain academic and theoretical without, in the first place, third party test results followed by online tests. Only then can the task of scaling up and integration with existing systems begin. The necessary third party tests started in 2015 and are well under way in 2016.

**Market drivers**

The three market drivers that determine introduction of Xzero technology to the industry are:

- the need to remove ever smaller nanoparticles that become a threat to quality;
- more water consumption per wafer necessitated by increased number of steps during production; and
- increased toxicity of some of the materials and chemicals being used.

The industry needs to be satisfied, in the first place, that Xzero offers progress on these vital market drivers and to be convinced over time on the reliability of incorporating Xzero systems. Having accepted the potential benefits, the industry needs to introduce the technology in a way that minimises risks attendant when UPW systems are changed.

There are three market segments within the semiconductor industry that will be addressed initially in the following order:

- Treatment of fab used water
- Premium niche markets such as removal of nanoparticles and particular problem areas
- Commodity Ultrapure Water
The above is the marketing strategy already being pursued. While Clarkson University has tested the ability to remove nanoparticles, imec has made promising tests in treatment of difficult to treat waste water streams.

No semiconductor fab can take the initial risk of relying on a relatively new and radical technology, but once Xzero technology is proven online in specific applications, the market prospects for large scale systems are very good because the cost of a new Xzero UPW system will be negligible compared to its impact on yield rates.

This graph illustrates the increase in Fab costs which makes the issue of defects and yield rates more and more pressing and will motivate semiconductor companies to invest in removal of “killer particles”. Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012. Of course, since 2005 the costs have continued to increase exponentially.

Probably the most important market driver for the introduction of Xzero technology will be the strong general demand for new equipment once the 450 technology is launched. The following graph shows the rapid increase in equipment spending when 300 was launched. Spending surge for 450 technology will certainly not be less.
The graph illustrates the great increase in spending on equipment when the 300 mm wafer technology was introduced. Excerpted from: *Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way*, 16th February 2012.

**Additional markets**

The market for semiconductor Ultrapure Water is very challenging, but also profitable. Xzero has decided to concentrate marketing efforts on this market because it has so very strong marketing arguments. Its main market driver is the need for increased purity in future semiconductor manufacture.

The other of Xzero’s market drivers, i.e. increased consumption of water and increasing toxicity of effluents are relevant also in other potential markets that Xzero’s potential for achieving Zero Liquid Discharge is applicable. These are for instance:


The technical results of these investigations have been made on full scale pilot stage equipment and have been very positive. Once Xzero is well established as a supplier to the semiconductor industry, the company will also venture on these other markets.
5 Technology

Extreme Ultrapure Water
Traditional water systems for semiconductor manufacture have grown extremely complicated, using all available types of state-of-the-art purification technology in consecutive steps. Even so they are unable to remove the smallest nanoparticles safely in a consistent way.

Since the technical set-up is entirely different, the physical process is different and the result is superior, the result of Xzero technology could be called Extreme Ultrapure Water.

Total removal of nanoparticles in the manufacture of Ultrapure Water
Xzero has developed proprietary technology that enables higher purity at the same time as it contributes to savings in energy, water use and cost. Xzero modules combined with proper pre-treatment and polishing will in time present very complex state-of-the-art systems consisting of series of technologies such as Reverse Osmosis and Ion Exchange.

The process
In the core module of its technology, Xzero uses water repellant (hydrophobic) membranes as a barrier for contaminated water. The process takes place at temperatures below 100°C and at ambient pressure.

Hot feed water flows alongside a micro porous, hydrophobic membrane. The surface tension of the hot feed prevents it from entering the membrane. However, part of the water evaporates and, as vapor, passes through the pores of the membrane, where after it condenses on the other side of the membrane.

The driving force in the process is created by a difference in vapor pressure on either side of the membrane which, in turn, is created by the temperature difference between the hot feed and a condensing surface.

The hydrophobic membranes in the Xzero technology create a total barrier for all particles, regardless of size. Even the smallest nanoparticles cannot leave the feed because they cannot overcome the surface tension of the feed. The surface tension acts like a skin on the water surface. By means of heating with heat exchangers parts of the water are continuously vaporized. Single water molecules get enough energy to escape the surface tension. They pass the membrane and are then condensed. Molecules of any other substances that are volatile at the pre-set temperature will also leave the water surface as vapour and may condense into the water on the other side of the membrane. Such molecules must be removed from the feed by degassing before the feed contacts the membrane. Otherwise they will contaminate the water. Some components may foul the system and will have to be removed separately. Other components may break the surface tension of the water and must be modified by chemical means.
The final result is - only water molecules on the condensing side. No particles will be pressured through as in filtration technologies, such as microfiltration, ultrafiltration, nanofiltration and hyperfiltration (reverse osmosis). No particles are entrained with the vapour as in distillation/evaporation technologies.

In contrast to distillation processes the quality of the condensate remains unchanged even up to very high feed concentrations. In contrast to filtration processes, no water enters the membrane, which reduces the need for back-washing and also the need for pre-treatment of the feed. Scaling and fouling will appear. This is tackled by conventional state-of-the-art methods.

Some materials that are crucial in manufacture of semiconductors such as silica, boron and arsenic are generally difficult to separate from water. Other threatening contaminants are small organic non-loaded particles, especially nanoparticles, and acids. All these are removed by the new Xzero technology. They remain in the feed because of the surface tension.

**Systems aspects**

**Pre-treatment**
In pre-treatment we need to remove all volatiles including VOCs, we need to counteract scaling if here are carbonates in the feed, we need to remove biological matter that may foul the system, we need to remove or break up surfactants if there are and we must remove large particles that may clog the system. All these technologies are included in the Xzero systems.

Removal of volatiles is preferably accomplished by use of heat degassing equipment, but also other degassing equipment, i.e. membrane degassers, can be used. It is also possible to change pH to turn some volatiles into non-volatiles before treatment.

To prevent scaling water has to be acidified. Otherwise pre-treatment is limited to remove large contaminants to prevent clogging and to remove biological fouling. If there are surfactants in the water they will break the surface tension and let many types of contaminants through. Surfactants – surface tension reducing chemicals - can for instance be decomposed by Ultraviolet light or Ozone.

**Post-treatment of Ultrapure water**
Post-treatment is limited to UV-equipment to prevent air-borne biological re-contamination and possibly an ultra-filter to prevent air-borne particles to re-contaminate the water.

**Post treatment of concentrate**
Concentrate (waste water) can be treated by crystallizers or evaporators to achieve Zero Liquid Discharge, i.e. that the concentrate is divided into purified water and solids. And the purified water is returned into the loop as feed water to the system.

**Advantages**
There is one main advantage over all other water treatment technologies. If pretreated with degassing, it removes all contaminants with higher efficiency than any other of the existing advanced water technologies – even the small nanoparticles.

Since the process itself takes place at temperatures below 100°C and at ambient pressure, requirements to withstand high temperatures and/or pressures are eliminated. Capital costs of equipment will therefore be low. For the same reason, operation and maintenance of the equipment is less exacting.
The process has high energy intensity, but can be powered by low temperature heat energy thereby utilizing any source of surplus heat. Waste heat sources with temperatures below 100°C can be readily employed as the driving force in the process.

Xzero technology is markedly suited for Zero Liquid Discharge applications because any type of feed can be concentrated to high concentrations.

**Other aspects**

- Lower operating temperatures than conventional distillation
- Lower operating pressure than other membrane separation processes
- Low sensitivity to variations in process variables (e.g. pH and mineral concentration)
- Good to excellent mechanical properties and chemical resistance
- Reduced use of chemicals, filters and other consumables
- Self-regulating process

**Efficiency**

In practical tests, transmembrane flux has been measured from 6 liters per square meter and hour in very low temperature intervals to 70 liters in high intervals. Theoretically possible is approximately 100 liters per square meter and hour. At normal working conditions and for the manufacture of UPW, transmembrane flux can be assumed to be from 10 to 50 liters per square meter and hour. This is similar to the transmembrane efficiency of hyperfiltration (Reverse Osmosis -RO) which is the major component in state-of-the-art UPW systems.

