



Patent Landscape Report on

Desalination Technologies and the Use of Alternative Energies for Desalination

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Patent Landscape Report on Desalination Technologies and the Use of Alternative Energies for Desalination

A patent landscape report prepared

for the
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Executive summary

This patent landscape report focuses on desalination technologies, and in particular on desalination technology integration with renewable energy sources. Water supply problems are constantly increasing due to climate change and have a major impact on many developing and least developed countries. Desalination is in principle a particularly suitable solution to a large number of areas with possible water shortages that are close to coastal areas or island locations. However, desalination has traditionally been considered as a very expensive and 'luxury' solution, in particular due to its high energy cost, but also due to the relatively low number of saleable technologies.

The patent landscape suggests that significant advances are being made in decreasing the cost of desalination and increasing its energy efficiency through novel desalination technologies, improvements in components design, and last but not least, through advances in the integration of desalination with renewable energy sources. Continued development and deployment of desalination technologies powered by renewable energy sources could provide a more affordable source of fresh water for both developed and developing countries currently under threat of water shortages.

Information based on patent landscaping can be a highly reliable information source to support decision-making in both the public and private sector. We trust that the patent datasets and analyses developed in this report can support policy makers and private sector participants alike in better understanding hotspots of development, identifying key suppliers and partners for further technology development, and improved formulation of patenting strategy. It is important to note that a patent landscape **does not** constitute a Freedom to Operate analysis, but can be used as the basis for such follow-on analyses (for instance to support the patenting of novel technologies).

The report begins by reviewing key desalination technologies that are currently commercially deployed (with some indicative energy spend figures), and technologies currently in the R&D phase. We also review the 'direct' and 'indirect' modes of integration with renewable energy sources. The patent landscaping is focused on the 'direct' modes of integration, but we provide some case study examples of 'indirect' integration, which may be a major growth area in the future

The subsets of desalination patents relating to the direct integration of renewable energy and desalination technologies are relatively small and suggest that significant space for further development remains. Of the renewable energy technologies analysed, most of the integration occurs with waste heat from solar, industrial or geothermal processes. Historically Japan has been a major patenting location in this space, but this has decreased considerably in the last 5 years with a considerable drop in patents from the Japanese companies. In contrast, companies like GE and Siemens have been very actively patenting in the last 5 years. In terms of countries, the major 'new' patenting locations in desalination are South Korea and China. We were surprised to find that Africa and the Middle East have not seen a very high number of desalination patents, even though they are some of the key potential markets for this technology.

In order to support a better understanding of how patents translates into products in practice, we also provided several case studies across a range of actors (industrial conglomerate, SMEs, renewable energy technology developers), and a range of desalination technologies. The case studies indicate ways in which patent and non-patent data can be combined to build a more complete picture of the technology and

innovation landscape of an industry. These are **not** exhaustive, and **not** to be taken as recommendations about which technology is most appropriate.

1 Introduction – Report objectives

1.1 WIPO Development Agenda context

This IP landscape report focuses on desalination technologies, in particular when integrated with renewable energy sources. It was prepared in the context of a collaboration of WIPO with the International Renewable Energies Agency (IRENA – www.irena.org) and the Global Institute for Water, Environment and Health (GIWEH – www.giweh.ch). It is also based on WIPO's Development Agenda project DA_19_30_31_01 ("Developing Tools for Access to Patent Information") described in document CDIP/4/6 adopted by WIPO CDIP at its fourth session held from November 16 to November 20, 2009. Patent landscape reports of the aforementioned DA project contributes, by focusing on particular technological fields, in highlighting essential technologies, know-how, processes and methods that are necessary to meet the basic development needs of developing countries, particularly with regard to improving the environment, life, health of human beings, animals, plants and food security.

The report is intended to support GIWEH and IRENA and their stakeholders in assessing the relevant desalination technologies and the related renewable energy opportunities suitable to the various regions to meet the increased needs of energy for water production. The report should further facilitate technology transfer to developing countries, establishment of best practices in the area of desalination and accelerated uptake of renewable energy technologies. In the context of the broader WIPO Development Agenda project, this report should also serve as an instructive example of how specific technical subject matter can be researched in patent databases. A comprehensive explanation of the applied search strategy and well documented, and thereby repeatable, search queries is provided in the methodology section of the report (Section 5).

1.2 Desalination in the Development Agenda context

Access to clean water is a basic human need, but is also an important driver of social development (e.g. as used in hospitals) and economic development (e.g. industrial processes need access to clean water) (UN-Water: United Nations Educational 2006). Access to clean water is particularly limited in developing countries and least developed countries (LDCs), but is also increasingly an important issue in middle-income and developed economies. One of the ways to improve water availability is through desalination, but most plants currently in operation worldwide use very energy intensive desalination methods.

Water supply problems are constantly increasing due to climate change and have a major impact on many developing and least developed countries. While desalination constitutes a solution, it has traditionally been considered too expensive. However, the

use of renewable energies could provide a more affordable alternative, principally in developing and least developed countries.

Desalination covers a wide range of applications, from agricultural and industrial to domestic use. This study focuses on the production of clean municipal and rural water supplies from sea or brackish water sources. We are not focusing on specialised applications, such as the production of ultra pure water for the medical industry, or partly desalinated water for cooling of power plants. Rather the study focuses on processes that can be integrated into the systems of municipal and rural water use. We are also not focusing on general waste-water treatment or water reuse, although when such technologies were found and also related to desalination, they were included.

Some of the areas where desalination can play the greatest role are also some of the countries with least resources for the deployment of such technologies. At the same time, given that existing infrastructure is either inadequate or non-existent, these economies have the opportunity to invest in altogether new water infrastructure, gaining access to the latest generation of desalination technologies. Coinciding with a global push toward renewable energy, a key question therefore emerges: which desalination technologies are developed with a focus on integration of renewable energy integration?

This patent landscape of desalination technologies therefore looks at two dimensions:

- a stock take of the overall patent landscape around key desalination technologies
- a particular focus on the integration of desalination and renewable energy technologies

1.3 Patent landscape of desalination

Patents registered around the world together represent a global technology library. Information from such patents can be used to promote innovation, enable access to technical information and foster other activities that support development. Patent landscape reports integrate expert synthesis of automated search result analyses with market information to provide a more accessible reference framework to technology, policy and business insights in a particular field. This patent landscape report on desalination-related patents aims to detect patterns of patenting activity and innovation in the area of desalination, with a separate focus on the use of renewable energies for desalination.

This report identifies patent families (including utility models) that claim inventions related to desalination of water. The search has covered both complete systems and components or details of systems if these components are specifically adapted to desalination. Components that can potentially be used in desalination, but are not exclusively adapted for it were not included. The scope of search also includes inventions where desalination of water is combined with purification of water, although inventions related only to purification are not included. As discussed above, a special focus of this report is inventions that describe the combination of desalination technologies with the use of renewable energies.

Since the report aims to provide an overview of patenting activity in the area of desalination, it has not focused on aspects of validity of patent protection or freedom-to-operate. We did not investigate, for instance, whether a patent that has been granted for a particular patent application has entered into force or is still valid, or what the exact scope of protection is. Claims were only used as general guidance as to what type of subject matter is claimed as invention. However, in order to assess coarsely the level of innovation of applications, for each patent family we researched whether the family comprises at least one granted patent.

2 Desalination technology in the context of global water sector challenges

2.1 Water in a global context

In the coming decades, access to water for drinking, agricultural and industrial uses will become an increasingly important challenge for countries globally. A predictable and consistent access to clean drinking water is universally seen as a core function of states, as it is crucial to a society's public health, economic vitality and national security (Elimelech and Phillip 2011). Yet in many countries there is already a scarcity of fresh water, or water systems are seen as vulnerable (see Figure 1). Moreover, even within countries where overall there is no perceived water scarcity, there may be regional shortages, frequently in coastal areas. In the coming decades, it is anticipated that continued population growth, rising incomes in emerging economies and continued industrialisation and urbanisation, as well as climate change pressures will put further pressure on existing water infrastructure and sources of clean drinking water. According to market research, a forecast *average* 3% increase in annual demand for fresh water would translate into *annual* investment requirements of up to €400–500bln in water infrastructure (Heymann 2011).

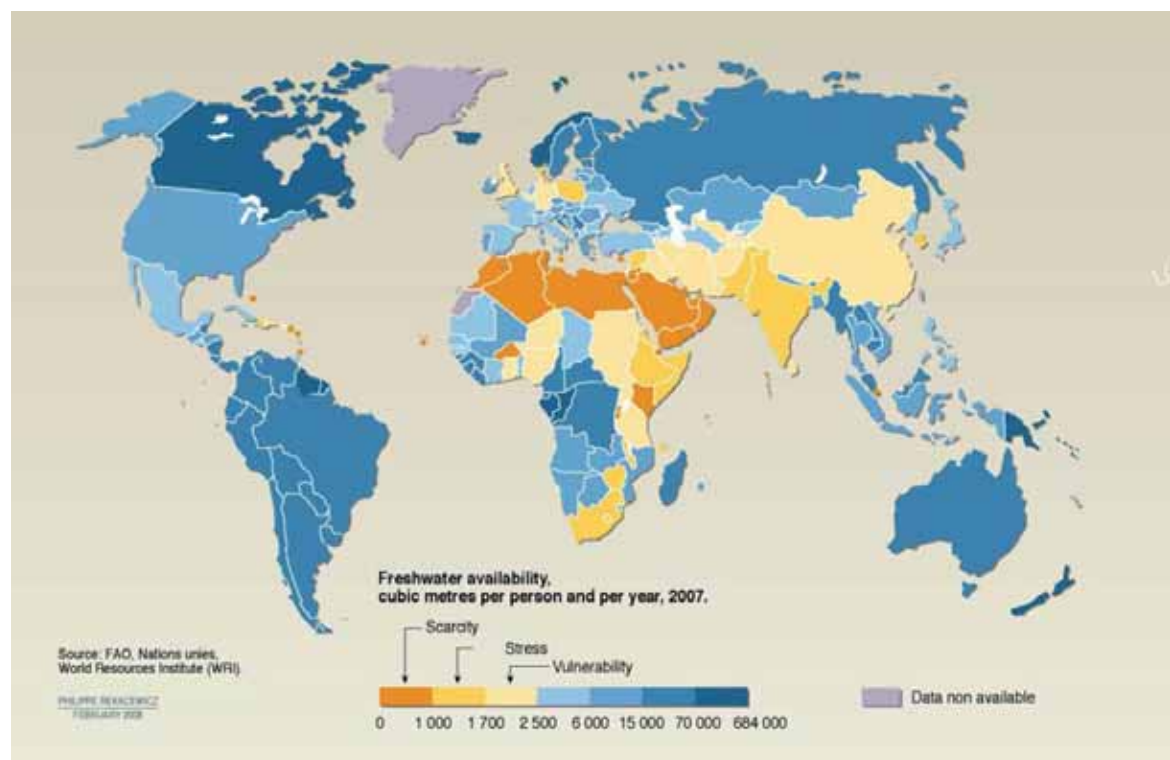


Figure 1: Global freshwater availability (UNEP 2008)

In addition to the requirements of water for drinking, there is a strong requirement for water for agricultural uses. In terms of usage, around 70% of potable water is used in agriculture, followed by industry (22%) and domestic use (8%) (see Figure 2). A large proportion of the industrial use is in the energy sector. Insufficient water supply would therefore not only have an impact on the availability of fresh drinking water, but also a potentially significant impact on global food and energy supplies. Downstream water services such as clean water supply in municipal services, waste-water services and sanitation are dependent on sufficient upstream water supply (McKinsey & Company 2009).

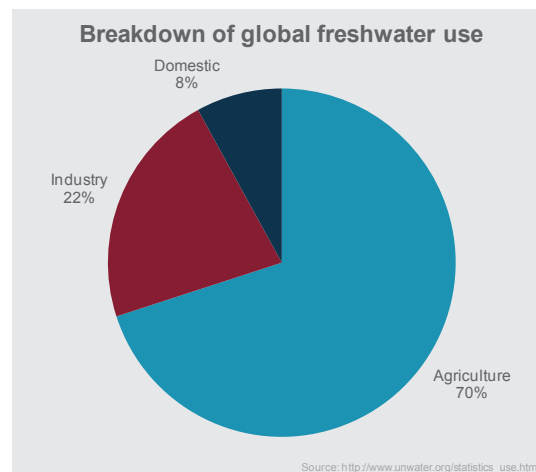


Figure 2: Worldwide use of fresh water (UN-Water 2011)

Water conservation, water reuse and improved catchment and distribution systems will play an important role, but ultimately offer a finite solution, and one that may be insufficient to secure adequate water supplies in many regions globally (Elimelech and Phillip 2011). As water demand continues to grow, and with it the scarcity of renewable natural water resources, we will need to find alternative water sources to *complement* better water management measures. Desalination therefore has to become a key component of the solution to long-term water supply shortages (Elimelech and Phillip 2011), (Mezher, et al. 2011).

2.2 Desalination challenges

While desalination technologies have been in use for many years, mass deployment of such technologies has a number of challenges. Current technologies have extremely high energy requirements, as well as a potentially high negative environmental impact through side-products and CO₂ emissions. More detailed information on energy usage and cost in desalination technologies can be found in Table 2. Key environmental concerns include:

- high energy usage and its related CO₂ emissions due to the power supply to desalination plants
 - direct, where desalination capacity is coupled with diesel or other fossil power generation deployed specifically for a desalination plant

- indirect, where desalination plants are fed power from the grid (and where the grid has a high level of fossil fuel composition)
- uncontrolled discharge or brine that can contaminate water aquifers and damage the aquatic ecosystem due to high temperature and salt content
- contaminants such as pre-treatment chemicals and anti-corrosives or nuclear contaminants (when integrated with nuclear power)
- other factors such as noise pollution, gaseous emissions and chemical spills

Challenges relating to location include:

- integration with off-grid energy source or a mobile technology
- energy usage for off-grid sites, especially on island systems where all fuel used also needs to be transported to the site
- footprint of the plant – where increased water supply is needed because of population increase in an urban area, there may not be a lot of space available to build the plant
- water transfer costs due to capital costs, energy costs, operation and maintenance, and cost of water at source (United Nations: Economic and Social Commission for Western Asia (ESCWA) 2009)
- creating the infrastructure to transfer water from the point of treatment to the point of use (especially for inland locations)
- where existing infrastructure is used, loss during water transfer due to seepage and leaky pipes, creating a lot of wastage as very expensive desalinated water is lost before reaching its destination

An additional challenge is the high level of upfront capital expenditure (capex) required for the deployment of sufficient desalination capacity, as well as the likely high levels of operational expenditure (opex) during a desalination plant's life cycle (Mezher, et al. 2011). Not surprisingly, the bulk of installed desalination capacity globally has been in high-income economies in the Middle East and elsewhere (see Figure 3). Technology improvements around modularity can decrease or make more manageable the capex requirements, as operators can add capacity as needed, while efficiency and maintenance technology improvements around existing technologies can improve the opex requirements. In short, innovation in this space can improve the investment profile of such projects, making it easier to finance and deploy.