**Cost**

Since Xzero is not in commercial production we have no exact figures for the capital costs. However, since the throughput per square meter membrane does not differ very much between RO and Xzero technology unnecessitates many steps in a state-of-the-art system, the capital cost will be favourable compared to state-of-the art equipment. Since Xzero equipment does not need extensive pre- and post-treatment, also the cost of maintenance and consumables will be less.

The energy use in state-of-the-art UPW water production accounts for 10 – 20 % of total ownership cost. Xzero equipment runs on waste heat from the industry. The energy cost will be considerably lower than for state-of-the-art equipment if waste heat is available. According to published reports from KTH the energy need per 1000 litres of UPW will be around one or two kWh of electricity for pumping and 15 -50 kWh of heat for driving the process.

Xzero based UPW systems would be less expensive than RO based existing systems because they would require fewer steps and are not more expensive. We expect that under commercial production, capital cost of Xzero based systems will be appreciably lower. The target is to make the water at point of use more than one-third lower but the expectation is that costs would be under half existing capital costs.
Pilot runs at The Royal Institute have shown that the equipment uses less than 50% of the electricity of State-of-the-art equipment which all include Reverse Osmosis components with high-power pumps that use much electricity.

Test figures from KTH

<table>
<thead>
<tr>
<th>Hot side</th>
<th>T2</th>
<th>Q kW</th>
<th>Flow</th>
<th>Flow</th>
<th>Temperature</th>
<th>Temperature</th>
<th>Total kW</th>
<th>Total kW</th>
<th>kwh/m3</th>
<th>W/kg</th>
<th>KWh/Kg</th>
<th>W/Kg</th>
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<th>W/kg</th>
<th>KWh/Kg</th>
<th>W/Kg</th>
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<tr>
<td>23/09/2016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Energy need for 1000 litres of water

The energy needed will differ depending on temperatures and flows according to the following values:

- Electricity for pumps: 0.5 - 0.9 kWh
- Hot water in: 630 - 645 kWh
- Warm water out: 620 - 630 kWh
- Heat energy used in desalination process: 6 - 14 kWh

Distributed production

Each waste stream in the semiconductor industry is different and often varies over time. Each tool needs a different quality of UPW and it has to be constantly absolutely pure. Yet, because the complexity and footprint of state-of-the-art technology the waste streams in the fabs are usually treated in one large waste treatment operation. For the same reason, the manufacture
of UPW is normally done in one central plant and then distributed to the various fabs, clean-
rooms, wet benches and tools.

Xzero technology has the advantage to turn any waste stream into perfect UPW in a limited
number of steps. This enables individual treatment of each waste stream. And it enables
individual manufacture of UPW for each process tool. Water treatment can be adapted to the
particular need of each process and can also be located next to the process and sometimes
even be integrated into it.

Distributed use also makes distributed energy supply to each UPW tool possible and
economical. The Xzero equipment can use the significant amounts of waste heat produced by
each tool and it could also use the heat generated by dedicated CHP-generators for the
process tools.

Distributed manufacture of UPW will increase the total resilience and reliability of the
semiconductor manufacturing plant. The cost of a shutdown of a central UPW plant can be
counted in million dollars per day.
Summary of what Xzero technology can contribute to the European 450 program

The requirements for Ultrapure Water listed by the European 450 initiative (EEMI450) are written in italics. Xzero’s ambition in bold.

Contamination and defect free operation
– the main ambition of Xzero

Ultra-low relative energy consumption
– energy use from excess heat

Severe reduction of consumables and operating materials, their re-use and regeneration
– Zero liquid discharge possible with Xzero technology

Waste free or waste reduced processing
– Xzero permits zero liquid discharge and recovery of materials such as metals and acids.

Comprehensive introduction of virtual metrology
– Xzero reduces the dependence on (new) metrology

Ownership improvements
– smaller distributed units permit individual process suppliers (lithography, CMP etc.) to include water treatment directly in their own

Mechanical handling improvements
– Xzero permits distributed manufacture of UPW – therefore less transportation of water volumes

Advanced Process Control (APC)
– only one type of indication needed for process monitoring that is also entirely reliable (one conductivity meter at each Point-of-use)

Innovative maintenance strategies
– no need to maintain a large central water treatment plant, less maintenance in general

Joint assessment for fast ramp-up
– distributed manufacture of UPW permits flexible initial build and possible extension of operations by additions of modules and clusters of modules
Status of Xzero Technology

Since several years, Xzero runs a full scale test unit in Stockholm in co-operation with the Swedish Environmental Research Institute and the Department of Energy technology at the Royal Institute of technology. On the picture is seen six of the ten module unit with project manager Miriam Åslin. The capacity is 10 000 litres per day.

To the left: the first equipment specially designed for the semiconductor industry was built for a project sponsored by EPA and DoD. The tests were conducted at Sandia Laboratories in Albuquerque, NM, USA and showed that Xzero technology could purify semiconductor waste water to new ultrapure water for the semiconductor process. No other known technology can do that. To the right: Another type of module was used for a solar powered desalination demo at University of Texas in El Paso, sponsored by the US Bureau of Reclamation.

Many different on site tests have been performed to verify the technology. From left to right for: Flue-gas concentrate from a power plant in Nyköping, Sweden, Produced water from gas-fields in Doha, Qatar and
brine concentrate from a reverse osmosis desalination plant in Jeddah, Saudi-Arabia. All tests showed excellent separation of contaminants and concentration of brine.

To the left: Small lab units have been sold or lent to technology partners in Sweden, Belgium, Australia and Italy for a diversity of tests.

To the right: A completely inert system has been tested at Clarkson University. On the picture Xzero project manager Miriam Åslin and Clarkson professors Chris Bellona and S.V. Babu.

The second prototype for treatment of difficult wastes, in this case Tetramethylammonium hydroxide (TMAH) was installed at imec in August 2016. Miriam Åslin of Xzero to the right and Jan Coenen of imec to the left.
Test results for Xzero technology

<table>
<thead>
<tr>
<th>Type of contamination</th>
<th>Amount</th>
<th>Result</th>
<th>Method</th>
<th>Detection limit</th>
<th>Test by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>14 000 (after 7 days)</td>
<td>BDL</td>
<td>Membrane filter count</td>
<td>-</td>
<td>National Bacteriologic Laboratory, Stockholm</td>
</tr>
<tr>
<td>Chlorine</td>
<td>3.4 mg/l</td>
<td>BDL</td>
<td>Photometric analysis (Perkin Elmer)</td>
<td>&lt; 0.01 mg/l</td>
<td>Water Protection Ass of South West Finland</td>
</tr>
<tr>
<td>Salt water</td>
<td>31 000 ppm</td>
<td>BDL</td>
<td>Ion chromatography</td>
<td>&lt; 1 ppm</td>
<td>VBB Viak Stockholm</td>
</tr>
<tr>
<td>Trihalomethanes</td>
<td>1 000 µg/l</td>
<td>BDL</td>
<td>Gas chromatography</td>
<td>&lt; 1 µg/l</td>
<td>University of Turku, Finland</td>
</tr>
<tr>
<td>Radon</td>
<td>380 Bq/l</td>
<td>BDL</td>
<td>Alfa detection</td>
<td>&lt; 4 Bq/l</td>
<td>Swedish Radiation Protection Institute</td>
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<tr>
<td>Cesium</td>
<td></td>
<td>BDL</td>
<td>Lithium Drifted Germanium Detector</td>
<td>&lt; 0.1 Bq</td>
<td>Radiation Physics Department, Univ of Lund</td>
</tr>
<tr>
<td>Strontium</td>
<td></td>
<td>BDL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plutonium</td>
<td></td>
<td>BDL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radium</td>
<td>2.4 Bq</td>
<td>BDL</td>
<td></td>
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<tr>
<td>Arsenic +3</td>
<td>10 mg/l</td>
<td>BDL</td>
<td>AAS Graphite</td>
<td>&lt; 0.003 mg/l</td>
<td>Analytica AB, Stockholm</td>
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<tr>
<td>Arsenic +5</td>
<td>10 mg/l</td>
<td>BDL</td>
<td>AAS Graphite</td>
<td>&lt; 0.003 mg/l</td>
<td>Analytica AB, Stockholm</td>
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<tr>
<td>Ag nanoparticles</td>
<td>3100 µg/l</td>
<td>BDL</td>
<td>HPLC</td>
<td>&lt; 2 µg/l</td>
<td>IVL Swedish Environmental Research Institute</td>
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<tr>
<td>SiO₂</td>
<td>10000 µg/l</td>
<td>BDL</td>
<td>AAS</td>
<td>&lt; 5 µg/l</td>
<td>Vattenfall AB, Stockholm</td>
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<tr>
<td>Setralin and 20 other pharmaceutical residuals</td>
<td>4 ng/l</td>
<td>BDL</td>
<td>HPLC</td>
<td>&lt; 0.8 ng/l</td>
<td>IVL Swedish Environmental Research Institute</td>
</tr>
</tbody>
</table>

BDL = below detection limit

Xzero technology has been used in numerous research projects. All these test results have been obtained in one or two steps without pre- or post-treatment. Contaminants with a large range of chemical and physical characteristics have been chosen for inclusion in the table to illustrate the theoretical proposition that all types of contaminants are completely removed.

For the project at hand the removal of nanoparticles is especially relevant. So during 2015 several third party tests have been made trying to detect nanoparticles in by Xzero purified water.

Report on Xzero test with nanoparticles

In the tests below, no extra purification equipment has been used. No degassing, no chemicals, no pretreatment, only a one-step Xzero module. Feed was added to the feed tank. The unit was turned on and permeate collected. All tests performed by third parties.

Ag+ nanoparticles:

Liquid containing 3 100 µg/l Ag+, 5nm and larger. After Xzero no detection in three consecutive tests. Analysis with Atom absorption spectroscopy (AAS). Detection limit was <2 ug/l.

Ag+ and AU+ nanoparticles:
1. Tap water spiked with Ag+ nano particles - 140mg/l with 80% 0.24nm particles and 20% 1-24nm particles. Result <0.1ug/l

2. Tap water spiked with 100% 2nm particles at a concentration of 37mg/l Au+ nano particles. Result < 0.1ug/l

*Test by Swedish Environmental Research Institute in June 2014 with HPLC. The results for nanoparticles have later in the year been verified by tests done with equipment with even more stringent detection levels.*

**Nano tests in 2017**

Since these first test was made several tests have been made in co-operation with KTH, ALS Global, Manta Instruments, Clarkson University and Anton Paar. All tests have verified excellent results. The tests have been done with silver and gold nanoparticles to verify the technology and improve the practical implementation. A program is underway in 2017 for testing of other types of nanoparticles such as polystyrene sphere nanoparticles, silica nanoparticles and other nanoparticles that are of interest in the industry. Since the method is not selective in regard to material or charge, it is expected that all nanoparticles will be removed in the same efficient way.

**Technical program**

**Research**

After a long research activity, Xzero built the first full scale demonstration system in 2011. The system has been tested for several difficult-to-treat contaminants. In parallel Xzero has supported several research programs that have used Xzero technology for dealing with a variety of difficult contaminants. Research into process performance and characterization is now completed, but research to further improve performance continues.

**Technological innovation and scale-up**

Present activities focus on the semiconductor application and involve demonstration, testing, design, prototyping, piloting and scaling-up to bring this innovation to industrial readiness and maturity for market introduction.

In 2014 - 2016 there have been two main activities:

1. Tests of substances of specific importance for the semiconductor industry such as nanoparticles, metals, acids and bases.

2. Design and test of improved scaled-up equipment for the commercial launch.

In 2016 a full scale test unit has been built for and installed at imec. It is used for test of difficult wastes. Another fully commercial unit will be built in the beginning of 2017 to verify the initial tests with difficult wastes. Yet another fully commercial unit will be used in imec’s new 450 mm line for one specific tool and will have the capacity of 600 l/h (personal communication from imec).

In 2017/18 additional full size commercial units will be built and tested. They will have a capacity of 10 000 l/h which is considered a good starting point for a scale up (personal communication from GLOBALFOUNDRIES).
Market launch

A full market launch is expected in 2018-20. Many of the systems will be for specialist purposes and the sizes can be between 100 to 1000 l/h. Since the technology is modular it will be possible to supply the entire need of UPW for a 450 mm plant which can be up to 2,000,000 l/h. It is however expected that the supply in all cases will not be of a central UPW plant but will be divided into distributed units serving single tools, separate clean-rooms or separate waste streams. This in itself is a great innovation and a great advantage for the customers which is allowed by Xzero systems having considerably less steps of technology compared to state-of-the-art systems.
6 IP-protection and ownership

Know-how

The technology has been developed in co-operation with leading industrial companies and research institutes. With each of these, Xzero has an elaborate Non-Disclosure Agreement which guarantees that all results of the co-operation pertaining to Xzero processes and designed equipment becomes Xzero’s property. None of these partners have separate development of similar or conflicting technology. There are no patents or reports that describe similar technology. Xzero owns all results of present development.

By these precautions, Xzero has ensured that the results from both the earlier and present development work are free for Xzero to exploit commercially ('freedom to operate').

Through continuous contacts with industry it is known that no other company or institute is openly developing similar technology. Once the technology is commercialized it will have such advantages that Xzero is expecting others to duplicate the technology trying to circumvent Xzero's IP-protection and patents. This will be counteracted by Xzero by keeping a constant lead in development with the aid of the company’s many and strong partners. Also by keeping latest development results secret as long as possible.

Patents

The first Xzero patent has been granted in Sweden on March 17, 2015 with the number of SE 537 249 C2 and is under process for international applications with the PCT number PCT/SE2014/050916. The following is the official summary.

"Device for producing pure water, where the water to be purified is caused to be membrane distilled using one or more units (1), wherein each of the units comprises a space which on its one side comprises a first disc-shaped wall (4,4’) and on its other side a membrane (3,3’) through which gaseous water can pass but not liquid water, and a second disc-shaped wall (5,10), which walls are disposed on different sides of and at a distance from the membrane, wherein water is led in between the first wall (4,4’) and the membrane (3,3’), and wherein the second wall (5,10) is caused to be colder than the water. The invention is characterized in that the first disc-shaped wall (4,4’) is also a membrane through which gaseous water can pass but not liquid water, in that two adjacent membranes (3, 4; 3’ 4’) are supported by a common frame (6), in that the space between the membranes is provided with an inlet opening (7,7’) for water to be purified and an outlet opening (8,8’), in that the second wall (5,10) is a part of a chamber (9) formed by two parallel walls, in that the chamber is provided with an inlet opening (11,11’) for water which is colder than the water to be purified and provided with an outlet opening (12,12’), and in that chambers (9,9’) are arranged in parallel with the membranes at both sides of the frame (6)."

This patent is general and can be used with any of our module configurations. It protects a method that will make the O&M cost of the equipment lower and will therefore be of advantage in competition.

Several years of research and development in regard to efficiency in throughput and in energy use will be patented when the designs of the next version of commercial modules are finally determined in 2017/18. Until then the technology will be protected by NDA agreements, some of which are already in place.
7 Competition

A disruptive change
Manufacture of UPW and treatment of waste streams have improved greatly during the last decades. In the early days UPW was made by a line of pre-treatment, ion exchange and polishing. Waste water was comparably harmless and often could be disposed of directly into the recipient.

During the years, as higher purity was needed and waste became increasingly toxic, one step after the other has been added and each step has been continuously fine-tuned by incremental innovations. State-of-the-art systems are now extremely sophisticated and complex. Still they do not measure up to the new challenges in the semiconductor industry. Xzero now offers a disruptive change based on a radical change in concept. It is a much less complex concept, but more efficient.

Xzero’s solution is radically different from the state-of-the-art. What we offer is not price competition. We offer better performance, higher quality and greater reliability.

Our equipment contains much fewer components and is therefore less costly to manufacture. It is also less costly to run, without any sacrifices in performance. Because it contains less than half as many sub-components as state-of-the-art the manufacturing the capital cost is less.

Because our core component uses less than half the electricity compared to the state-of-the-art core, which is RO or double pass RO, and because we have no components that use up chemicals, the running cost is also probably less than half that at present.

The bottom line is that even with a healthy profit for Xzero, the cost of water for the customer at point of use is expected to be reduced by at least 30%. In the long run, even greater savings should be possible.