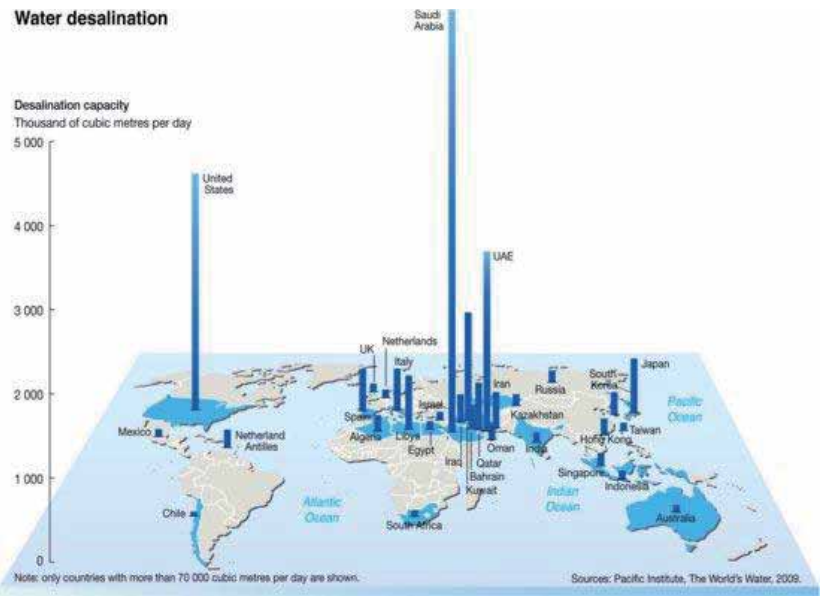


Figure 3: Global desalination capacity – by country (Pacific Institute 2009)

3 Desalination: existing technologies and future outlook

3.1 Key desalination technologies

Desalination is a technology that removes dissolved salts and other minerals from seawater or brackish water. The process produces one stream of water with a low concentration of salt (the product stream) and another with a high concentration of remaining salts (the brine or concentrate). The product stream is then used to provide water for domestic, municipal or irrigation purposes (United Nations: Economic and Social Commission for Western Asia (ESCWA) 2009). The feed water to be desalinated can be either seawater (TDS¹ of 30,000–50,000 ppm) or brackish water (TDS of 500–30,000 ppm). The resultant brine solution typically has a TDS of greater than 50,000 ppm (Lewis 1982).

Desalination technologies have been under development for many years. Some of the first reported experimentations for desalination date from 1627 (Sir Francis Bacon with sand filtration) and 1791 (Thomas Jefferson with distillation). In the modern era, one of the first major industrial programmes around desalination was launched in the USA through the Saline Water Act of 1952, establishing a \$160mIn R&D programme (MacGowan 1963). Since then, there has been a proliferation of research and commercial deployment of desalination technologies. Table 1 summarises the key desalination technology types around which this report is focused, including technologies at research, development, pilot and commercial stages of development. A short description of each technology type is given in Appendix 1. A more in-depth study of each of these technologies is possible, but does not fall within the scope of this project.

Table 1: Key desalination technologies

Membrane technologies	Thermal technologies	Other technologies
Reverse osmosis (RO)	Solar distillation	Membrane distillation (MD)
Forward osmosis (FO)	Multistage flash (MSF)	Electrodeionisation (EDI)
Electrodialysis (ED)	Multi-effect distillations (MED, sometimes called multi-effect evaporation or MEE)	Capacitive deionisation (CDI)
Electrodialysis reversal (EDR)	Thermal vapour compression (TVC)	Freeze separation (FS)
	Mechanical vapour compression (MVC)	Rapid spray evaporation
	Adsorption vapour compression	Vacuum distillation
		Gas hydrates
		Ion exchange

The academic and industry literature typically uses categorisation according to the type of technology used. However, an alternative way for categorising of desalination

¹ Total dissolved solids (TDS) refers to the total amount of mobile charged ions, including minerals, salts or metals, dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/litre) or as parts per million (ppm)

technologies can be based on the type of energy that drives the process (pressure, temperature, chemical energy, electrical charge). We have adopted the ‘technology-based’ classification, as this is more widely used, and is also easier to translate into a patent search strategy. However, for some policy purposes an ‘energy-type’ categorisation may be more appropriate.

3.2 Industrial deployment of desalination technologies

The technologies most commonly used commercially are reverse osmosis (RO), multistage flash (MSF), multi-effect distillations (MED, sometimes called multi-effect evaporation or MEE) (see Figure 4). Historically, thermal technology dominated the desalination market, especially in the Middle East (Elimelech and Phillip 2011), (Mezher, et al. 2011). The most commonly used thermal technologies are MSF and MED. MSF is still employed in more plants than the newer MED technology, even though MED has lower energy consumption. While both of these technologies require considerable amounts of thermal as well as electric energy to run, MED has a higher upfront investment/capex, but lower opex than MSF (Elimelech and Phillip 2011), (Mezher, et al. 2011).

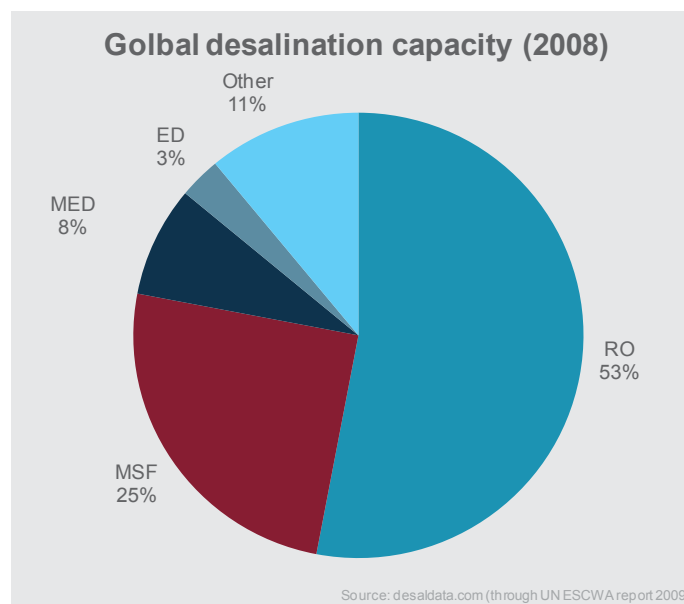


Figure 4: Global desalination capacity – by Technology (United Nations: Economic and Social Commission for Western Asia (ESCWA) 2009)

RO has lower energy consumption when compared to MSF and MED (see Table 2).² With increasing energy costs, more RO plants are built. Therefore, since 1990 most plants have used RO technology, with RO plants currently at 53% of deployed capacity (see Figure 4 above) (Mezher, et al. 2011), reflecting the increasing role that energy costs play in the operating costs of desalination, and water treatment generally (Elimelech and Phillip 2011). However, the non-energy operating costs of RO can be higher than that of thermal technologies, so there has been a significant level of

² While RO technology has a theoretical energy efficiency limit calculated at 1.06 kWh/m³, the practical operating energy consumption is higher than this (Elimelech and Phillip 2011).

innovation focused on decreasing the operating costs. Some examples of RO-related innovations include:

- the development of low-cost membranes
- the use of energy recovery devices
- nano-enhanced membranes (which use carbon nanotubes or aquaporins to improve flow)³
- staged membrane operation

Table 2: Desalination process outcomes of selected desalination technologies (Mezher, et al. 2011), (United Nations: Economic and Social Commission for Western Asia (ESCWA) 2009)

Specifications	MSF	MED	RO
Energy requirement (kWh/m ³)	Electrical: 3.5–5.0 SA ⁴ : Thermal 69–83 CG ⁵ : Thermal: 44–47	Electrical: 1.5–2.5 SA: Thermal: 41–6 1 CG: Thermal: 28	Seawater (SW): 4–8 Brackish water (BW):2–3
Cost of water (\$/m ³)	0.9–1.5 (the cost reduces with co-generation and unit capacity)	Around 1 (the cost reduces with cogeneration use of thermal VC (TVC)) 0.827 for Jubail II plant	SW: 0.99 BW: 0.2–0.7
Environmental impact	Discharge is 10–15°C hotter than ambient, TDS increase of 15–20%	Brine discharge and temperature rise are similar to MSF	Brine discharge at ambient temperature, TDS increase of 50–80%

Depending on the feed water and location, RO may not always be the most cost-effective desalination technology. For instance, the cost of running pre-treatment systems may be too high in the presence of high feed water salinity and turbidity and the high presence of marine life in the feed water (causing bio-fouling) (Elimelech and Phillip 2011), (Mezher, et al. 2011).

In some instances, hybrid desalination plants offer the most economic option, generally MSF–RO or MED–RO plants. These plants allow more flexibility than MSF and MED plants would have on their own and also address some of the post-treatment costs associated with RO. For instance, the brine from RO processes is cooler than that of thermal processes, and when mixed with MSF/MED discharge the plant brine can more easily be released (Mezher, et al. 2011).

Finally, various processes and chemicals are used to fine-tune and optimise the pre- and post-treatment of water during the desalination process. Innovation in these areas can be important enablers of improved efficiency, decreased costs of operation and reduced environmental impact (see Appendix 1 for greater detail)

³ Nano-enhanced membranes enable smaller membranes to achieve the same water throughput, but will require redesign of the membrane modules currently in use due to the problems associated with increased water flux. Nano-enhanced RO membranes should not be confused with nanofiltration membranes – the latter is a technology used in the pre-treatment of desalination feedwater.

⁴ SA stands for 'stand alone'.

⁵ CG stands for 'co-generation'.

3.3 Desalination – Renewable energy integration

For desalination, especially in remote, coastal and island regions, renewable energy sources can provide energy solutions which use a local resource and reduces the plant’s carbon footprint.

Broadly, integration with renewable energy sources can be direct (using the heat or pressure generated by the device directly) or indirect (where renewable energy generates electricity which then drives desalination processes) (see Figure 5). Although the scope of this project includes only direct integration, indirect integration is also discussed in order to ensure completeness.

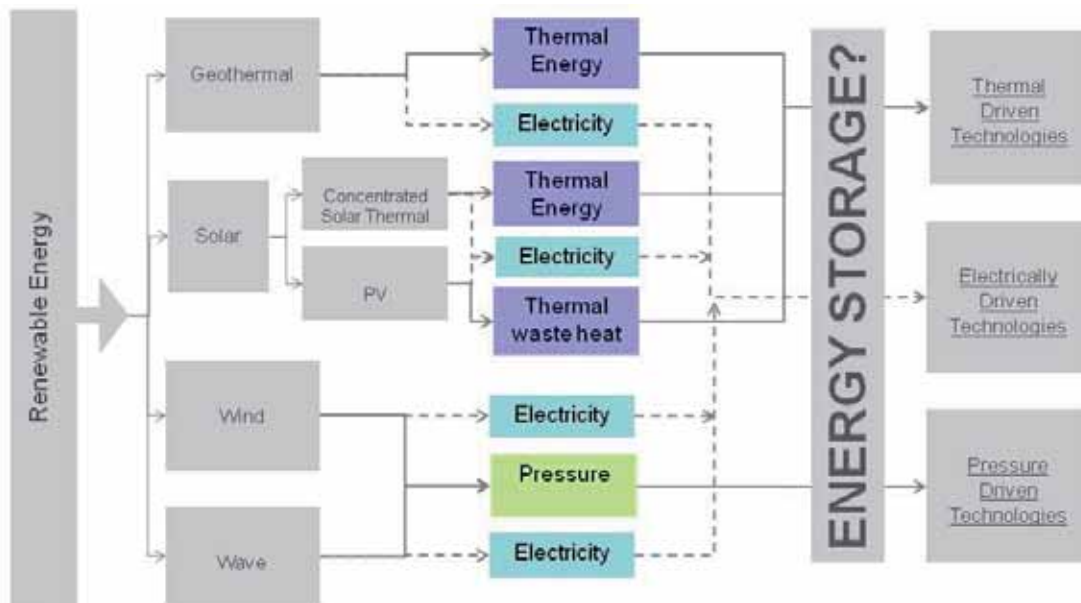


Figure 5: Desalination – renewable energy integration key options, where a solid line indicates direct integration and a dotted line indirect integration.

Indirect integration

While the indirect integration is outside the scope of focus in this project, clearly there are significant opportunities for desalination deployment as the cost of renewable energy continues to decrease *and* as the efficiency of desalination increases.

Modular integration: Small-scale/modular desalination technology can be integrated with a wind turbine, solar PV array or other small-scale renewable power generation. This could be done for instance on a container basis or some other form of mobile deployment. In such deployments, a key challenge is the intermittence of power. This can be addressed through energy storage technologies, as well as back-up diesel or natural gas generation. Such technology combinations may be particularly suitable for off-grid/rural or resources exploration applications.

Grid/utility-scale integration: Exciting opportunities lie for instance in the co-location of solar or wind energy farms close to desalination operational locations. As energy storage technologies improve, it may be possible to decouple utility-level solar, wind or other

renewable power generation resources from the grid, thus providing a dedicated renewable power source to desalination plants. Interesting opportunities lie in the 'hybridisation' of renewable power sources with natural gas power generation as a stable power source for utility-level desalination plants. Key barriers to adoption here may lie more around project finance and engineering systems integration, rather than desalination technology *per se*. Nevertheless, improving energy efficiency by desalination technologies makes indirect integration more feasible and cost-effective.

Direct integration

The patent landscape has a specific focus on direct integration solutions, which see the integration of desalination with thermal energy or pressure as energy sources. The type of direct integration that is feasible depends on the desalination technology type. For instance, as reverse osmosis is primarily pressure driven, there have been RO-integrated solutions with wave/tidal and wind energy sources in which renewable energy is converted into pressure rather than electricity. Similarly, some of the thermally driven technologies listed in Table 1 have seen direct integration with solar power or thermal waste heat from industrial sources. We discuss these technologies in detail in Sections 6 and 7.

There are advantages for both direct and indirect integration solutions. Direct integration through heat or pressure can have advantages on a modular level, as it avoids some of the energy losses associated with electricity conversion. However, large-scale renewable energy generation (through, for example, wind or solar PV farms) can provide economies of scale for larger desalination operations (with the possibility of backup energy through diesel or natural gas generators). Location-based differences in renewable energy availability, and technology-based specificities as to what technologies are most easily integrated mean that it is important to develop a range of desalination technologies to allow maximum flexibility for future water systems.

3.4 Key drivers around emerging technologies

Ongoing R&D in the desalination space is facing a very different environment from the R&D efforts of a decade ago. Increased awareness of the importance of renewable energy, increased flexibility around modularity or centralisation of water supplies, better understanding of the environmental impact of desalination technologies, and the widening of potential markets to other emerging markets with income growth are just some of the factors that have led to an acceleration of innovation in this space. We discuss some of these factors in greater detail below.