Process intensification
The semiconductor industry uses the most advanced water treatment technologies available. Advancement in efficiency for state-of-the-art water treatment has led to increasingly specialized technologies each tackling different specific contaminants. The semiconductor industry at present uses around 20 steps of 10 different technologies, some like Reverse Osmosis, Ion Exchangers and Activated Carbon more than once.

Initially Xzero would add its technology to existing systems in order to remove those nanoparticles which are not possible to remove with present state-of-the-art systems. Later Xzero will be able to replace some or all of present technologies.
Illustration by Slava Liebman

Typical flow-sheet from Ovivo
A typical State of the art system has about 20 sub-components while an Xzero system has less than ten. Not only the capital cost, but also the cost of maintenance and consumables is therefore less than half in an Xzero system.
Basic Xzero system

This typical Xzero installation will contain considerably fewer components than state-of-the-art installations and will still produce UPW of higher quality and reliability.

Competitors

The various water purification technologies used are each marketed by more than one supplier and represent major sub-sectors that also service other industries. Since each technology has a specific task, competition is more intense between suppliers of any one technology than between the different technologies, especially in the semiconductor industry where virtually all existing state-of-the-art technologies are used in tandem.
At the current stage of development, Xzero is not competing with other water purification technologies. Instead, it has been establishing its ability to match current UPW standards and to go beyond in removal of nanoparticles, to meet a need currently not being met for which a solution is being actively sought.

As to the task of removal of sub-20 nanoparticles, Xzero, at the moment, has no competition. That is why leading institutes and companies are interested in the technology already at this stage of development.

Through use of a combination of technologies, some integrators offer systems that can reclaim up to 70% of fab spent water. The reclaimed water is used as feed water for scrubbers and other such uses but it cannot be recycled as feed to the process (rinse) water.

Xzero has demonstrated at the Sandia National Laboratory on a Sematech/EPA/DoD project that it can reclaim and recycle spent rinse water to UPW feed water standards which are far higher than facility feed water. Recently we have also proven that this can be done even when the spent water contains sub-20 nanoparticles.

There may be new technologies around the corner that have not yet gone public. However, we know from our own research and from published reports that none of the integrators – i.e. GE Water, Kurita, Ovivo, Christ, Veolia, MWGroup and others - today offer equipment that can match Xzero’s in performance.

Because of the great market opportunity in both making Ultrapure Water and in recycling difficult wastes, others will definitely follow once Xzero takes the lead in commercialisation. It will be difficult to stave off all competition with IP-protection. Xzero therefore aims at keeping the lead in developing its technology in regard to increased efficiency and reduction in cost of ownership. This will be possible thanks to the strong research infrastructure with partners that Xzero already has built and will continue to build.

**Summary of advantages**

Xzero equipment has

- Better removal of nanoparticles
- Higher retention of all other contaminants
- Less addition of contaminants from the equipment
- More reliable performance
- Automated quality control

Also

- Fewer treatment steps enable compact equipment and smaller foot-print
- Fewer treatment steps makes it easier to maintain and operate
- Fewer treatment steps enables equipment customized to different needs in the fab
- Fewer treatment steps ensures lower capital cost
- Higher purification efficiency enables recycling of water
- Higher purification efficiency enables closed loop and zero liquid discharge
- Closed loop enables recovery of rare materials
- Compact equipment enables distributed water treatment
- Removal of chemical treatment steps contributes lower running costs
- Use of waste heat contributes to lower running costs and less global warming
8 Management

The company
Xzero was established in 1997 with the sole purpose to develop systems for Ultrapure water for the semiconductor industry. It is today a public non-listed company with approximately 1500 shareholders. Xzero's system is originally based on proprietary technology and then developed in co-operation with other companies and research institutes under extremely lean management in order to be cautious with investor's money in the development phase. Also today Xzero has a lean and efficient management structure.

Creating value for Xzero customers
1. Absolute quality to customer for complete contentment
2. Well thought-out production and delivery
3. Continuous information to customers
4. Creating a recognizable brand and concepts
5. Improve equipment continuously
6. Abreast with latest research
7. Co-operative research with institutes and customers
8. Protect know-how
9. Good relationship with suppliers and sub-contractors

Employees
Xzero has a management structure that reflects the stage of development of the company. The Chairman is the entrepreneur who founded the company and raised finances to translate a technology into a product concept, lab units, prototypes, tests, demonstrations and now into commercial launch.

The CEO is a senior marketing consultant with field experience in USA, Europe, Japan and Korea who has also maintained customer relations for the company for over 16 years.

There are two technical staff, an engineer who supervises development and a research assistant, and one administrative staff. For all specialist tasks in research, design, engineering, construction and IP protection selected consultants mainly from leading Swedish industrial companies are used.

For the industrialisation phase three professional engineers have been employed. After commercial manufacture has been achieved two technical sales persons will immediately be employed to work on the commercialisation programme. After the present industrialisation process, manufacture of proprietary components and assembly of systems will be sub-contracted to one of several European industrial companies selected after tender. We are presently in contact with integrators in order to learn about the industry requirements, but integrators for actual installation of systems will be selected not by us but by the actual customer.

The main task of the company after the first commercial deliveries have been made are close contacts with potential customers, improvement of technology and manufacturing techniques and IP-protection.
In the next chapter it can be seen how Xzero has built an extremely strong development team by partnerships. The same structure will be used during the commercial launch.

**Key persons**

**Vinay Chand (male); Project Leader**

Vinay Chand graduated in Economics in 1966 and completed his Master's degree in International Relations in 1968 from the London School of Economics. He served for one year as a trainee Inspector of Taxes, 9 years as Lecturer/Senior Lecturer at University of the South Bank, London. For 38 years Chand has been a Consultant on Development Projects to, amongst others, EU, World Bank, Asian Development Bank, UNDP, FAO, ITC, USAID, DANIDA, AFD, NORAD, Ausaid, NZaid and the private sector. He has also been CEO of Xzero for 8 years.

**Education:**

- B.Sc.Econ (Hons), London School of Economics and Political Science, London University.

**Aapo Saask (male): Chairman of the Board**

Aapo Saask was born in 1943 in Estonia and presently lives in Sweden. Since 1973, Aapo Saask has developed proprietary technology in water treatment and sustainable energy which has resulted in formation of several private and public companies, which reflect different applications for the technologies developed. One of the main areas of development is a novel water purification and desalination technology called 'Membrane Distillation' (MD).

**Education:**

- BA 1964 at Brown University, Providence, Rhode Island, USA
- Postgraduate Scholarship 1964-65 at Rutgers University, New Jersey, USA
- MA Political Science and Philosophy 1968 at University of Stockholm, Sweden
- M.Sc. in Education 1970 at University of Linkoping, Sweden
- MBA 1973, University of Stockholm, Sweden

**Miriam Aslin (female): systems engineer**

**Education:**

Master in Biology with specialization in Eco-toxicology, 2003

**Work experience:**

Internship at AstraZeneca water treatment plant in 2003

R&D at Xzero since 2004

**Henrik Dolfe (male); technician**

**Education:**

Bachelor in Chemical Engineering, 1989
Bachelor in Informatics, 2005

**Work experience:**

Johnson Matthey Pic; Goteborg, Sweden, (chem. laboratory)
Daimler AG; Stuttgart, Germany (computer/software development)
Xzero AB/Scarab Development AB, Stockholm Sweden (chem. engineer) since 2001
Anna Peira Ohlsson (female), administrator

Education:
Basic Economic Education 1995
Tourism administration 1998

Work experience
Customer service and education administrator, Conferator Kompetens
Travel producer, Haman Scandinavia
Conference hostess, Scandic Hotels

The industrialization team

Mikael Andersson
B.Sc in Electronics
Product Development, all levels
Medical Device projects
Company and staff management
Sales and recruiting
Expert in troubleshooting
Electronics development mentor

Leif Hall
35+ years of mechanical design, Injection moulding,
Plastic welding, Mechatronics, DFA/DFM
High volume production of medical devices
Tolerance critical applications
Machining and sheet metal
Production lines and automation

Peter Nilsson
B.Sc. in Mechanical engineering
Project management - mechatronic devices
Medical device development
ISO 13485
QA and Regulatory affairs

Board of Directors

The Board of Directors consists of Aapo Sääsk, Henrik Unné and Håkan Klingén, the latter two as representatives for the minority shareholders.
**Accountant**
Nexia (nexia.com)
*Johan Isbrand*

**Patent attorney**
Noréns (norens.se)
*Bertil Örtenblad*

**Legal counsel**
Thorelli & Associates (thorelli.com)
*Tom Thorelli*

**Bank**
Swedbank (swedbank.se)
Research in Membrane Distillation at KTH Royal Institute of Technology

Since 2002 the Division of Heat and Power Technology at KTH, under the leadership of Prof. Andrew Martin, has been active in membrane distillation in partnership with Scarab Development AB and its subsidiaries. Research projects have been financed by the Swedish Energy Agency, SIDA, Energiforsk, EU FP6, and others.