Energy cost reduction

The increase in energy prices over the last decade has made energy costs a key consideration in water desalination (and water treatment in general). This is related to both 'fuels' that can be used to directly power desalination plants (oil and gas), and energy costs more broadly in the economy (e.g. rising electricity costs due to regulation and investment programmes). Traditional desalination technologies are a particularly energy-intensive industrial process. Hence one of the major drivers in desalination

technology development is decreasing the energy usage. While component cost reduction (see below) can lead to significant energy savings, partial or full integration with renewable energy can lead to significant savings over the operational life of a desalination plant. In remote coastal or island locations where transportation costs can add significant margins on overall fuel costs, desalination - renewable energy integration may already be economically feasible.

Component cost reduction

In order for desalination technology to be mass deployed outside its current main areas of operation (see Figure 3 above), there is a need for a significant reduction in operational costs. There has been much work in this area to date, for example membrane prices for RO technologies have been considerably reduced. Where more novel technologies come to market, the key barrier to entry may not be around technical feasibility, but around achieving operational costs low enough to compete with more established desalination technologies *and* alternatives to desalination (e.g. transport of water by tankers). Some of the novel desalination technology developers have sought to address the cost issue by initially entering less cost-sensitive markets, such as mining or oil & gas. The expectation is that market entry in such industrial niches will help the companies go down the experience curve faster, and reduce operational costs. It should be noted that anecdotal examples and interviews by the authors suggest a general perception that utilities do not 'pay' for innovation, and hence it is difficult to do utility level introduction of commercial-grade technologies where costs are not yet sufficiently low.

Environmental sustainability

CO₂ emissions: In recent years, the CO₂ impact of water treatment technologies has become an increasingly important issue. Legacy systems in particular have a very high energy input, with sometimes utility-scale plants powered by diesel generators. Current utility-scale installations are already becoming more energy-efficient, for instance by using gas-powered generation and grid-integration, but they are still significant contributors to CO₂ emissions. Importantly, there is an awareness among the developer community that wider dissemination of desalination technologies outside key existing markets would require significant reductions in CO₂ emissions. Hence, there is growing clarity of the market need for partial- or full integration of desalination with renewable energy sources.

Brine output: Brine output from desalination plants remains probably the key sustainability problem with desalination. The brine salinity is very often too high for it to be released back into the ocean or a river system, and so costly post-treatment (such as pre-mixing with seawater or deep sea pumping) is required. The temperature could also cause damage to the ecosystem as brine is usually at very high temperature (especially for thermal processes). Furthermore, the brine solution can contain harmful chemicals from the pre- and post-processing procedures. The salinity and the chemical content can not only harm marine ecosystems, but could also contaminate existing ground water sources. All of these issues need to be addressed during the planning of a desalination plant.

Brine management is not an area of focus of this patent landscaping report. However, given the importance of this issue, we are aware of a growing number of research projects and technologies around brine management. We would recommend further research in this area, as the lack of brine management solutions may become a barrier to the more rapid diffusion of desalination technology

Centralised vs. decentralised water systems

The traditional ‘Victorian’ model of water utility systems is typically characterised by large centralised water treatment or processing facilities, distributed to users by a pipeline infrastructure. While the centralised system is almost certain to continue to dominate water system design in large cities, the combination of technological developments and diverse needs of developing countries means that a significant part of water consumption may be done ‘off-grid’ or in a decentralised manner. For instance, remote areas that are non-economic in terms of size or distance from urban centres may require an off-grid/modular approach to water supply. It may also be that a move to decentralised (or smaller unit) water supply could make sense in rapidly growing urban areas where investment requirements for the upgrade and extension of old infrastructure may be unsustainable. More decentralised water supplies also increases security of the supply, especially if the water produced is made available throughout the network. In addition, increased focus on sustainability means that many water-hungry industrial applications (such as food processing, paper and pulp, mining) are developing sustainable/closed-loop systems. Smaller scale units and mobile systems could be used to improve agriculture in water scarce countries. If a unit can be moved between fields together with the rest of the irrigation system it could potentially supply a very large area, assuming that the original saline water supply is available. Hence, in addition to technologies favouring centralised/utility-scale solutions, there is an increasing need for mobile or modular solutions to water requirements.

The ‘decoupling’ of the economics of supply in such locations from the main centralised water system may mean that integrated renewable energy–desalination systems may be best applied in such locations. There is therefore a specific focus around mobility/modularity in this patent landscape report.

Location specific challenges

When desalination systems are required in areas which are off the energy grid, power generation at the source is required. The systems can be powered through conventional energy sources such as Diesel or other fossil fuels, but this requires the fuel to be continuously be transported to the site. In these circumstances, it may be beneficial to integrate the desalination technology with a renewable energy source instead.

In rural areas, inappropriate brine disposal may have significant negative impacts on agricultural land, as it may increase the salinity of the land and runoffs.

Desalination plants can take up valuable space in urban areas.. In urban areas where a growing urban population has growing requirements for potable water, land is at even more of a premium. One solution is to build large desalination plants outside urban areas. However, this incurs cost to transfer the water from the location of production to

the point of use. In developed countries, this infrastructure may already exist, but can be old and prone to leakage. In developing countries this infrastructure will very often not exist and can be very costly to develop.

Decreasing the space requirements of desalination plants and modularisation is therefore a potentially very important area of development. For instance, modular solutions could enable usage of existing and smaller water treatment facilities and allow a gradual build-up of desalination capacity.

4 Patents and patent landscaping

4.1 Patents and IPRs

Intellectual property rights (IPRs) protect the application of ideas and information which have commercial value. In addition to patents, other forms of IPRs include copyright, industrial designs and trade secrets. Patents are perhaps the richest source of information within IPRs, containing structured information that has been 'audited' by patent examiners.

Inventions are patentable when they are genuinely novel and have not been in the public domain before the patent application and are 'non-obvious'. With improved electronic availability of patent data through online databases and search engines, it is also increasingly easy to discover such patents. Hence, effective disclosure and information dissemination thereafter is one of the most important aspects of the patent system (Ordover 1991).

Patents are country-specific documents. Consequently, an invention is only protected in countries where the inventor has a valid patent. The system implemented by the Patent Cooperation Treaty of 1970⁶ (PCT) helps with the harmonisation of the patent application process, while allowing each member country to maintain its own patenting practices regarding the granting of the applications.

Patent applications may be published even though a patent has not yet been granted. Most patent applications filed in countries that are members of the PCT are published within 18 months of the filing date or the priority date. This information, even for patent applications which have not yet been granted, can be used as prior art by patent researchers.

Once a patent has been granted it will exclude other parties from producing, selling, importing or even using similar products in the jurisdiction where a patent has been granted. Patent protection is valid for a limited time, in most jurisdictions for 20 years from date of filing. Either a patent owner can use their invention themselves or alternatively they may choose to license or reassign the patent to a third party, or to withdraw it. A patent is therefore a legal instrument which provides the owner with the right to exclude others from using it, while at the same time providing some level of disclosure of the technology. Once a patent expires, it becomes free for anyone to use as prior art.

4.2 Patents as a source of structured information

Taken together, the patents filed around the world represent a global technology library that contains information on technology concepts, the implementation of those concepts and details of who created and owns them. Patents are a useful indicator of commercially valuable inventions, as patents cost money to obtain and maintain.

⁶ <http://www.wipo.int/pct/en/treaty/about.html>

Usually, individuals and companies are only prepared to invest in securing patents where they believe there is commercial advantage in doing so.

Patents are therefore an important source of structured and highly accurate information about technology, innovative activity, inventors and technology organisations globally. Aggregating patents around an industry or a specific technology can reveal important trends and comparisons about the origins of a technology, how a technology space is evolving, and the evolving composition of industry players, as well as identifying the most important (commercially or scientifically) patent documents in a space. Information based on the analysis of patent data can be a highly reliable information source to support decision-making in both the public and private sector.

The techniques related to data mining and analysis of technology-/industry-specific patent datasets have come to be known as ‘patent landscaping’. Patent landscaping is based on the development of a patent dataset specific to a particular technology space, application area or problem focus. This dataset can be made up of patents and patent applications, as well as patent families, as explained below. Patent applications may be published even though a patent has not yet been granted, which provides early information about innovative activity. Differences in the rates between granted and non-granted patent applications can also provide proxies for the level of genuine inventiveness in a technology space, or provide an insight into industry players’ patenting strategy.

The many uses of patent landscaping include:

- supporting the development of a company’s IP strategy (including freedom to operate, white space and patentability analysis)
- understanding the competitive landscape in R&D-intensive fields
- identifying emerging technologies and technology trends within an industry
- supporting improved targeting of innovation and industrial policies, and evaluation of their impact
- identifying networks of inventors and knowledge flows within industries and between countries

For more detailed information about how patent landscaping can be used in business strategy, see Appendix

Below we outline some key aspects of patent landscaping that provide background to the patent landscaping section of this report.⁷

4.3 Patent landscaping dataset creation methodology

To our knowledge, this is as yet the most extensive and thorough patent mapping effort for the desalination and renewable energy technology space in the public domain. Below

⁷ It is important to emphasise that there are many variations on the patent landscaping methodology. The description below reflects the methodology adopted for this patent landscaping project. WIPO’s compilation of patent landscape reports provides a wider selection of methodologies – see http://www.wipo.int/patentscope/en/programs/patent_landscapes/pl_existing_reports.html

is a description of the key steps undertaken to create the patent datasets, including numbers of patents/families identified during each step. This information should be sufficient for an experienced patent landscaping professional to be able to replicate our results.⁸

Defining the research questions

The first and perhaps most critical step in the development of a patent landscape relates to the development of a thorough and sufficiently detailed technology focus, or definition of the focus space boundaries, with the final user of a patent landscape. As an initial point of entry, we used the WIPO Terms of Reference for the project, which provided a detailed outline of the technology space boundaries. The technology focus was refined and re-confirmed through several discussions with WIPO and IRENA, until a final and detailed technology focus map was developed.

Patent search strategy

On the basis of interviews and desktop research, and on the back of previous researchers' experience in the desalination, water treatment and renewable energy space, we built a technology matrix of the different technology subsystems, or subsectors in the technology space. This information was combined and used to develop an inclusive patent search strategy.

Patents are tagged by various classification codes by the patent examiners dealing with their application, for example IPC (international patent classification) codes, ECLA (European classification), US classification codes. Note that the methodology did not solely rely on IPC codes, as even the use of a highly specific IPC is insufficient to distinguish between different technology systems and components. As illustrated in Figure 6 and Figure 7, we developed a multi-pronged search strategy based on different techniques, in order to minimise the risk of false negatives (i.e. not spotting relevant patents), described in more detail below.

⁸ The authors of the report are happy to provide further information on this report, or to benchmark our processes to those of other organisations.

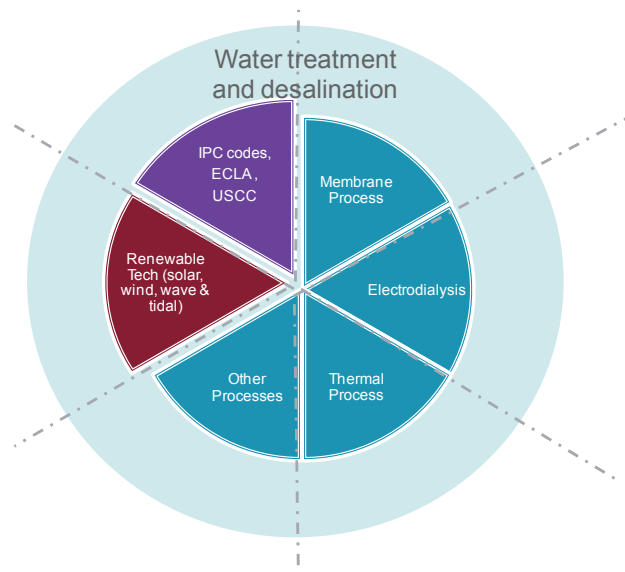


Figure 6: Various aspects of the search strategy for patents relating to desalination and its integration with renewable energy

Lists of keywords were developed for technology categories as well as general desalination systems (to include other emerging inventions not identified by the experts). Boundaries between categories are not clear-cut and there are data overlaps between all of the categories. Most of these categories and combinations generated not only relevant patents, but also patents outside the technology focus areas.



Type	Code	Description
IPC	C02F 103/08	Seawater, e.g. for desalination
IPC	C02F 1/*	Treatment of water, waste water, or sewage
IPC	C02F 9/*	Multistep treatment of water, waste water or sewage
IPC	B63J 1/00	Arrangements of installations for producing fresh water, e.g. by evaporation and condensation of sea water
ECLA	C02F 1/*	Treatment of water, waste water, sewage or sludge
USCC	210*	Liquid purification or separation

Figure 7: Categories of keyword lists and classification codes used for search strategy

We then developed a range of complex ('nested') Boolean search strings to create a wide patent dataset. This was supplemented by additional search strings using patent classification codes and keyword-based Boolean search strings were developed to compile the patent datasets. The IPC-based searches used patent examiner assigned IPC, ECLA and US classification codes as a way of limiting the space. We see IPC-based searches as insufficient on their own, but as a valuable complement to Boolean searches. The patent searches were conducted in the last quarter of 2011. Searches were performed for Title, Abstract and Claims across all available patent databases, using a combination of Boliven.com, ThomsonReuters, and publicly available patent database services (including Espacenet). (See Appendix 3 for detailed patent coverage information.) Table 3 shows the evolution of the dataset as various search string categories were added.

Table 3: The evolution of the dataset

Algorithm	Number of additional patents
1. Desalination and (renewable energy OR technology)	8,974
2. Desalination and IPC codes	5,982
3. Desalination and ECLA codes	4,343
4. Desalination and US classification codes	188

Patent dataset development: iterative dataset cleaning, patent categorisation and expert review

The patent dataset for analysis was built on the back of the Boliven.com infrastructure, which is integrated with CambridgeIP's RedEye workflow and analytics platform on which the dataset refinement and analysis was performed. We developed an initial patent dataset of 19,487. This was then 'cleaned' (removal of false positives) through a number of automated and semi-automated steps.

The first cleaning step included a patent family cleaning – retaining one patent per simple patent family (see Appendix 4 for definition of patent families). This left a dataset of 11,571 patents, each representing a simple patent family, for review and classification. This dataset was categorised by desalination technology and type of renewable energy integration, as well as whether it is a mobile/off-grid system. The dataset and categorisation process then underwent iterative process of expert review, during which various classes of false positives were identified and eliminated where possible. These false positives included patents relating to:

- medical applications for ultra pure water
- medical dialysis
- cleaning oil spills, refining oil
- cooling energy plants
- photographic solutions

Quality control steps:

A number of quality control steps were undertaken, including removal of false positives from the dataset, and benchmarking of the dataset results against initial data points. Patent family members of the cleaned patent dataset were supplemented back from the initial dataset of 19,487. However, not all family members of the selected patents were part of the initial dataset. An in-depth investigation of the missing family members was conducted. The same was done for the references of patent in the final dataset.

After review, approximately 2% of extended family members and less than 1% of the references and missing simple family members were relevant and not yet part of the dataset. These were subsequently inserted. Some of the reasons for non-inclusion in the initial dataset related to data composition and/or peripheral relevance of the patent (e.g. certain family members relate more to the photovoltaic technology and not desalination components).