Team Members

Prof. Andrew Martin
Head, Division of Heat and Power Technology
Interests: membrane distillation, polygeneration, biomass, solar energy

Ershad Ullah Khan
PhD Candidate
Interests: Combined heat and power technology, polygeneration, thermal power plants, hybrid renewable energy distributed system, water purification, and membrane distillation.

Daniel Minilu Woldemariam
PhD candidate
Research area: Membrane distillation process development for new industrial applications

Alaa Kullab,
PhD, Researcher
Research interests: Water purification, water-energy nexus, solar energy

Uday Kumar N T
Sr. R&D Engineer, RAK Research and Innovation Center, AURAK, UAE
PhD Candidate, KTH
Interests: Solar thermal desalination systems, polygeneration, membrane distillation, water and wastewater treatment
9 Partnerships

Since the final decision on whether to use a new component in production facilities is made by the semiconductor producers, the most important consideration is how to reach that point. From the earliest stage of development, Xzero established and has maintained direct contact with the leading players. In particular, Intel and IBM were consulted and visited when the theoretical work was being tested in a laboratory at ABB in Sweden. There has to be a dialogue with the end-users at all stages of development and Xzero was fortunate to be advised by Intel and IBM during the early development process. The most important partners today are two main semiconductor manufacturers both of which have mutual Non-disclosure agreements with Xzero.

The process of convincing water engineers in the semiconductor industry to try out new technology on line, whether treatment of waste water at specialist lines or in the main fabs, requires partnership with those who are working with the industry in developing production, including UPW, technologies. These not only have to be centres of excellence by objective criteria, they have to be recognised as being such by the industry and be actively engaged with the main consortiums in doing so. Xzero has developed working collaboration with imec for introducing the technology to the semiconductor industry and works very closely with the Royal Institute of Technology (KTH) in Sweden in developing and improving the basic concepts of the technology in all aspects of quality manufacturing and cost of ownership.

As the technology becomes proven through demonstrations and is actively under consideration for being used, system integrators become important. These are companies who are main contractors for UPW systems in fabs such as Veolia of France, Kurita of Japan, M+W Group of Germany and Christ (Ovivo) of Netherlands.

The buyers, in this case the semiconductor manufacturers, decide where and when the new technology is included. At the same time, choice of integrators is made by the semiconductor industry based on more than one criteria. However, there has to be understanding between component suppliers and integrators and Xzero has and will continue to develop partnerships with contractors and integrators.

Investment partners

Several leading sources for institutional finance have expressed interest for financing Xzero. Xzero has however decided that this type of investment and possible listing will have to wait until Xzero has achieved a strong Cash Flow. Likewise discussions with industrial investors will have to wait until such a date.

Until then Xzero will rely on finance from its present approximately 1 500 shareholders. All shareholders are private individuals or SMEs.

Partners and consultants

imec, Leuven, Belgium

Imec performs world-leading research in nanoelectronics. Imec leverages its scientific knowledge with the innovative power of its global partnerships in ICT, healthcare and energy. Imec delivers industry-relevant technology solutions. In a unique high-tech environment, its
international top talent is committed to providing the building blocks for a better life in a sustainable society. http://www2.imec.be/be_en/about-imec.html

imec is the leading research institute in European microelectronics. imec has tested Xzero equipment in lab scale with good results and has installed a small commercial size prototype for concentration of difficult wastes in order to save money on destruction costs. (ref. Alain Pardon).

Xzero is also testing the separating and concentrating sulfuric acid for recycling or reuse and with polishing of Isopropyl alcohol (IPA – isopropanol) for specific cleaning operations. (ref. Frank Holsteyns)

A somewhat larger unit will later be tested in a polishing operation for the sake of determining the potential improvement in yield rates. (ref. Paul Mertens)

Imec employs about 2000 people among them 500 residents from companies. It is funded by the EU and European Governments and by payments from more than 80 private companies, among them the largest ones in the microelectronics industry. Compared to its US equivalent Sematech, it is more orientated into process technology.

Through co-operation with imec, Xzero has also become part of EEMI 450, European 450mm Equipment & Materials Initiative, an association of main European semiconductor companies which has as objective to support the 450mm wafer program and thereby the economic growth of the corresponding sectors of industry.

The most important program at imec as far as Xzero is concerned is probably E450EDL (European 450mm Equipment Demo) which aims at demonstrating the readiness of 450 mm semiconductor manufacturing equipment. The overall goal of the E450EDL project is to install a 450mm pilot line at imec in Leuven, equipped with European systems implementing first critical modules. The budget is €205.7 million. EU will fund €30.9 million, local PAs €30.2 million. Many parties are involved that all have to work together and contribute their piece of the puzzle. Its imec’s role to bring all these parties together and understand how all the pieces fit together. (See Appendix Collaboration…)

Many parties are involved that all have to work together and contribute their piece of the puzzle. Its imec’s role to bring all these parties together and understand how all the pieces fit together. This is done in our core CMOS program where all the main chip manufacturers, tool and material suppliers are gathered. But also the supplier hub that imec set up a few years ago, has evolved as a very important aspect of the collaboration platform. Tool and material suppliers can evaluate their products in an early phase of technology development and get valuable feedback on how to further optimize them. In the collaboration process, they bring in not only state-of-the-art tools and materials, but also valuable insights and experiences that help fuel imec’s developments and thus strengthen the core CMOS program. In 2015, various supplier interactions ramped up and have definitely started to pay off. In summary, by serving as the collaboration hub of the industry, imec is playing a valuable role in pushing the limits of physical scaling. “Collaboration is the centerpiece to push the limits of lithography, Greg McIntyre, Director Advanced Patterning, imec, Solid State Technology, January 12, 2016.

Xzero is one piece of imec’s puzzle.
Clarkson University, Potsdam, NY, USA
Clarkson participates in the international Global 450 Consortium and co-operates with several leading US semiconductor manufacturers. A test unit has been evaluated by Clarkson with good results. A larger unit is being designed for further testing. It will be decided later whether this larger unit shall be tested at Clarkson or at the site of a semiconductor manufacturer that Clarkson works with. (ref. Professor S.V. Babu).

Royal Institute of Technology (KTH), Stockholm, Sweden
Xzero has co-operated with KTH in just over ten years and several Masters and PhD projects have concerned Xzero technology. At present KTH uses two small lab units (2 l/h) for testing and also a semi-commercial test unit (40 l/h).

One of the small lab units has been in operation for ten years. The other is one year old. The semi-commercial test unit is located at a waste water treatment plant in Stockholm and has been in reliable use for about five years.

At the moment three PhD-candidates and two post docs are working with issues related to Xzero technology. (ref. Professor Andrew Martin).

Alfa Laval, various locations in Sweden and Denmark
Xzero has a longtime relationship with Alfa Laval because of Alfa Laval’s competence in plate and frame technology.

Alfa Laval is a world leader within heat transfer, separation and fluid handling. The company has two water treatment subsidiaries and also makes heat-exchangers for Ultrapure Water systems.

The company is active in close to 100 countries and has 42 major production units of which 22 in Europe and has approximately 18 000 employees, the majority of whom are located in Sweden, Denmark, India, China, the US and France.

At present, Alfa Laval participates with a non-disclosure agreement on a pro bono basis in the design of a new module. (ref. Mats Nilsson).

Istituto per la Tecnologia delle Membrane (ITM-CNR)
ITM is a leading authority on the type of membranes that Xzero uses and also on the concentration/crystallization of concentrate from the process. Xzero has been in contact with ITM for many years and has supplied a test module to ITM during 2016. (ref. Professor Enrico Drioli). http://www.itm.cnr.it

In addition to these partners, Xzero employs several Swedish engineering consultancy companies for the practical design, construction and test of equipment.

Preparation for marketing
In order to prepare for testing of the commercial equipment Xzero has signed Non-Disclosure Agreements with two of the leading companies in the Global 450 Consortium in 2015.

There are also dialogs with suppliers of components, especially membranes. And with leading integrators, i.e. companies that sell and install water treatment equipment to the semiconductor industry such as Christ of Holland, MWGroup of Germany and Kurita of Japan.

Over the years, Xzero has been in contact with several members of the water committee of The International Technology Roadmap for Semiconductors (ITRS 2.0) in order to adapt its technology to the developing needs of the industry. We are seeking their advice on how to
best prove and present the technology to the industry. Today, the main contact is Dr. Vyacheslav (Slava) Libman, the Director of Advanced Water Analysis at Air Liquide - Balazs NanoAnalysis.

**Partnering with institutes**

**Imec**

During 2015 Xzero has conducted lab scale tests in co-operation with imec (2l/h). In 2016, a full scale prototype has been delivered for concentration of dangerous wastes which are presently not possible to treat but have to be sent to destruction.

**E450EDL**

E450EDL (European 450mm Equipment Demo) aims at demonstrating the readiness of 450mm semiconductor manufacturing equipment. The overall goal of the E450EDL project is to install a 450mm pilot line at IMEC in Leuven, equipped with European systems implementing first critical modules. Budget of €205.7 million. EC will fund €30.9 million, local PAs €30.2 million.

"The joint Dutch-Belgian E450EDL pilot line in Leuven & Veldhoven. Electronics components are increasingly pervasive in our life thanks to continuously declining costs and increasing performance. Future technologies will cut costs by using new basic materials. To consolidate the Europe leadership in this field, the E450EDL pilot line based in Leuven & Veldhoven will establish a realistic environment in which 43 partners from 11 countries will be able to validate novel equipment, materials and first processing sequences, until September 2016."

Five major projects announced as part of new EU Electronics strategy EUROPEAN COMMISSION, MEM, Brussels, 29 May 2013

By participating with imec, Xzero gets exposure to all the 43 partners in the program which will be beneficial both in the development (demonstration) phase as later in the commercialization and marketing phase.

**F450C**

The Facilities 450mm Consortium (F450C) is a first-of-its-kind partnership at SUNY's College of Nanoscale Science and Engineering (CNSE) that is leading the global effort to design and build next-generation 450mm computer chip fabrication facilities. The collaboration includes 10 of the world's leading nanoelectronics facility companies, including Air Liquide, CH2M HILL, CS Clean Systems, Ceres Technologies, Edwards, Haws Corporation, Mega Fluid Systems, M+W Group, Ovivo, and Swagelok. Members of F450C are working closely with the Global 450mm Consortium (G450C)

Of the members in F450C, Xzero has an ongoing relationship with Air Liquide, Haws, Ovivo, and M+W. The latter two are considered as integrators for commercial UPW systems.

**EIDEC**

EIDEC is a Japan-based international consortium founded in 2011. The world's leading suppliers of semiconductor, mask, resist, and production equipment collaborate to challenge half-pitch 11nm node and beyond to establish EUV lithography. In April 2014, DSA program was started to realize sub-10nm technology with a combination of EUV lithography.

The shareholder in EIDEC are Asahi Glass Co. Ltd., Dai Nippon Printing Co., Ltd., FUJIFILM Corporation, HOYA Corporation, JSR Corporation, NIKON Corporation, Shin-Etsu Chemical

Other participants in the joint development work are Intel Corporation, Merck Performance Materials G.K., Samsung Electronics Co., Ltd., San Disk Corporation, Kyoto University, Osaka University, Tohoku University, Tokyo Institute of Technology, Tokyo University of Science, University of Hyogo, EBARA Corporation, Lasertec Corporation and National Institute of Advanced Industrial Science and Technology.

Xzero has direct contact to Japanese companies, especially the water company Kurita and the conglomerate Hitachi, but EIDEC is also collaborating with imec.

**SEATECH**

The Center of Excellence in Nanoelectronics and Nanotechnology at SUNY Polytechnic Institute’s Colleges of Nanoscale Science and Engineering is the location for the global headquarters and operations of SUNY Poly SEMATECH, a 12-member global consortium of major computer chip manufacturers.

SUNY Poly SEMATECH coordinates and oversees next-generation research, development and commercialization programs in lithography, interconnects, and metrology, among others, while managing global reach and influence through various program partnerships around the world in emerging nanotechnology-driven applications such as nanobiotechnology and sustainable energy.

During early development stages Xzero co-operated with Sematech and for marketing analysis and Sematech was also involved in Xzero’s initial testing at Sandia National laboratories in Albuquerque, NM, USA, where the possibility to recycle UPW was first proven in prototype tests. The contact with Sematech will be renewed when the tests at Clarkson have gone into the full scale phase but at the moment imec replaces the services that were earlier provided by SEMATECH.

**SEMI**

Semiconductor Equipment and Materials International is the global industry association serving the manufacturing supply chain for the micro- and nano-electronics industries, including: Semiconductors, Photovoltaics (PV), LED, Flat Panel Display (FPD), Micro-electromechanical systems (MEMS), Printed and flexible electronics, Related micro- and nano-electronics.

The industries, companies, and people SEMI represents are the architects of the electronics revolution. SEMI members are responsible for the innovations and technologies that enable smarter, faster, more powerful, and more affordable electronic products and devices that bring the power of the digital age to more people every day.

SEMI works closely with Sematech and will be a good avenue for marketing of commercial units.

**ITRS 2.0**

The objective of the ITRS is to ensure cost-effective advancements in the performance of the integrated circuit and the advanced products and applications that employ such devices, thereby continuing the health and success of this industry. The ITRS is devised and intended for technology assessment only and is without regard to any commercial considerations pertaining to individual products or equipment.

ITRS 2.0 is sponsored by the five leading chip manufacturing regions in the world: Europe, Japan, Korea, Taiwan, and the United States. The sponsoring organizations are the European
Semiconductor Industry Association (ESIA), the Japan Electronics and Information Technology Industries Association (JEITA), the Korean Semiconductor Industry Association (KSIA), the Taiwan Semiconductor Industry Association (TSIA), and the United States Semiconductor Industry Association (SIA).

Xzero has been in continuous contact with members of the ITRS in order to monitor developments in the industry by impartial evaluations.

"UPW quality is a critical component in enabling existing and future semiconductor manufacturing technologies. The UPW ITRS group, involving key industry experts, develops risk analyses of the effects of UPW impurities on manufacturing processes.

While many of the UPW quality parameters are considered to present no threat to the wafer, some are still viewed as having the potential to pose risk to the most advanced production facilities. Particles in UPW are viewed as a high risk parameter due to the high probability of their occurrence, the insufficient ability to detect them, and the potential for significant negative device impact. Other parameters, such as organics and hydrogen peroxide, are being investigated for their potential adverse effects on the wafer." (Libman et.al.. 2015)

Industrial structure

Manufacture and delivery
Assembly of module systems, Test of module systems, In-house (in co-operation with Alfa-Laval)

Suppliers
Membranes, Injection molded proprietary parts, Welding, Heat exchangers, Tanks, Pipes, Pumps and Control instruments (sourced on the international market).

Integrators
Assembly of full systems, Test of full systems, Installation of full systems, Service and maintenance and Operation - possible BOT. (for example Christ, Ovivo, M+W Group and Kurita, mainly selected by customers).

R&D
Xzero in co-operation with customers and research institutes

Sales
Xzero in co-operation with integrators and research institutes

Applicable standards
The industry is largely guided by The SEMI International Standards Program. The program is one of the key services offered by Semiconductor Equipment and Materials International (SEMI) for the benefit of the worldwide semiconductor, photovoltaic (PV), LED, MEMS and flat panel display (FPD) industries. Standards offer a way to meet the challenges of increasing productivity while enabling business opportunities around the globe. The program, started over 40 years ago in North America, was expanded in 1985 to include programs in Europe and Japan, and now also has technical committees in China, Korea and Taiwan.