We are confident that the final cleaned patent dataset is of a 'commercial grade' quality appropriate for industry-level analysis. The dataset is not appropriate for freedom-to-operate analysis, but can be used to accelerate such analyses by providing a detailed and well-defined entry point in this space.

4.4 Patent landscaping analysis methodology

In order to perform the analyses, we used the 'full patent dataset' as well as 'patent families' and 'core patent' datasets as defined below:

- **full patent dataset:** the dataset of all the extended patents family members (granted patents and published applications)
- **the patent families:** extended patent families that make up each dataset and subset – includes also 'orphan' patents, or single-patents families
- **core patent dataset:** core desalination patents identified within each extended family, since within the full set of all extended patent family members, some members may relate to peripheral technologies. Appendix 5 (the patent family dataset) lists these core patents

Kind code duplicates were removed for the analyses to avoid duplicates skewing the results. Data analysis was performed through the RedEye™ workflow and analytics platform, and was supplemented by expert analysis. The sections below outline the analyses that were conducted on the dataset.

Overall trends

This section provides data and numbers based on the relevant patent families and full patent dataset, as well as the core patent dataset. It provides information on how many families include a granted patent and how many include a PCT application. It also provides statistics of the renewable energy integration subsets. Applications time trends were conducted on the patent family dataset. It shows the number of new families per year based on application date of the parent patent (see Appendix 5).

Assignee and inventor analysis

This analysis was conducted on the patent families dataset. An assignee is only counted once for each for a patent family observation. Although assignees can sometimes vary through the patent family (for instance, due to patent re-assignment), we have included in this analysis only the parent patent's assignee as the source of the innovation.

IPC code analysis

By looking at the various trends in IPC, ECLA and US classification codes, we can see how the research focus in a field has changed from one aspect to another. IPC codes are most frequently used, as it is associated with the most patents. This analysis was conducted on the core patent dataset (as patents in the same family may have different IPC codes) but the results were given per family containing the IPC code in one of the family members.

When identifying how the technology space focus has changed over time, the most prolific IPC codes were identified. This was done using the IPC occurrences in the core patent dataset. When an IPC code occurs more often, even in the same dataset, it indicates increased activity in the related subspace.

Geography analysis

The office of first filing was determined from the priority number of the parent patent in each patent family dataset as defined in the table in Appendix 5. The earliest priority number does not have to correspond with the first published patent/application in the family, as the initial application is often submitted in a convenient jurisdiction, while the published application is later submitted in a jurisdiction of more strategic importance to the technology.

The office(s) of second filing was obtained from the full patent dataset. Each country in which an application or granted patent occurs is counted once per family, and the office of first filing is omitted. This means that if there is more than one US application in one family, the US will only be counted once. However, if the two US applications fall within two different patent families it will count for two occurrences.

4.5 Patent landscaping limitations

To our knowledge, this is as yet the most extensive and thorough patent mapping effort for the desalination and renewable energy technology space in the public domain. But a number of challenges raised by this approach are not examined fully in the report owing to resource, time and project scope constraints. Below we list the limitations of the analysis, as well as possible measures that can be taken to mitigate these.

Lag in patent publications

There is a lag of up to eighteen months in the publication of patent data by various patent offices. In a fast-moving field there may be rapid changes, and so future updates to this analysis may be required if it is to be used to support policy objectives. There may

also be opportunities to integrate third-party patent landscape datasets with WIPO and national patent offices' internal datasets to achieve live/real-time intelligence.

Language

The search strings were performed in English. This should capture the vast majority of commercially relevant patents and patent families, at least from their entry into the PCT system. However, owing to language differences a number of patents in the national phase are likely to have been missed. A relatively simple fix would be to expand the search strategy through translation of the search strings across major non-English language patent offices. This could be performed *ex post* with limited duplication, as the dataset could supplement the core dataset developed in this project.

Assignee names

A well-known problem in patent landscaping is that of ensuring accurate and consistent assignee names. We have undertaken several steps to address this. The RedEye™ system includes a name merge facility which can be automated to search for potential matches, which are then confirmed by an operator. It also integrates a library of previous matches from 130+ patent landscaping projects, which includes past M&A information. However, despite our best efforts in ensuring the harmonisation of assignee names, the energy industry is undergoing continuous M&A activities. Following an acquisition, the patent names are on occasion not reassigned, or whole divisions may be spun-off. Up-to-date and accurate assignee name harmonisation are ultimately an industry challenge. We are aware of initiatives underway that could lead to unique assignee (and inventor) IDs which would address this problem.

Technology definition

The process of technology space definition was thorough and combined multiple approaches as well as quality control steps. Yet in selected fields, where there are new technologies under development as yet unknown to the market, it is possible that a small number of technology descriptors may have been missed. In addition, the boundaries of the technology spaces shift over time – technology is ultimately a social artefact, and its uses shift and change constantly. Therefore some radical areas of innovation may have been missed from this study.

.As technology systems are often patented as a group of distinct inventions, there are likely to be technologies and technology subsystems that we have not identified, especially where the subsystems are used more generally than in desalination. This report as focussed on technologies which are specifically adapted to desalination.

Patents vs. patent families

One of the aspects investigated in this study was analysing a dataset of patents vs. patent families. We have found that frequently only a small number of patents belonging to an extended patent family is relevant to our dataset. Where possible we have added the relevant family members to the data through a combination of automated and expert reviewed processes. However there is a limitation on identifying the relevant family

members where there is limited title, abstract and/or claims data available in the patent search platforms used.

Data sources

We have undertaken analysis and data searching in the most extensive way possible. However, in spite of drawing data from a number of sources, title, abstract and claims data is still not available for all patents.

Many assignees work hard to avoid obvious search terms in their patents' titles and abstracts, and we have tried our best to find these through the use of classification assisted search supplementations. In certain circumstances, desalination technologies developed for multiple uses may not list desalination explicitly in the claims, and it would be very difficult to include all such patents.

Top cited patent data was only available for US patents, as we have not yet integrated this data for other authorities with our in-house system.

Finding patent data for LDC countries (listed in Appendix 6) is very difficult. Of the LDC countries, only Malawi and Zambia's information is included in this dataset, but no relevant patents were found in these jurisdictions. Many of these countries will be covered through African Regional Intellectual Property Organization (ARIPO) and Organisation Africaine de la Propriété Intellectuelle (OAPI) filings. When considering the results, it is important to take into consideration that South Africa is not part of ARIPO.

5 Desalination technology patent landscape – Key results and analysis

5.1 Overall trends and patent family analysis

The final clean dataset underwent strict quality control procedures to deliver a dataset of 4,551 patent families and a focus data subset of 921 patent families relating to desalination and renewable energy integration, Table 4 provides a summary of the number of patent families found in each subspace. The average family size is based on the families containing 2 or more patents. The number % of single-patent families is also given for each space.

In addition, we built specific datasets focused around patents related to the integration of renewable energy and desalination in the following areas:

- solar thermal and other waste heat sources (this will be referred to as solar thermal for the remainder of the report)
- photovoltaic (PV) technologies
- wind energy systems
- wave energy technologies
- geothermal energy

Table 4: Patents and patent applications relating to desalination processes and its integration with renewable energy sources

Dataset	Nr Families	% families – last 5 years	Full patent dataset	Core patent dataset	Families with single patent	Largest family size	Average family size ⁹
Desalination overall	4,551	25%	13,358	6,337	60%	219	7
Desalination–renewables overall	921	31%	2023	1173	66%	64	7
Desalination–solar thermal patents	747	29%	1563	922	69%	51	7
Desalination–solar PV patents	59	46%	157	152	59%	52	7
Desalination–wind patents	87	44%	357	136	54%	64	9
Desalination–wave patents	114	45%	357	158	48%	18	6
Desalination–geothermal patents	19	26%	111	34	32%	51	9

As can be seen in Figure 8, while the desalination space had inherited a significant level of prior art in the pre-1980 period, the last 30 years have seen an acceleration of technological activity, in particular since 2000¹⁰.

⁹ Based on families of 2 or more members

¹⁰ The application date for the analysis here is the application date for the parent patent listed for each family in Appendix 5.

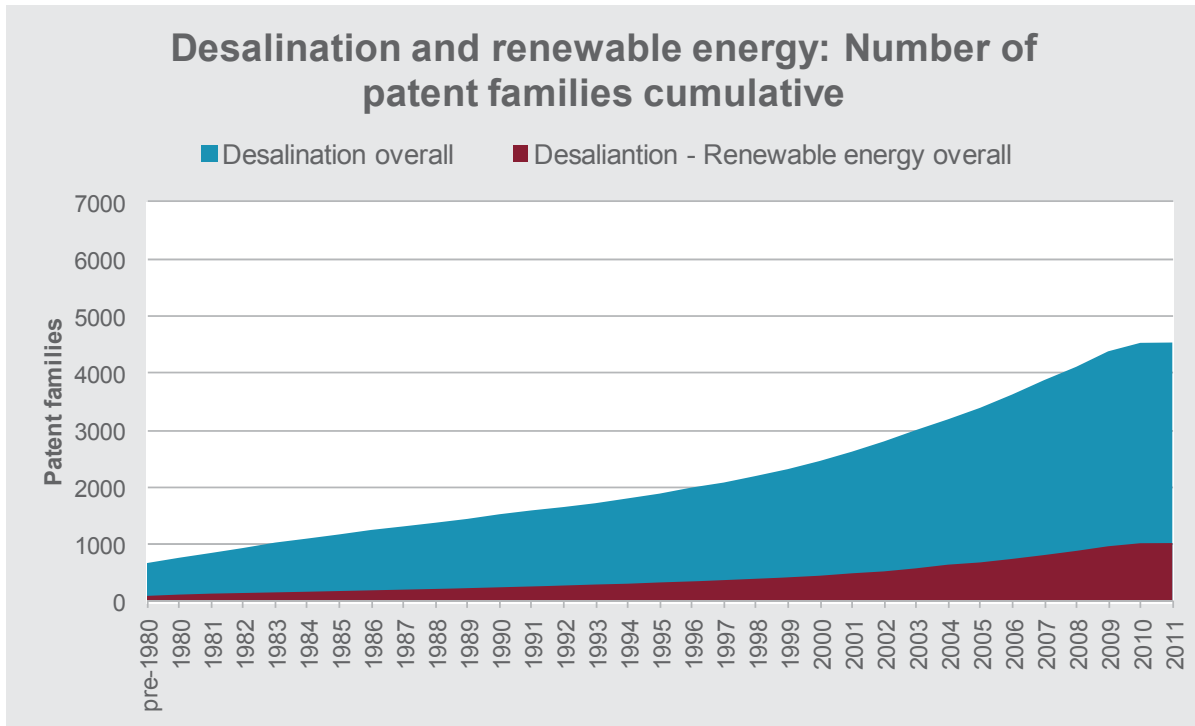


Figure 8: Desalination space – number of patent families by year (cumulative)

Desalination– Renewable energy integration

We identified a total of 921 patent families related to ‘direct’ desalination–renewable energy integration, representing about 20.2% of the overall desalination dataset. The largest number of integration-related patents is related to solar thermal technology. It was interesting to find that solar PV integration was a less prolific field. A possible interpretation is that integration with solar PV tends to take place through ‘indirect’ integration, as defined earlier in the report. The relatively low number of patents related to geothermal energy integration may be related to the inland location of geothermal resources in many countries, as well as due to ‘indirect’ integration. In addition, geothermal-integrated technologies may also be integrated with other waste heat sources, and therefore may fall in the solar thermal and waste heat dataset, with geothermal energy not being explicitly mentioned as a source of the heat.

In order to capture the level of recent innovation in a space we analysed a subset of results for the last 5 years. We found that 25% of all desalination technology patent families originate in the last 5 years, and 31% respectively for desalination–renewables. This supports a view that renewable integration is a ‘younger’ space compared to desalination overall. For solar thermal and waste heat integration, which is by far the larger desalination–renewable energy integration subspace, less than a third of the patent families were filed in the last 5 years. However, for solar PV, wind energy and wave and tidal energy this number is between 40% and 50%. The geothermal energy integration dataset is the smallest, related to the factors listed above.

Patent families results analysis

Patent families in the focus dataset were fully categorised by energy integration and desalination technology class and, to the extent possible, by whether the technology is intended for large scale of mobile applications. This was done using automated ranking and categorisation procedures which consider patent title abstract and claim data, in conjunction with expert review. Note that the patent family definition we used means that a single patent can form a patent family. Patent analysts differ in their views of whether a 'single patent' patent family should be seen as similarly meaningful as a patent family with many members. For instance, for many major US companies the majority of their patent portfolio consists of 'single patent' patent family, where the patent is filed through the US PTO. Furthermore, where the analysis is focused on more novel technologies, it is likely that we will observe 'younger' patent families which may be yet to expand. Other analysts argue that, especially where smaller economies are concerned; it is only when a patent family is extended outside the parent country that we can see a commercialisation commitment by the owner.

Our analysis is neutral in this regard, but to accommodate an analysis from either perspective point we undertook some further analysis (see Table 4). The results show that the most active innovation spaces (integration of desalination with thermal energy) also have the highest proportion of 'single-patent' patent families (69% respectively), while smaller spaces such as Solar thermal, wind, wave & tidal and geothermal integration have a smaller proportion (32% to 59%). We also calculated the average patent family size for patent families with *more than 1 member*, thus stripping out the 'noise' from the 'single patent' patent families. We found that the average patent family has between 6 and 9 members. Moreover, this does not seem to be particularly related to the overall size of the technology space. Possible interpretations of these findings could be that:

- more dynamic spaces have a higher number of small entrants, who due to resource constraints may only file one patent or abandon experimental technology
- a 'younger' technology would have had less space to develop 'mature' patent families
- when we strip out the 'single patent' patent families, patent family size is similar across technology spaces, possibly reflecting similar corporate IP management styles

Further analysis may be possible using econometrics to confirm the validity of these points across a wider set of technology spaces.

It is apparent from Figure 9 that the integration relating to solar thermal and other waste heat sources have a much longer history than the other sources, except for wave and tidal energy integration, which also dates back further than the other technologies. Wind energy integration come a close third, but although the wind energy patent dataset initiates later than the wave and tidal dataset it increases at a higher rate. This indicates that wind energy integration, although smaller than wave and tidal energy overall, is a higher growth technology field. Within this analysis we are unable to provide a definitive answer about the reasons behind this. A possible interpretation could involve comparing these trends to the general patenting trends for these renewable energy solutions. It may

be that the size of the subspaces is not an indication of their suitability for desalination integration, but rather a result of the relevant renewable energy technology patent landscapes. Further research would be needed to verify such interpretations.

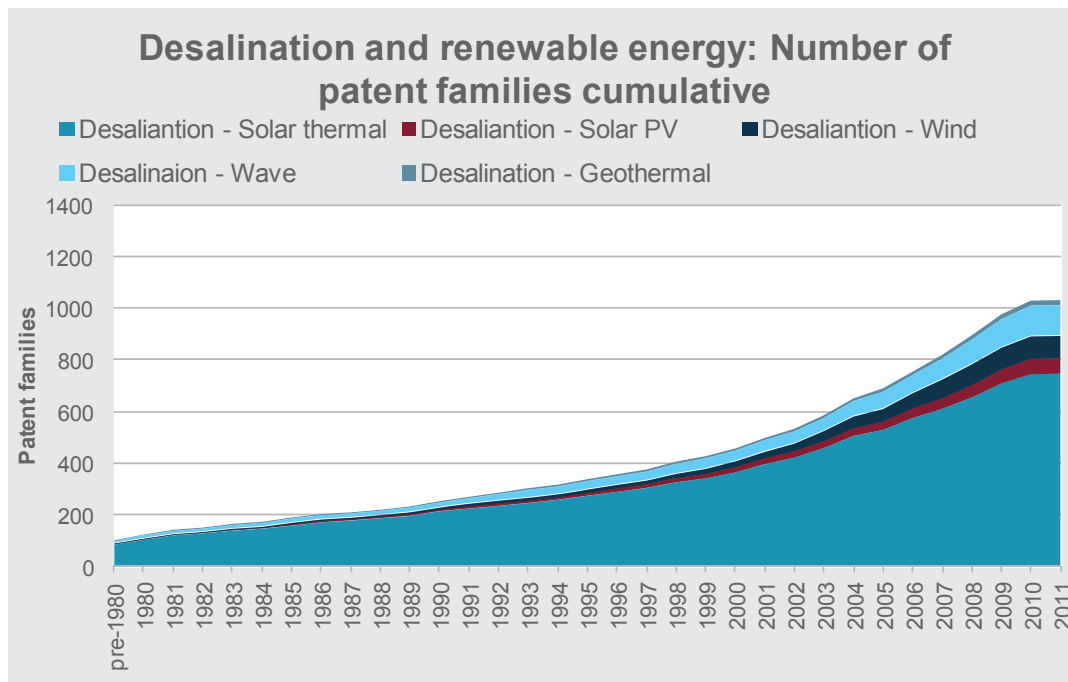


Figure 9: Desalination – renewable energy integration – number of patent families by year (cumulative)¹¹

Table 5 shows how many patents from each of the renewable energy sources datasets fall in each desalination technology category. It is evident that solar thermal (which is the largest patent subset) is most focused around ‘thermal’ and ‘other’ technologies, and has very few patents related to membrane-type technologies (such as RO). As is to be expected from a pressure-driven technology, most of the membrane-based integration is with wind and wave energy.

Table 5: Number of patent families for each desalination technology and renewable energy source

	Solar thermal	Solar PV	Wind	Wave	Geothermal
Total number of families	747	59	87	114	19
Membrane	65	16	20	25	3
Thermal	358	23	26	36	15
Other	441	24	50	75	3

¹¹ Note that the total number of patents shown in the renewable energy integration graph is higher than 921 as there are some overlaps between the datasets which are not captured in the graph.

5.2 Key assignees

Top assignees – All time

Of the top 20 assignees in the desalination space, the vast majority are Japanese companies. However, when we consider patents filed in the last 20 years, Japanese companies are much less actively innovating in this space. Table 6 shows the rank of the top 20 assignees by number of patent families, and also their activities in the renewable energy integration subspaces. A number of the companies have activity in integrating solar thermal and waste heat sources, and there are a few instances of integration with solar PV and wave and tidal energy sources. No integration of these companies' technologies with wind or geothermal energy sources were found.

Table 6: Top 20 assignees – number of patent families per space¹²

Ranking (overall desalination)	Assignee	Overall	Solar thermal	Solar PV	Wind	Wave	Geo-thermal
1	mitsubishi heavy industries ltd	119	8				
2	hitachi ltd	118	10	1			
3	japan organo co ltd	99					
4	kurita water ind ltd	87					
5	ebara corp	75	6				
6	toshiba corp	49	6				
7	toray industries inc	42					
8	hitachi zosen corp	37	7			1	
9	chen ming	33	2				
10	ishikawajima harima heavy ind co ltd	31					
11	nitto denko corp	29					
12	sasakura engineering co ltd	26	4	1			
13	suh hee dong	25					
14	general electric company	23	2				
15	mitsui shipbuilding and engineering co ltd	19	2	1			
16	asaahi glass co ltd	18					
17	lee sang ha	16	2				
18	united states of america as represented by the secretary of the interior	14	1			1	
18	university tianjin	14	1				
18	asaahi chemical ind	14					
18	nippon rensui co ltd	14					

¹² The energy spaces refer to *integration* with desalination technologies.

The following discussion focuses on companies and institutions, and does not include individuals.

Mitsubishi Heavy Industries (Japan) is the assignee with the most patent families. This position reflects its major role in the desalination industry, especially in the construction of large desalination plants. It is interesting that it also owns patents in the solar thermal/waste heat space. It is not very active in the renewable energy integration spaces, and most of its solar thermal and waste heat integrated technologies date from the 1970s and 1980s. In the last 5 years, Mitsubishi Heavy Industries only accounts for 10 of the patent families, overtaken by General Electric, which has 18 of its 13 patent families in the last 5 years. It has also been overtaken by Kurita Water Industries, with 12 families in the last 5 years.

Hitachi (Japan) has moved down from 2nd rank over all time, to 18th if we consider only patents from the last 5 years. It also shows activity in the solar energy space, however, as with Mitsubishi, most of its solar-related technologies, including the one referring to solar PV integration, date back to the 1970s and 1980s.

Japan Organo (Japan) has moved down to 8th rank with only 7 families in the last 5 years. It produces both thermal and EDI desalination units, but also manufacture systems for producing ultra pure water. It does not hold patents relating to integration with renewable energy sources.

Kurita Water (Japan) is one Japanese company that has managed to maintain its market share in the desalination space with a continuous focus on patenting in the last 5 years.

Ebara (Japan) is one of the leading pumps manufacturers for the desalination space, providing pumps both for RO and thermal desalination plants. Its patent portfolio also indicated a number of families in the solar thermal desalination technology space, but no products relating to this portfolio were found.

Toshiba (Japan) drops from 6th to 11th when we only consider patents from the last 5 years. It has a number of patent families in the solar thermal energy integration subspace, but these date from the 1970s and 1980s. Currently, it is commercially involved in control systems and energy recovery for desalination systems.

Toray Industries and Nitto Denko (Japan) are the two main RO membrane providers worldwide. Their patenting activity has also decreased compared to other companies in the space and in the last 5 years.

Other Japanese contracting companies which show a marked decrease in patenting activity in the last 5 years include Hitachi Zosen, Sasakura Engineering, Mitsui Shipbuilding and Engineering, Asahi Glass, Asahi Chemical Industries and Nippon Rensui. Where these companies' portfolios include integration with renewable energy sources, their patents typically date from the 1970s and 1980s. Ishikawajima Harima Heavy Industry (Japan) was involved in constructing Algeria's first desalination and electricity generating plant as well as the construction of four LNG plant boilers.

General Electric (US) is a relatively new player in the space compared to the Japanese companies (see Table 7). The majority of its patent families originate in the last 5 years, some of which are integrated with the solar thermal energy supplies.

The **United States Government** (US), through the Ministry of Interior, has a patent portfolio in the desalination space which includes 14 patent families. These all date from the 1970s, when there was a \$160mIn R&D programme around desalination. However, a patent family relating to the integration with solar energy and EDR technology was filed in 1998. A further 5 patent families are held by the US Navy, the latest of which was filed in 2007. Access to fresh water is an important military requirement, and will frequently require production away from conventional power sources. It is possible that additional solutions exist in this space, but are not covered by patents due to security-related considerations.

University Tianjin (China) is in the top 20 assignees overall, but most of its patent portfolio was filed in the last 5 years. This means that even though it ranks 18th in the overall dataset, it is ranked 6th when only considering the patents filed in the last 5 years.

Finally, it is worth noting that while the Top 20 ranking is dominated by Asian assignees, a wider focus around companies with a smaller number of, but well-developed patent families reveals a higher geographical spread. An interesting question for future research could be to match products in commercial operation to number (and size) of patent families, and more broadly on cross-national differences in patenting strategy. For instance, it may be that US and EU companies in the engineering space have a lower but more targeted number of patents and patent families than Japanese corporations. It should also be noted that some of the most interesting and disruptive technologies are unlikely to enter the rankings, as these are typically characterised by one or several patent families.

Top assignees – Last 5 years

Part of the problem in considering an ‘all time’ analysis is that some of the legacy patents (and the related technologies) may be abandoned or outdated, and the company itself may have had a shift of strategy. ‘Time-slicing’ the analysis can reveal significant changes in the industry structure. Our analysis of patenting in the last 5 years (see Table 7) shows a slightly different picture. Mitsubishi Heavy Industries is now ranked 5th (from 1st), General Electric is ranked 2nd, and Germany’s Siemens is now in the Top 10. Interestingly, two of the top assignees are individuals, Suh Hee Dong and Lee Sang Ha, with the vast majority of their patents only filed in Korea (we were unable to identify any corporate entity to whom they may be affiliated). Their patent families are mostly ‘one member’ patent families, so this may indicate independent serial inventors, rather than a proxy relationship with a corporate assignee.

Table 7: Top 10 assignees by patent families for desalination technologies in the last 5 years

Rank	Assignee	Number of patent families
1	SUH HEE DONG	20
2	GENERAL ELECTRIC COMPANY	18
3	LEE SANG HA	15
4	KURITA WATER IND LTD	12
5	MITSUBISHI HEAVY INDUSTRIES LTD	10
6	DOOSAN	9
6	UNIVERSITY TIANJIN	9
8	JAPAN ORGANO CO LTD	7
8	KOBELCO ECO-SOLUTIONS CO LTD	7
8	SIEMENS AG	7

Key assignees for solar thermal energy integration

Table 8 shows the Top 10 assignees in the desalination and solar thermal technology space. The first 6 assignees are also found in the top 20 assignees overall. Companies with more than one patent family in this space filed in the last 5 years include Massachusetts Institute of Technology, University of North China Elec. Power, Saltworks Technologies, Mitaki Koki, General Electric and Doosan.

Table 8: Top 10 assignees by patent families for desalination-solar thermal energy integration

Rank	Assignee	Number of patent families
1	HITACHI LTD	10
2	MITSUBISHI HEAVY INDUSTRIES LTD	8
3	HITACHI ZOSEN CORP	7
4	EBARA CORP	6
4	TOSHIBA CORP	6
6	SASAKURA ENGINEERING CO LTD	4
7	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	3
7	JOHANNES MARKOPULOS	3
7	IIDA TOMIMARU	3
7	VG GOL PROEKTNO IZYSKATELSKIJ	3

Key assignees for solar PV energy integration

Most assignees in the solar PV energy integration space only included one patent family, which makes it unsuitable for analysing assignee trends.

Key assignees for wind energy integration

Table 9 shows the assignees which own at least 2 patent families in the desalination–wind energy integration space. From the MSC power portfolio, there is only one granted patent, which was granted in the US (US7552589B2) and reassigned to Airbus Operations Ltd, UK in April 2011. Both Enis Windgen and Aerodyn Engineering have

products on the market which are discussed in more detail in the case studies section (Section 7).

Table 9: Top assignees: desalination–wind energy integration (with at least 2 patent families)

Assignee
MONTENAY RENE VINCENT
MSC POWER S PTE LTD
ENIS WINDGEN
TORRES MARTINEZ M
YU LIQUN
AERODYN ENGINEERING GMBH

Key assignees for wave and tidal energy integration

Table 10 shows the assignees with at least 2 patent families in the desalination wave and tidal energy integration space. ecOcean renewables is described as a case study in Section 7. Seahorse Wave Energy S/A appears to be a Brazilian company, but very little information about it is available.

Table 10: Top assignees: desalination–wave & tidal integration (with at least 2 patent families)

Assignee
CHILTON WILLIAM
ECOCEAN RENEWABLES LTD
OCEAN RESOURCES ENGINEERING INC
OVADIA SHMUEL
SALTER STEPHEN H
SEAHORSE WAVE ENERGY- ENERGIA DAS ONDAS S/A
UNIVERSITY OF DELAWARE

Geothermal energy integration

None of the assignees in this space had more than one patent family. As mentioned earlier, desalination technologies that can integrate with geothermal energy sources should also be able to integrate with other sources of waste heat and therefore geothermal energy may not be specified in the patent. There are also factors that make geothermal a less likely energy source for direct integration. Yale University has a patent in this space which is discussed as a case study in Section 7.

5.3 Key inventors

Most of the top inventors are related to the top Japanese assignees, with the exception of Cai Wei (ranked 15th) and Xiong Rihua (ranked 18th), both from GE. A number of inventors are themselves listed as the assignees on their inventions with no company listed (e.g. Chen Ming (China), Suh Hee Dong (South Korea), Lee Sang Ha (South

Korea). Further information on inventor relationships is provided in the patent-based inventor network maps shown in Section 7.

Table 11: Top 20 inventors in the desalination technology by patent families

Rank	Inventor	Number of patent families	Related assignees
1	CHEN MING	33	CHEN MING
2	TAKAHASHI SANKICHI	27	HITACHI LTD, HITACHI PLANT ENG & CONSTR CO LTD, AGENCY OF IND SCIENCE & TECHNO, TOKYO GAS CO LTD
3	SUH HEE DONG	25	SUH HEE DONG
4	EBARA KATSUYA	21	HITACHI LTD, HITACHI PLANT ENG & CONSTR CO LTD, TOKYO GAS CO LTD
5	TSEJTLIN ILYA M SU	18	ALEKSEEV NIKOLAJ A SU, STEPANOV VLADIMIR G SU, TSEJTLIN ILYA M SU, KOLESNIK NIKOLAJ N SU, NELEPIN RONALD A SU, MILOVIDOV RATMIR G SU, LEVIN ARKADIJ Z SU, TSNII SUDOVOGO MASHINOSTROENIYA, LE OB PROLETARSKIJ ZAVOD, TSNII SUDOVOGO MASH LE OBEDINENIYA PROLETARSKIJ ZAVOD
6	LEE SANG HA	16	LEE SANG HA
7	IWAHASHI HIDEO	15	MITSUBISHI HEAVY INDUSTRIES LTD
7	MILOVIDOV RATMIR G SU	15	ALEKSEEV NIKOLAJ A SU, STEPANOV V, TSEJTLIN ILYA M SU, KOLESNIK NIKOLAJ N SU, NELEPIN RONALD A SU, MILOVIDOV RATMIR G SU, LEVIN ARKADIJ Z SU
9	SATO SHIN	14	KURITA WATER IND LTD, SATO SHIN
9	NISHIMURA YUSAKU	14	HITACHI LTD
9	OSUMI KATSUMI	14	HITACHI LTD
12	HIROSE MASAHIKO	13	NITTO DENKO CORP, HYDRANAUTICS, YAMAMOTO KAZUO
12	IZUMI KENKICHI	13	HITACHI LTD, HITACHI PLANT ENG & CONSTR CO LTD, AGENCY OF IND SCIENCE & TECHNO
14	ODA NOBUHIRO	11	KURITA WATER IND LTD, JAPAN ATOM POWER CO
15	CAI WEI	10	GENERAL ELECTRIC COMPANY
15	NOSHITA MASANOBU	10	KOBELCO ECO-SOLUTIONS CO LTD, KOBE STEEL LTD, NITTO DENKO CORP
15	USUI SHINICHI	10	EBARA CORP
18	XIONG RIHUA	9	GENERAL ELECTRIC COMPANY
18	YAMADA AKIRA	9	HITACHI LTD
18	TANAKA KENJI	9	MITSUBISHI HEAVY INDUSTRIES LTD, ARISAWA MFG CO
18	OSAWA KIMINOBU	9	KURITA WATER IND LTD
18	MIYA SHIGEO	9	EBARA CORP
18	IGARASHI HIROO	9	HITACHI LTD
18	NOMURA MAKOTO	9	KURITA WATER IND LTD
18	INOUE OSAYUKI	9	EBARA CORP

5.4 Classification code analysis

Figure 10 shows the number of patent families for each of the top 5 IPC codes. By far the largest proportion of the dataset lies in the water treatment code (C02F), as would be expected. Patent families not falling into this category could be due to the fact that they only cover a single aspect of the desalination process, or alternatively could simply be due to limited data availability of the IPC codes. Just less than 50% of the patents fall in the category describing physical or chemical processes of separation (B01D). In essence, this covers how most desalination processes remove dissolved salts and other compounds from water solutions. The next three IPC codes all refer to aspects of the desalination process: B01J also deals with physical and chemical separation, F24J deals with heat production and use (an important aspect of the thermal and even some of the other desalination techniques), and F04B relates to pumps, which, although not directly a desalination technique, relates to the very important function of moving water around the system during the desalination process.