In 1997, the Program was expanded to cover other areas with activity in these industries among suppliers and users. The program operates as a neutral forum for the exchange of information among suppliers and users resulting in the production of timely and technically accurate specifications and other standards of economic importance to the industry. It is a vehicle for networking, partnering, and professional growth. Over 4,600 technologists worldwide, representing both device manufacturers and equipment and materials suppliers, participate in the program. These individuals work toward resolving a variety of process and product related
issues in both the front and back-end areas in semiconductor, photovoltaic, and flat panel display manufacturing.

SEMI standards are written documents in the form of specifications, guides, test methods, terminology, practices, etc. These documents are published in the 16 volume set of SEMI International Standards.
10 Business Model

Xzero has used a model of extensive co-operation in the development of the technology and will continue this model in the launch, intensified marketing and technical improvement of the technology.

The most important advantage that Xzero has is that it is developing and marketing a different technology than anyone else to the semiconductor industry. It is a unique product based on proprietary technology and supported by long and solid research. Others will inevitably, over sufficient time, also offer similar technology, despite Xzero’s Intellectual Property barrier. This will probably not happen until the technology is proven and adopted by the customers. It is therefore absolutely necessary for Xzero to hold a lead in technology development.

From the early time when Xzero was hived off as a separate company, Xzero has had a close co-operation with future final customers, full system suppliers (integrators), component suppliers and research institutes. This is a business model that the company will keep.

There is ample capacity available to assemble under contract. Xzero has used contractors to help design and provide pilot systems and, by using the experience gained in doing so, the need for own manufacturing capacity will not arise in the next three years. At some stage after that it may be necessary to have an own manufacturing capacity which will be largely an assembly operation.

In the next two years, Xzero needs to demonstrate that it can remove all nanoparticles, also in full-scale operation which is already established on a lab scale level at Clarkson and other institutes. Xzero needs to show that its technology can tackle particular contaminants that need to be tackled on a limited scale in terms of throughput, so that the technology is demonstrated during the scale up process. Additionally, that waste water can be treated and recycled in order to start reducing water consumption and to enable recovery of valuable minerals.

It is normal practice in the semiconductor industry for potential equipment suppliers to make available test units free of charge. Once online tests have proved to be positive, buyers pay a price for further tests and demonstrations but payment would be on commercial scale which is well below the cost of producing such one-off pilot units.

Once offline results have been affirmative, there will have to be discussions with early adopters as to the best initial applications and the scale of systems required.

Budget calculations are based on modules of a 10 l/h capacity, arrangement of clusters of modules which will begin with 40 modules in a cluster and then upscaling to arrangements of multiple clusters in a system. For the demonstration period, it is envisaged that there will be two clusters, each of a capacity of 400 l/h capacity, alternatively one and a half cluster with a total capacity of 600 l/h. Reserve modules will be included to replace any modules that are damaged in transit, set up or operation.

Finance would be required to undertake upscaling but with orders from leading industry players it should not be difficult to arrange. There is also the possibility of securing investment from the potential end-users.
Even when fully commercial, Xzero will need to act together with one or more partners, the choice being between an assembler, integrator or other engineering firm. In order not to limit the range of customers by being tied to one supplier, it would be best to combine with an engineering firm or an assembly operation.
11 Progress in hand

Xzero has presented its technology to semiconductor companies, integrators and potential industry partners. This has been done at forums, in industry magazines and at face to face meetings as well as telephone and emails exchanges.

In the 450 programme, the removal of nano particles from UPW has been proven at lab scale at Clarkson University. An NDA has then been signed with two major semiconductor manufacturers to take this work to the prototype stage.

Until today, Xzero has built and sold ten lab and test units to research institutes/projects or industries in several countries for several purposes. Five of these are still in active use and four new are under construction.

Two of the new units are for companies that may become major customers. The other units are used for joint research which will keep Xzero in the lead of development.

In Europe, a detailed technical dialogue with imec has resulted in an NDA and with agreement to test on particular contaminants. Xzero intends to use its growing understanding and collaboration with imec to implement the strategy outlined above. Imec has a mission that allows new technologies to be tested both on and off line at its 300 nm fab and is preparing for a 450 wafer line. They have a critical role in developing European technology and capacity in the semiconductor industry.

Preliminary contacts have also been established with several leading integrators.

Under the programme proposed Xzero will use a new generation of its modules in clusters to upscale systems. It will also produce clusters and systems with sufficient capacity to be demonstrated on line for removal of nanoparticles and reuse of fab waste water.

Summary of events in 2015

1. NDAs signed with two major semiconductor companies in the 450 program, with imec and with Alfa Laval.
2. The first two prototypes for testing by customers have been ordered for delivery in 2016 and construction has started already in 2015.
3. Own lab results that the technology can remove killer nanoparticles confirmed by tests of Xzero equipment at Clarkson University and by a supplier of nanoparticle detection equipment, Manta instruments Inc. in La Jolla, Cal., US.
4. Report on removal of pharmaceutical residue from municipal waste water by the Swedish Environmental Research Institute, Stockholm.
5. Report on feasibility evaluation for industrial applications (fuel alcohol, dairy, pharmaceutical) by the Royal Institute of Technology.
6. Co-operation has been initiated with new membrane suppliers.
7. A new patent has been granted for easy to remove cassettes. Other patents are being planned.
8. New improved commercial size test units for removal of nanoparticles have been designed.
Summary of events in 2016

1. Consecutively three equipments have been tested at imec—first one lab unit, then one prototype was delivered in April and finally a first prototype in the industrialization program was installed in August.

2. Since these tests were successful, a 3D model of improved modules was built and verified in September.

3. During 2016, we have tested membranes from two new suppliers. From initial one, we now have six possible suppliers.

4. Tools for first commercial module has been ordered in October.

5. A plan for manufacture of the first commercial module has been made and a full system using these modules will be completed in first Q 2017.

6. Test program for difficult wastes has been set up at imec, starting with Tetramethylammonium hydroxide (TMAH). TMAH is used in large quantities for etching in the industry and is very difficult to remove by conventional purification methods and is presently sent to destruction.

7. Because of the good results from the tests with TMAH we have decided to prioritize the waste water treatment aspect of our technology and get to the market as soon as possible in that area. Successfully solving an actual problem for imec will open up possibilities in the entire nanoelectronics industry after it has been disseminated by imec.

8. Sales of "nanoparticle free" reference water on flasks has been initiated and first shipment made.

9. A new webpage called type1water.com has been designed and will be online in October. We will sell reference water on flasks. This will bring some income, but is mainly to get future customers to test our water in an inexpensive way. They can buy one liter for around €50.

10. As a next step the customer can buy a small lab equipment for Type1 water. We have verification from customers that it is superior to MilliQ, the leading state-of-the-art equipment from Merck/Millipore. The design of the lab equipment has been made and it will be on the market in 2017. This will, of course, also bring some income, but has a higher purpose of attracting customers for large scale UPW-systems.

11. In view of the start of marketing of Type1 reference water, the websites of Xzero and Scarab will be redesigned and updated during October.