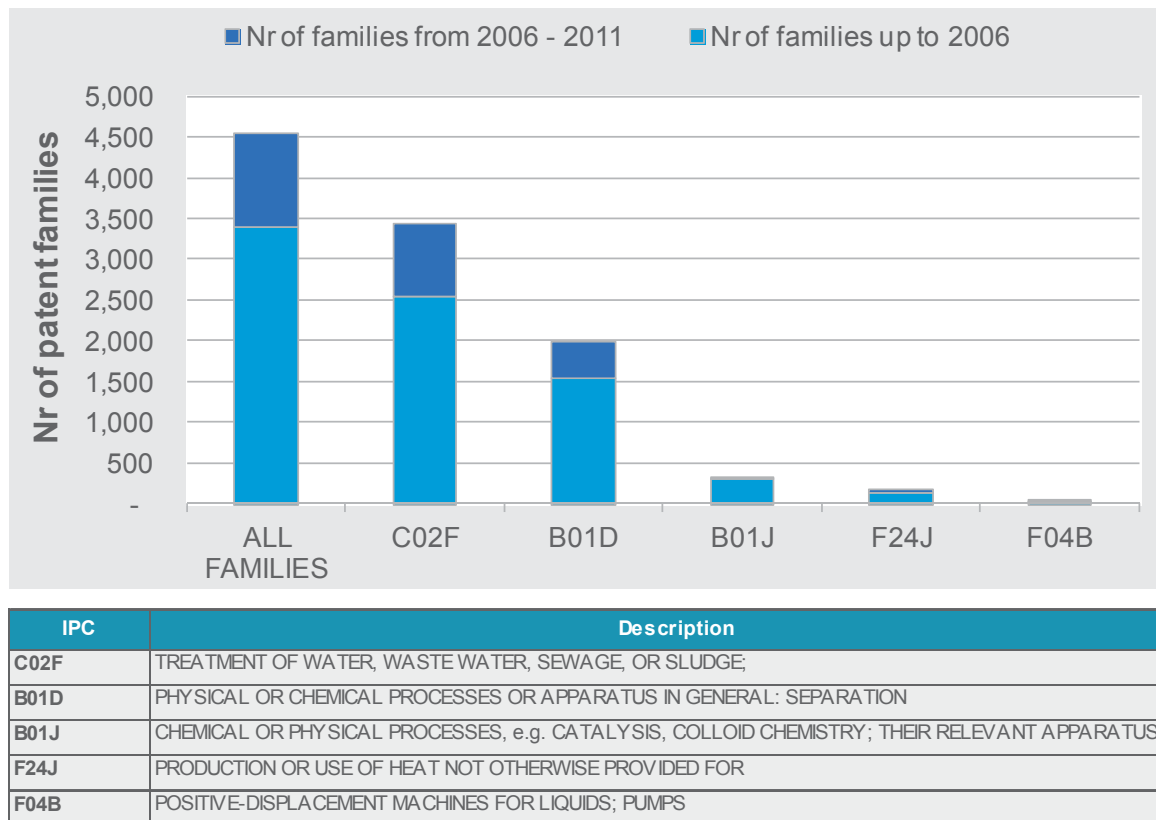
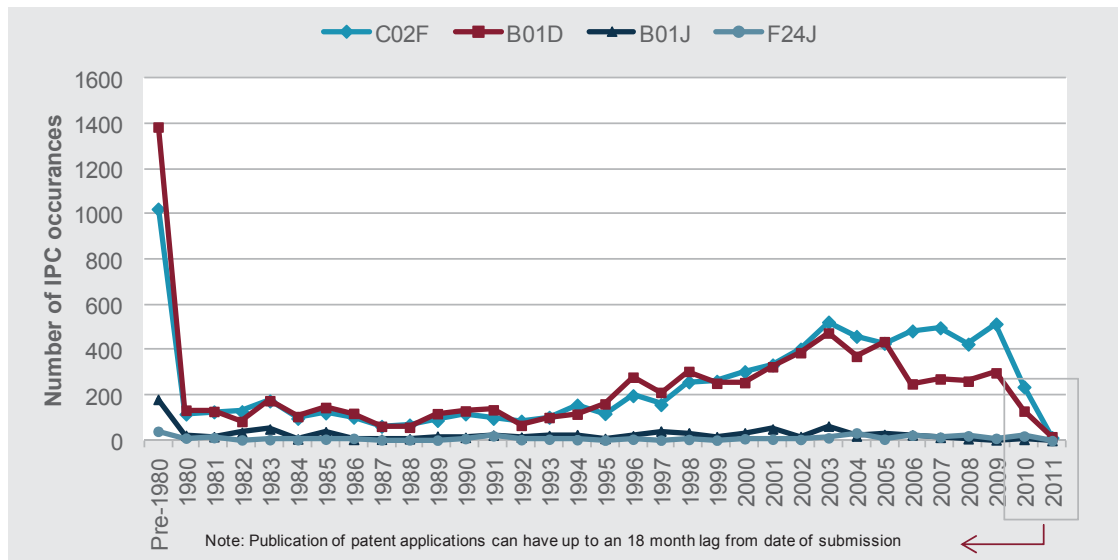


Figure 10: Desalination overall space: number of patent families in top 5 IPC codes

Figure 11 shows the number of IPC occurrences in the patent dataset. This makes clear that the water treatment and separation aspects of desalination specifically have received more focus in recent years, whereas earlier patents deal with various components of the desalination systems more equally. One way of interpreting this is that recent patents have been more focused on a single aspect of the technology compared to broader, earlier patents. It is also clear that there is a legacy of patents falling within the 2 main IPC code categories from before 1980.



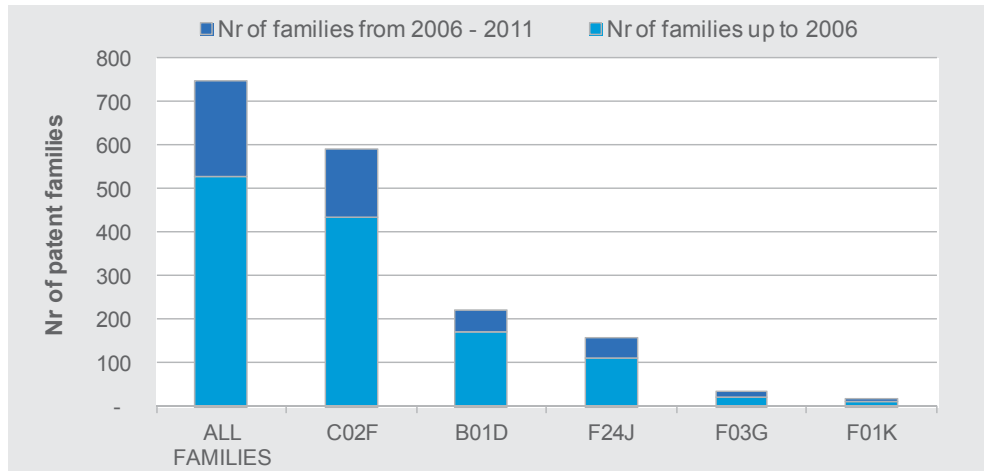
IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
B01J	CHEMICAL OR PHYSICAL PROCESSES, e.g. CATALYSIS, COLLOID CHEMISTRY; THEIR RELEVANT APPARATUS
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR
F04B	POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS; PUMPS

Figure 11: IPC distribution in overall desalination space

Classification codes for solar thermal and other waste heat desalination

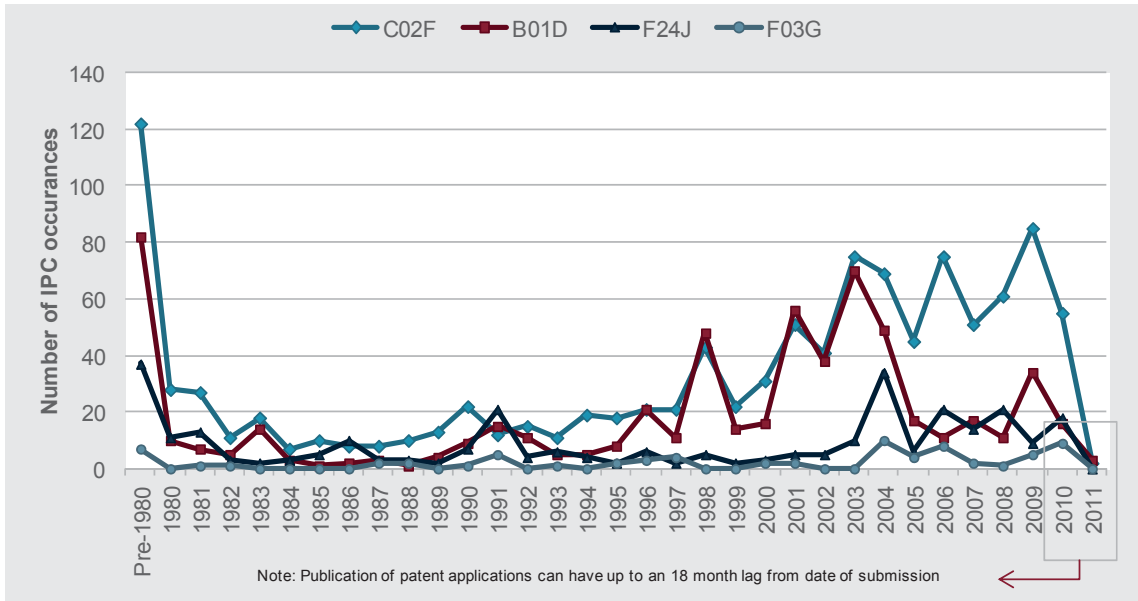
The top two IPC codes are the same in this space as in the overall desalination space (see Figure 12). However F24J ('Production or use of heat not otherwise provided for') has now moved into third place and is followed by two more IPC codes relating to heat and heated water.

The time trends of IPC codes in the dataset reflect a similar trend as in the overall desalination space (see Figure 13). From 2003, there is a sudden drop in the focus on separation techniques, although water-treatment-related innovations continue to increase. Around the same time, there is also a small increase in thermal-related patents. This could indicate that the focus of patenting in this space has moved away from desalination techniques *per se* and is becoming more focused on the integration with thermal energy sources. As with desalination technology in general, solar thermal desalination also shows a significant legacy of patents filed before 1980.



IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR;
F03G	SPRING, WEIGHT, INERTIA, OR LIKE MOTORS; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR;
F01K	STEAM ENGINE PLANTS; STEAM ACCUMULATORS; ENGINE PLANTS NOT OTHERWISE PROVIDED FOR; ENGINES USING SPECIAL WORKING FLUIDS OR CYCLES;

Figure 12: Desalination–solar thermal energy integration – number of patent families in top 5 IPC codes

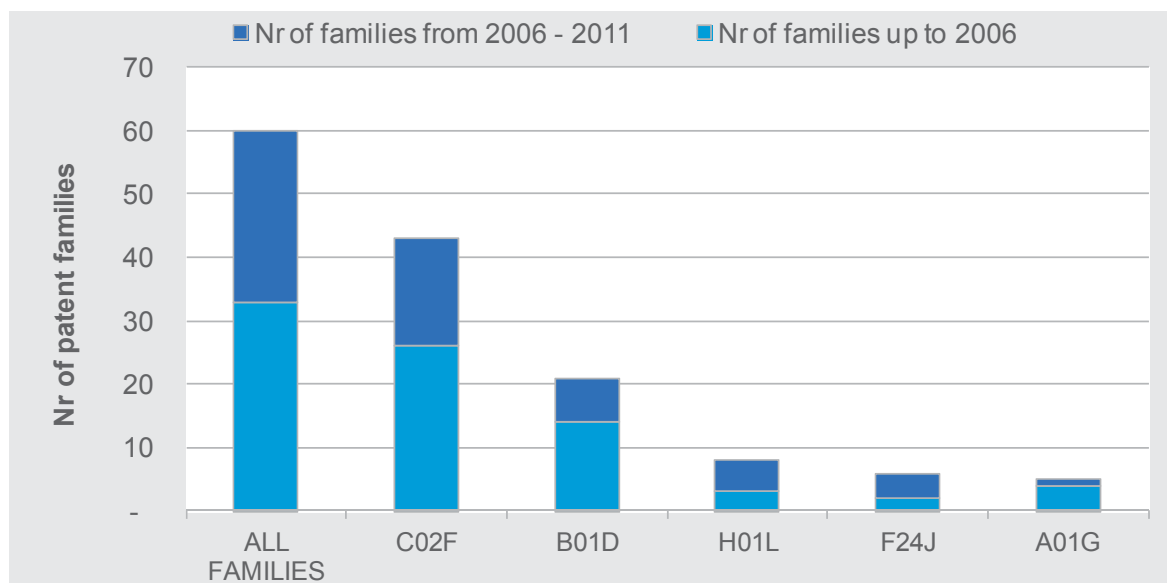


IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR;
F03G	SPRING, WEIGHT, INERTIA, OR LIKE MOTORS; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR;
F01K	STEAM ENGINE PLANTS; STEAM ACCUMULATORS; ENGINE PLANTS NOT OTHERWISE PROVIDED FOR; ENGINES USING SPECIAL WORKING FLUIDS OR CYCLES;

Figure 13: IPC distribution in desalination – desalination–solar thermal energy integration

Classification codes for solar PV desalination

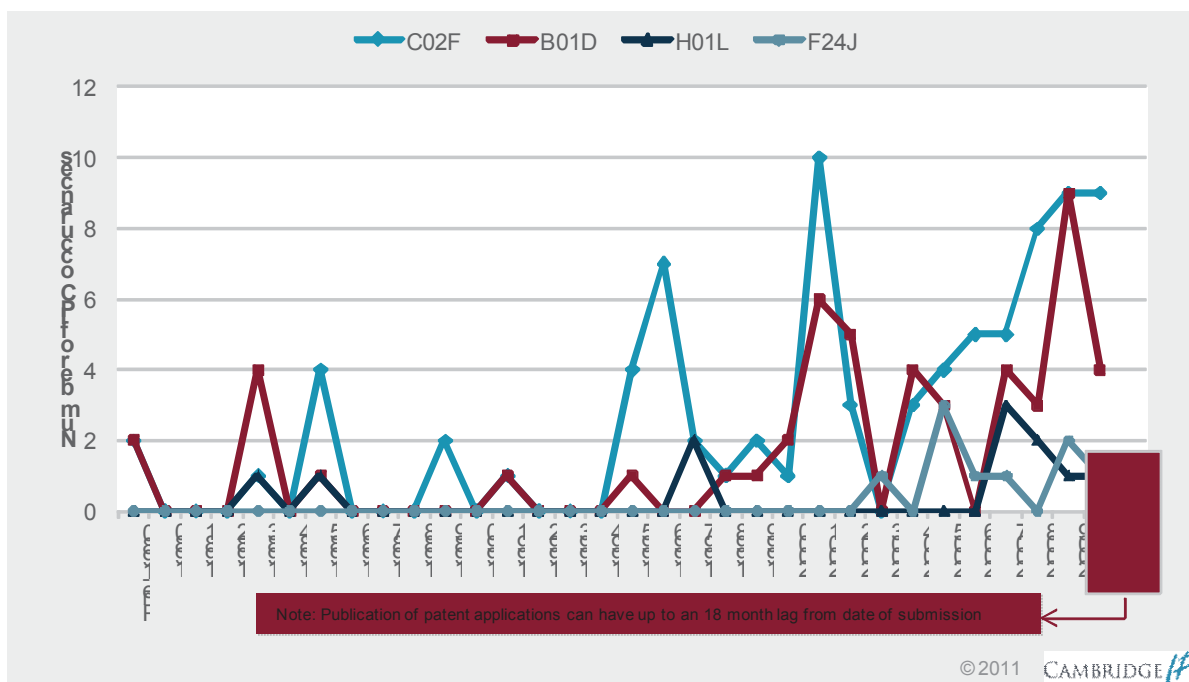
Figure 14 shows the number of patent families per IPC code for desalination and solar PV integrated technologies. The two top IPC codes (C02F and B01D) are the same as for overall desalination space. The third most common is semiconductor devices (H01L), an IPC code relating to solar PV devices specifically. The fourth IPC code (F24J) concerns heat production, which can be explained in one of two ways. Either it is an indication of desalination patents that list the integration with solar power in general, so both solar thermal and solar PV will be included in these patents; or it could relate to devices that use the waste heat generated by solar PV devices to drive desalination (in general, the PV panels heat up and need to be constantly cooled to operate at an optimal temperature). The last of the top 5 IPC codes is relates to a specific application of the solar-powered desalination units in agriculture.



IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION;
H01L	SEMICONDUCTOR DEVICES; ELECTRIC SOLID STATE DEVICES NOT OTHERWISE PROVIDED FOR;
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR;
A01G	HORTICULTURE; CULTIVATION OF VEGETABLES, FLOWERS, RICE, FRUIT, VINES, HOPS, OR SEAWEED; FORESTRY; WATERING

Figure 14: Desalination–solar PV energy integration – number of patent families in top 5 IPC codes

The IPC trends over time in Figure 15 provide some more in-depth information about the evolution of innovation in this space. Prior to 1994, there were some isolated occurrences of patenting activity in the desalination–solar PV integration space. From 1994, there is an increase in activity in this space, the majority of which is accounted for by the top 2 IPC codes. From 2002 there is increased activity in usage of heat energy, whereas the inclusion of aspects of the semiconductors in the solar PV panels remains isolated throughout the technology space’s evolution.

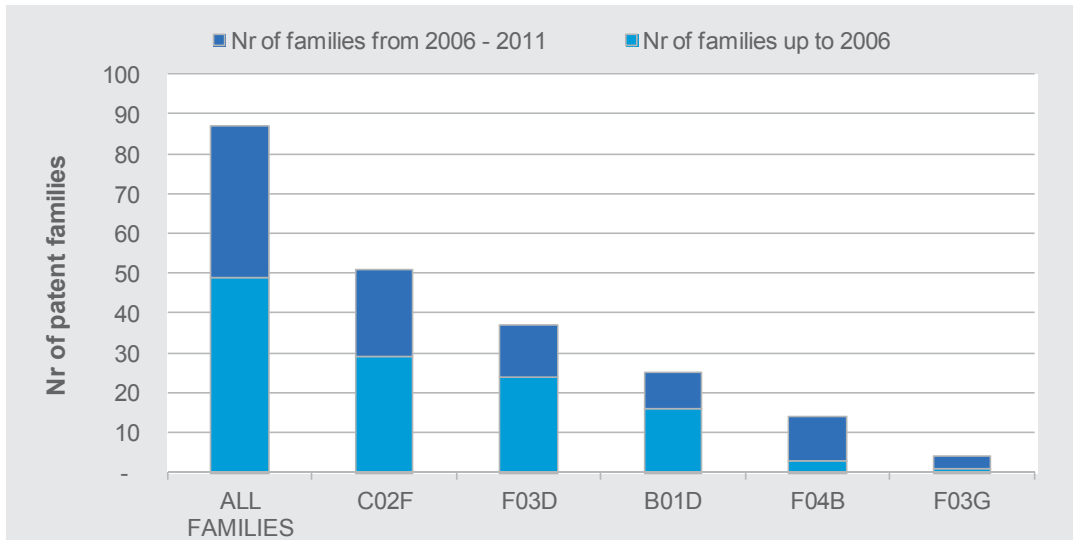


IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION;
H01L	SEMICONDUCTOR DEVICES; ELECTRIC SOLID STATE DEVICES NOT OTHERWISE PROVIDED FOR;
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR;
A01G	HORTICULTURE; CULTIVATION OF VEGETABLES, FLOWERS, RICE, FRUIT, VINES, HOPS, OR SEAWEED; FORESTRY; WATERING;

Figure 15: IPC distribution – desalination–solar PV integration

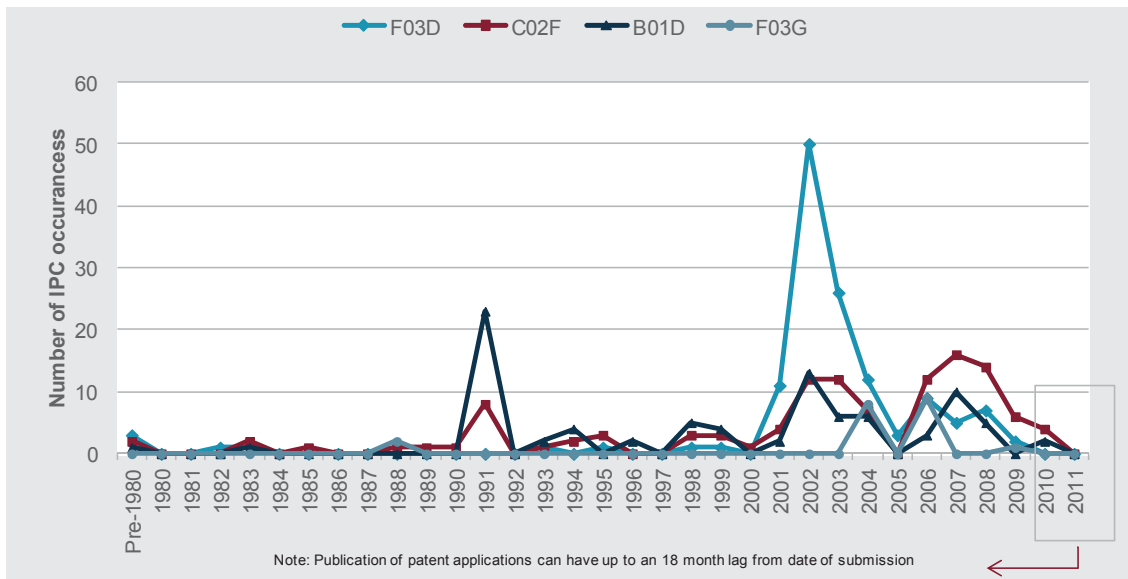
Classification codes for wind energy desalination

In the wind energy desalination subspace, the IPC code for wind motors (F03D) has displaced that of separation techniques from the second position (see Figure 16). If we consider Figure 17, it is clear that this is due to a spike in activity in this space in 2002. Upon closer investigation, we have found that this is due to two large patent families (WO02063165A1 and WO02097265A1) by wind turbine manufacturer Aerodyn, which has developed an integrated wind energy desalination system. The high ranking of F04B (which deals with pumps) in this dataset is an indicator of the direct integration option of wind energy desalination systems, where the pressure generated by the wind turbine is used directly to pump water through the desalination system.



IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
F03D	WIND MOTORS;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
F04B	POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS; PUMPS;
F03G	SPRING, WEIGHT, INERTIA, OR LIKE MOTORS; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR;

Figure 16: Desalination-wind energy integration – number of patent families in top 5 IPC codes



IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
F03D	WIND MOTORS;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
F04B	POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS; PUMPS;
F03G	SPRING, WEIGHT, INERTIA, OR LIKE MOTORS; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR;

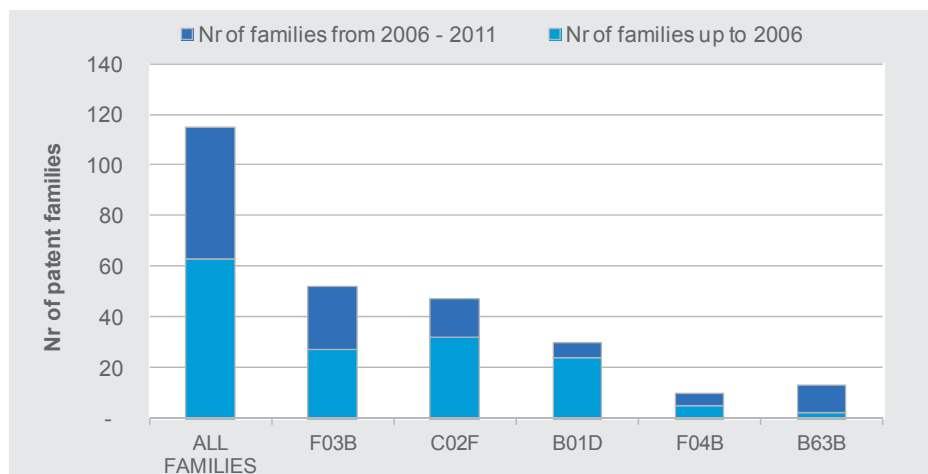
Figure 17: IPC distribution – desalination – wind energy integration

The evolution of IPC code occurrences in this space (Figure 17) show that activity in the main IPC code (C02F) is fairly recent, only starting from the early 1990s. The top two IPC codes (water treatment and wind motors) start to increase gradually after an initial spike in 1991 (due to a number of patents by Alfa Laval). Initial increase in activity is due mainly to the two main desalination IPC codes found across all the datasets (C02F and B01D), then in 2002 the peak in the wind motors IPC (F03D) occurs due to the Aerodyn patents. From 2003, the dataset sees an increase in patents relating to alternative energy motors, which form an important part of directly integrated wind energy desalination systems. This shows how individual companies’ patenting activities can dominate a young/small space’s composition.

Classification codes for wave and tidal energy desalination

Figure 18 shows that, unlike for solar and wind energy, which has water treatment as the top IPC code, in the wave and tidal desalination space the main IPC code relates to machines or engines for liquids, which is one of the top 10 IPC codes in the desalination space, but by definition is also an important IPC code for wave and tidal energy generators. The superposition of the effect from both spaces means that this code moves into the leading position in the wave and tidal desalination space. As with the solar PV space, we also see the presence of an application-related IPC code in the wave and tidal desalination space – B63B equipment for shipping. Desalination and water purification systems are very important for shipping, not only to produce drinking water,

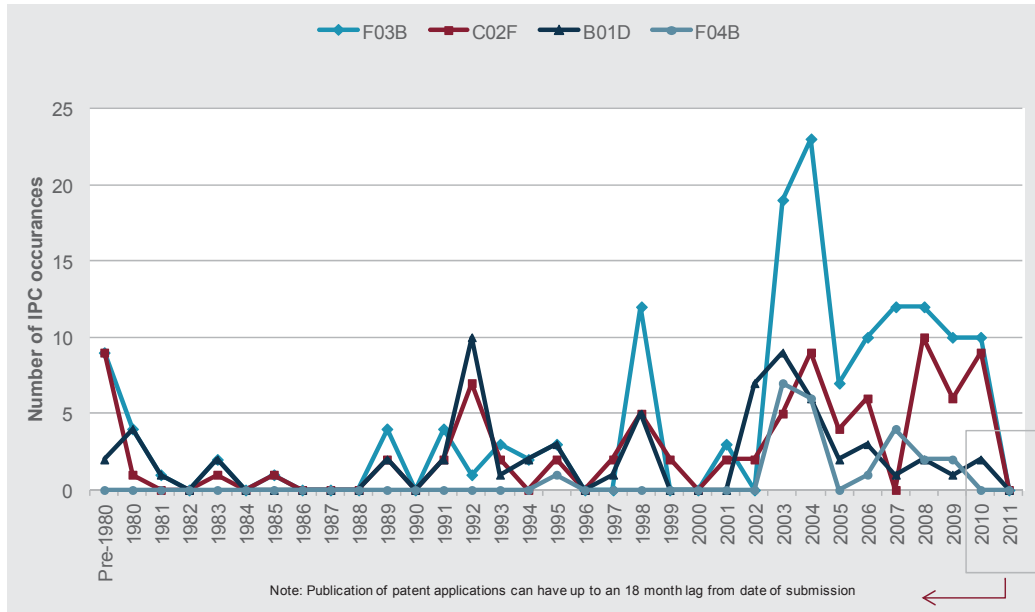
but also because there are strict regulations regarding the transfer of water within ships between harbours for environmental reasons.



IPC	Description
F03B	MACHINES OR ENGINES FOR LIQUIDS;
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
F04B	POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS; PUMPS;
B63B	SHIPS OR OTHER WATERBORNE VESSELS; EQUIPMENT FOR SHIPPING;

Figure 18: Desalination–wave and tidal energy integration – number of patent families in top 5 IPC codes

Figure 19 shows some level of legacy in the wave and tidal driven desalination space, but most of the activity is focused from 2000 onwards. Activity relating to the pumps aspect of the space starts from around 2002. This increased activity is linked to various patents from multiple assignees, and thus cannot be linked to one specific event but rather a change in the market focus.