12. Because of good liquidity we have postponed a planned subscription to our shareholder (0.5 – 1 M€) to April 2017.

13. We have updated our Business Plan in the beginning of October and presented it to our bank, Swedbank, to start discussions about a listing on the Stockholm stock market in 2018.
Recent progress in research

KTH projects and reports

KTH has initiated the following projects involving membrane distillation equipment from Xzero during 2016:

a.   Membrane Distillation and Applications for Renewables-driven Water Purification: a PhD student research project funded by SELECT+, and Erasmus Mundus Joint Doctoral program. This project will focus on innovative water treatment and recovery, including ultrapure water provision, in semiconductor manufacturing and in the pulp and paper industry.


c.   Removal of arsenic, fluoride and uranium from groundwater by using air gap membrane distillation (AGMD) in inland area: a PhD student research project at the University of Southern Queensland, led by Prof. Jochen Bundschuh. Prof. Andrew Martin co-supervises the student.

d.   Zero liquid discharge in semiconductor manufacturing: a proposal submitted by University of Technology Sydney (Prof. Ali Altaee) to the Global Connections Fund of Australia. KTH and Xzero participate as international partners.

e.   Space Water: a MSc student project examining options for membrane distillation-based water recovery future space missions to Mars

KTH has recently published the following research reports involving membrane distillation equipment from Xzero:


12 Costs for commercialization

Costs for commercialisation fall within the following categories:

- Marketing
- Customer relations
- Design of demonstration systems to customer specifications
- Production of demonstration units
- Technical staff to support demonstrations
- Manufacture of full size industrialised modules
- Overheads

<table>
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<tr>
<th>Equipment costs</th>
<th>SEK</th>
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<td>Design of pilots</td>
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<td>Assembly equipment for pilots and demos</td>
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<td>40 l/h pilot</td>
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<td>180 l/h demo for recycling of UPW</td>
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Total costs are estimated as follows:

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<th>Hardware</th>
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<td>Contingencies</td>
<td>-100000</td>
<td></td>
<td>-100000</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>-48864,9</td>
<td>-1466486</td>
<td>-586378</td>
<td>-586378</td>
<td>-2639243</td>
<td></td>
</tr>
</tbody>
</table>

The travel budget is adequate to the needs of working with imec in Europe as well as contacts with USA, Korea and Taiwan.
Normally innovative SMEs are have difficulties in financing advanced industrial projects. Xzero has created a structure with research grants and individual financial backers who have this far invested more than 10 M€ in developing Xzero technology and will therefore also be able to raise money to fulfil its mission once the demonstration stage is over. We are not at risk in the Valley of Death.

This picture illustrates the difficulties of financing new projects in SME. Thanks to financing from approximately 1500 individual share-holders, Xzero is about to leave the "Valley of Death". Excerpted from: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.
13 Financial Analysis

The Mission for this project is to develop and market water purification systems that are capable of removing nanoparticles from UPW grade water and can be used to recycle spent fab water as UPW. Also some valuable materials will be recovered, as will ones that threaten the environment.

Revenues will come from sales of systems, they need not be produced by the company and can be assembled under contract. Engineering, profiling, design, tools, prototypes and test units have already been undertaken on this basis. Following a two year demonstration phase, Xzero will offer systems for sale, essentially consisting of clusters of membrane modules.

Although Xzero continuously have sold small test units during the last few years and has orders for additional small test units, no commercial sales are assumed during the two years of demonstration but during that period it is expected that the company will receive orders for full scale on line test units from more than one semiconductor manufacturer. The orders will be of lower magnitude than a full UPW system at first because they may be for treating fab spent water as well as for special tasks such as particle removal from UPW for the CMP process.

At present, state of the art systems cost half for core elements and half for peripherals including piping, storage, circulation and measurement. An Xzero based system would cost less for core elements and have a lower cost for peripherals. For financial purposes, the cost assumption has been like for like. In reality Xzero based systems will cost less but as unique products will be more profitable at least until competition equalizes profits.

Cash flow projections are given below, they assume an initial period where Xzero will not face competition in the supply of proprietary based systems but it is inevitable that market share will fall over time. The chart below also takes it into account that system sales include components made by others and 50% is allowed for this.

<table>
<thead>
<tr>
<th>CASHFLOW ANALYSIS</th>
<th>Year</th>
<th>millions Euros</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Annual Systems Sales</td>
<td>13%</td>
<td>2,057</td>
</tr>
<tr>
<td>Annual New Systems Sales Projected</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>% share total equivalent system sales</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Xzero System Sales Projected</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>expressed as % share New sales</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Xzero share of system sales</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Target Net Profit for Xzero</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Net Profit as share of revenue</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>Investment*</td>
<td>Euros</td>
<td>(1,340,022)</td>
</tr>
<tr>
<td>Cashflow</td>
<td>(1,340,022)</td>
<td>(1,082,984)</td>
</tr>
</tbody>
</table>

It is anticipated that there will be positive margins from the time that sales commence. In year 3, it is expected that Xzero will need an investment of 20 million Euros for the upscaling and tooling that will be required. Other than that, the cash flow will be positive from year one of sales.
14 Capital Requirement

The longer term scale of investment and working capital required is difficult to estimate at present and, although a 20 million Euros investment in year 3 is included under cash flow, it is a nominal allocation. This sum would cover all the requirements listed below. Sales revenue should be strong enough to attract investment, although partnership with a larger company will be considered.

Following the two year demonstration phase, there will need to be substantial capital investment for the following purposes:

1 **Upscaling towards full fab capacity**
The demonstration units planned are for a capacity of 24,000 litres per day each. Within a three years period it will be necessary to produce systems of over 2,000,000 million litres. Both, Xzero and prospective buyers are aware of this need and the latter are willing to actively help such a process through contacts with existing suppliers or through equity funds they manage.

2 **Working capital**
In the demonstration phase units costing approximately 530,000 € each in manufacturing costs are to be provided free of charge and will be accompanied by technical support costs. However, once systems costing tens of millions are ordered, the company will have to finance the gap between payments and expenditures.

3 **Quality control**
There will have to be a unit that ensures quality control at point of assembly, despatch and arrival at the customer. There is no leeway for poor quality in UPW systems.

4 **Assembly plant**
Most of the system will need to be assembled from specialist components and with accelerating sales and the need to keep tight schedules, an assembly plant or a close collaboration with one will be urgent and essential.

5 **Module manufacturing**
A logical extension after an assembly plant is to have own key component manufacture and the heart of the system is the membrane module.

6 **Research and Development.**
It will be important to extend the head start period and to take advantage of being the first to market through research and development to improve further the efficiency and operation of the system as well as technical improvements for lowering of costs.
15 Appendixes

European semiconductor industry development
1. The move to 450mm: Benefits and Measures to set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe. A single European semiconductor strategy is on its way, 16th February 2012.
2. A single European semiconductor strategy is on its way, Solid State Technology, Mike Clayton March 1, 2013
3. EEMI 450, European 450mm Equipment & Materials Initiative
4. EEMI 450 The move to the next silicon wafer size Jan2013
5. Alfa-Laval heat-transfer-solutions-for-the-semiconductor-industry
6. EU Semi Funding, January 22 2015
8. European Electronics strategy MEMO EU 2013
9. European consortia, ASML, supplier network plan for 450mm transition, Tom Morrow, executive vice president, Emerging Markets Group, SEMI, Solid State Technology
10. imec to begin 450mm cleanroom construction in 2013, Solid State Technology

Development of line width and wafer size
1. Celebrating the 50th anniversary of Moore’s law, Dale Ford, HIS
3. Is 450mm Dead In The Water? May 15th, 2014
5. 5nm Fab Challenges, January 21st, 2016
6. What to Expect in 2016 in the Chipworld
7. SUNY and GLOBAL FOUNDRIES announce new $500M R&D program, Solid State Technology, 2016/02

The need for purer water

The Xzero project
2. Water for Nanoelectronics, Xzero, August 2014
3. Evaluation of Membrane Distillation (MDU) prototypes for Use in Semiconductor manufacturing, Robert P Donovan, Dennis J Morrison, Sandia National Laboratories; Albuquerque, USA.
4. Polypgeneration of electricity, heat and ultrapure water for the semiconductor industry, KTH, 2004
Marketing
1. Market prospects for Ultrapure water, Xzero, March 2013
2. Market opportunities in the semiconductor industry in China, Scarab Development AB 2013

Selected recent publications on Xzero technology outside of semiconductor industry
3. Membrane Distillation pilot tests for different wastewaters. Separation of pharmaceutical residues and treatment of flue gas condensate with Xzero Membrane Distillation in Pilot Scale at Hammarby Sjöstadsverk, October 2015
5. Membrane distillation for thermal co-generation, KTH, 2008

Appendices can be downloaded at www.xzero.se/Euro450
Password is: Horizon2016
For business confidential information, please contact the company directly.
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For references to potential suppliers, manufacturing partners, integrators and customers, please contact Xzero.

Internet links

Xzero http://www.xzero.se/en/

Imec http://www2.imec.be/be_en/about-imec.html

KTH https://www.kth.se/en/itm/om/organisation/institutioner/energiteknik/

Clarkson http://www.clarkson.edu/chemeng/faculty_pages/babu.html

ITRS http://www.itrs2.net/

The Facilities 450mm Consortium (F450C) http://www.f450c.org

The Global 450 Consortium (G450C) http://www.g450c.org/