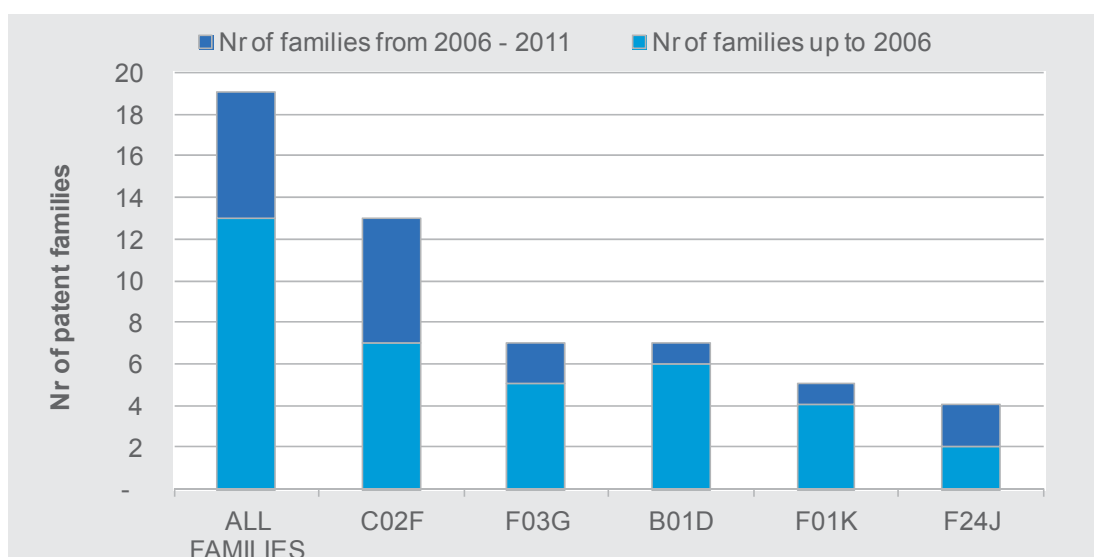


IPC	Description
F03B	MACHINES OR ENGINES FOR LIQUIDS;
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPARATION
F04B	POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS; PUMPS;
B63B	SHIPS OR OTHER WATERBORNE VESSELS; EQUIPMENT FOR SHIPPING;

Figure 19: IPC distribution – desalination–wave and tidal energy integration

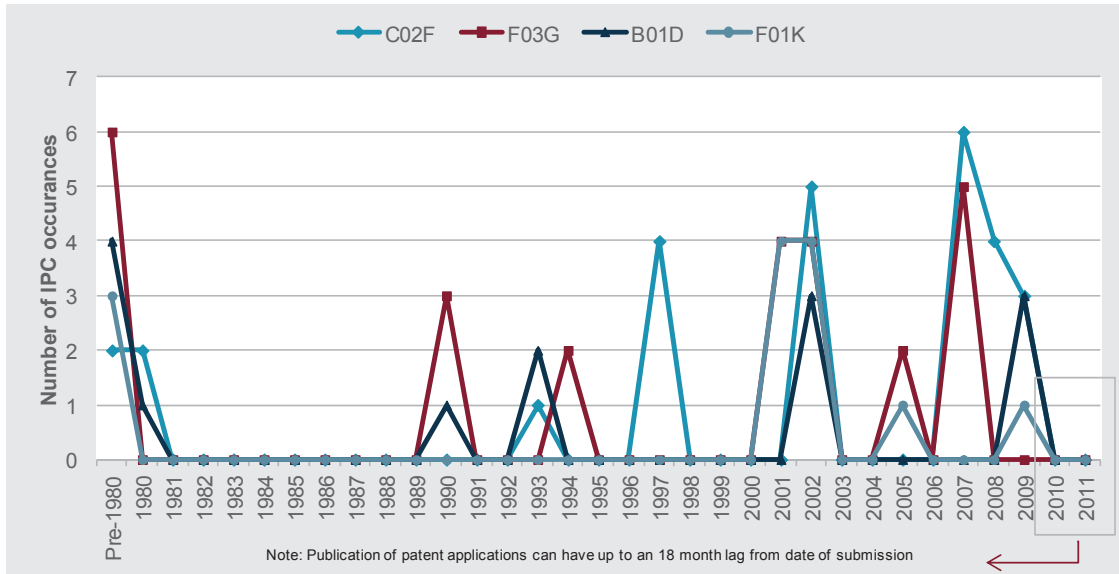
Classification codes for geothermal energy desalination

Figure 20 and Figure 21 show the trends for geothermal desalination technology patents. The dataset is the smallest of all of the renewable energy desalination datasets. Given the small number of observation points, it is difficult to discern any particular trend. The field has a number of legacy patents from before 1980 and does not show significant growth in the last three decades. This could be linked to the maturity and level of adoption of geothermal energy in general.



IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
F03G	SPRING, WEIGHT, INERTIA, OR LIKE MOTORS; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPERATION
F01K	STEAM ENGINE PLANTS; STEAM ACCUMULATORS; ENGINE PLANTS NOT OTHERWISE PROVIDED FOR; ENGINES USING SPECIAL WORKING FLUIDS OR CYCLES;
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR;

Figure 20: Desalination-geothermal energy integration – number of patent families in top 5 IPC codes



IPC	Description
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE;
F03G	SPRING, WEIGHT, INERTIA, OR LIKE MOTORS; MECHANICAL-POWER-PRODUCING DEVICES OR MECHANISMS, NOT OTHERWISE PROVIDED FOR OR USING ENERGY SOURCES NOT OTHERWISE PROVIDED FOR;
B01D	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL: SEPERATION
F01K	STEAM ENGINE PLANTS; STEAM ACCUMULATORS; ENGINE PLANTS NOT OTHERWISE PROVIDED FOR; ENGINES USING SPECIAL WORKING FLUIDS OR CYCLES;
F24J	PRODUCTION OR USE OF HEAT NOT OTHERWISE PROVIDED FOR;

Figure 21: IPC distribution – desalination–geothermal energy integration

5.5 Geographic analysis

Figure 22 shows the geographic analysis of Office of First Filing (OFF) and Office of Second Filing (OSF). One way to interpret OFF and OSF data is that OFF most likely represents where the invention is being done (or at least where a company’s patent department is located), whereas OSF represents the most important geographic areas of patent protection.

In the overall desalination dataset, the most important OFFs are (in order of share) those of Japan, Europe, the US and China. When looking at the last 5 years of filing, this picture is significantly different, with China the most important OFF, followed by the US, Europe and Japan, as well as ‘other’ accounting for a wider share than in previous years. This development certainly suggests that China as a patent filing *origin* is becoming increasingly important in this industry. It is not clear that the results suggest a reduction in inventive activity in any of these countries, as the overall level of innovation has increased significantly. Rather, it illustrates the considerable and above-trend growth in China as a patenting destination.

While China has undergone some growth as an OSF, it has nearly doubled its share as an OFF when considering only patents filed in the last 5 years. This indicates that many companies are filing in China as an initial filing, but not many companies holding patents in other jurisdiction file family members in China. Only 2% of Chinese patents investigated do not have China as OFF, compared to the US where this is 30–34%. This

gives a strong indication that companies filing patents in China are likely to only have Chinese patents.

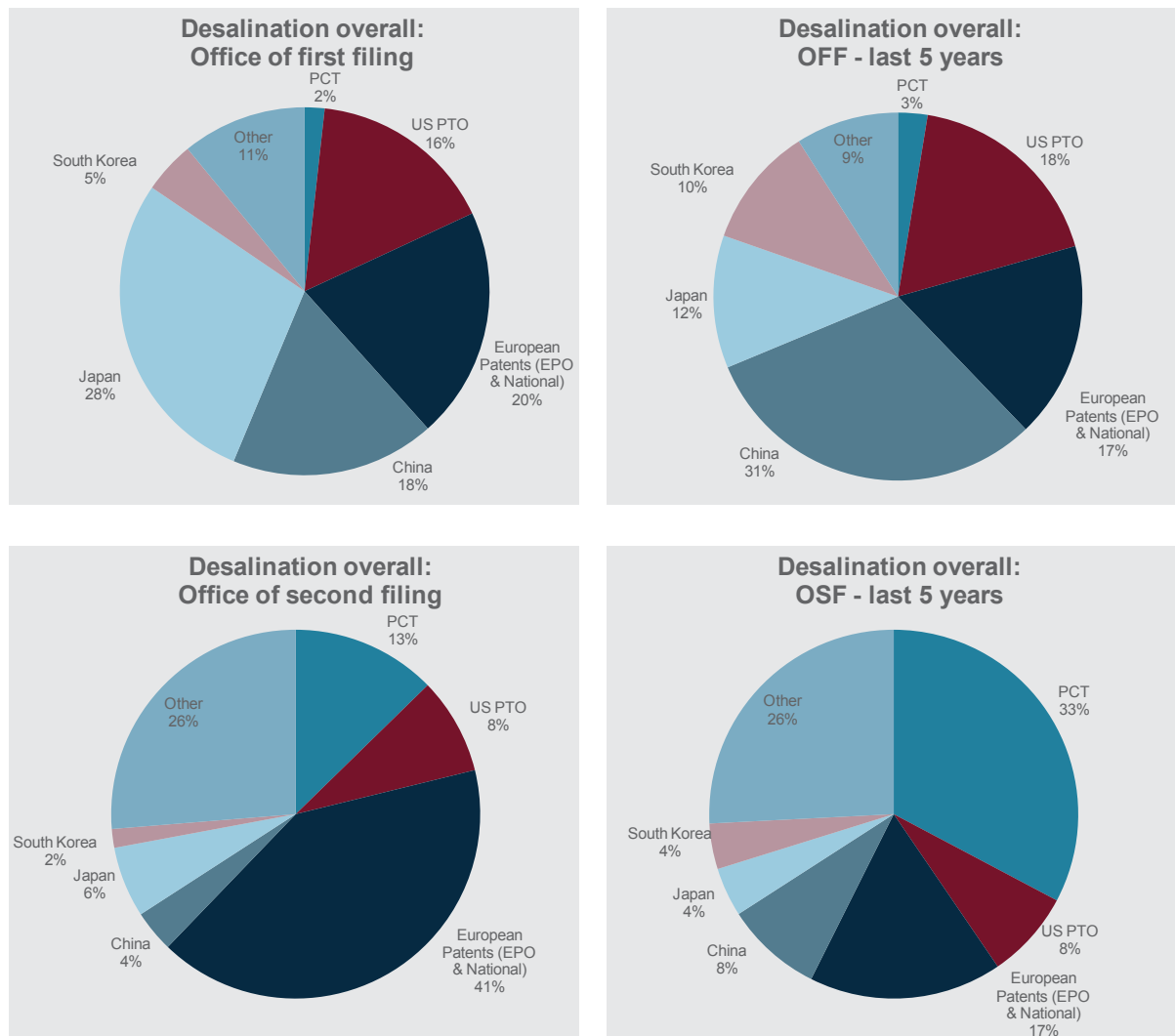


Figure 22: Analysis of patent filings by geography for desalination: OFF and OSF

Europe has lost some of its share as an OFF, but as an OSF it has gone down from 41% over all time to 17% in the last 5 years – less than half its previous share. While PCT applications in the last 5 years make up only 2% of European OFFs, PCT applications make up a third of the OSFs, compared to 13% of applications when considering applications from all time.

Table 12 shows in greater detail the composition of the OFF and OSF patent filings. From this analysis it is apparent that that Russia, South Korea and Australia/New Zealand all constitute a low but significant share of the patents and patent applications as well as OFFs and OSFs. Korea is especially significant as an OFF, constituting 11% of the filings (just 1% less than Japan) in the last 5 years.

Table 12: Geographic analysis of desalination space – number and % of filings

Geography	OFF	OFF – last 5 years	OSF	OSF – last 5 years
PCT	79 (2%)	30 (3%)	686 (13%)	335 (33%)
European Patents (EPO & National)	924 (20%)	198 (17%)	2219 (41%)	173 (17%)
US PTO	743 (16%)	207 (18%)	459 (8%)	79 (8%)
Canada	20 (0%)	6 (1%)	258 (5%)	58 (6%)
Russia and USSR	263 (6%)	25 (2%)	30 (1%)	4 (0%)
China	816 (18%)	356 (31%)	198 (4%)	87 (9%)
Japan	1284 (28%)	134 (12%)	336 (6%)	44 (4%)
South Korea	208 (5%)	122 (11%)	89 (2%)	41 (4%)
Other Asian patents	49 (1%)	23 (2%)	95 (2%)	9 (1%)
Middle East	46 (1%)	7 (1%)	190 (4%)	35 (3%)
Africa	23 (1%)	7 (1%)	205 (4%)	21 (2%)
Australia and New Zealand	66 (1%)	24 (2%)	448 (8%)	87 (9%)
Central and South America	24 (1%)	10 (1%)	194 (4%)	50 (5%)

Africa, the Middle East and Asia are areas of particular policy interest, given that these are *both* areas of high potential for desalination technology *and* contain a large number of LDC countries.

Africa: Where African jurisdictions were the OFFs, 4% of the time this was through OAPI and 96% were filed in individual countries, although all African OFFs in the last 5 years have been individual countries. Where African jurisdictions were OSFs, 11% of the filings were through ARIPO, 11% through OAPI and 78% were filed in individual countries. For the last 5 years, 33% of the second filings were through ARIPO and 67% in individual countries. This shows that Africa is more popular as an OSF than as an OFF, although the % of the overall activity is still marginal.

African countries listed as an OFF are South Africa (50% of total for Africa), Egypt (40%) and Morocco (10%). As OSFs, the relevant African countries are South Africa (64%), Egypt (21%), Morocco (14%), Algeria (3%) and Malawi (1%). However, patents filed in the last 5 years only have South Africa and Morocco as OFF or OSF, with the exception of one filing in Egypt.

Middle East: Middle Eastern countries listed as OFFs are Israel (93% of total for Middle East) with one filing each in the Gulf Cooperation Council (GCC), Lebanon and Saudi Arabia. As an OSF, 99% of the share is held by Israel, with one filing from the GCC. In the last 5 years, not much has changed in this structure, with Israel constituting the majority of the share.

Asia: We have already discussed Japan and Korea, which are two of the main patenting geographies in the desalination space. Other countries in Asia that are used as an OFF are Taiwan (59% of 'rest of Asia'), Singapore (24%), India (12%) and one filing each in Nepal and Malaysia. OSFs include Hong Kong (23%), Taiwan (20%), India (20%), Singapore (16%), and Indonesia, Malaysia and the Philippines (7% each).

Geographic analysis for desalination – Solar thermal energy integration

Figure 23 shows that Europe and China are the most popular OFFs for desalination - solar thermal integration, with Japan and the US following close behind. Although Europe and the US are the most popular OSF, a large proportion of OSFs were in other jurisdictions, particularly Australia, Africa and Israel.

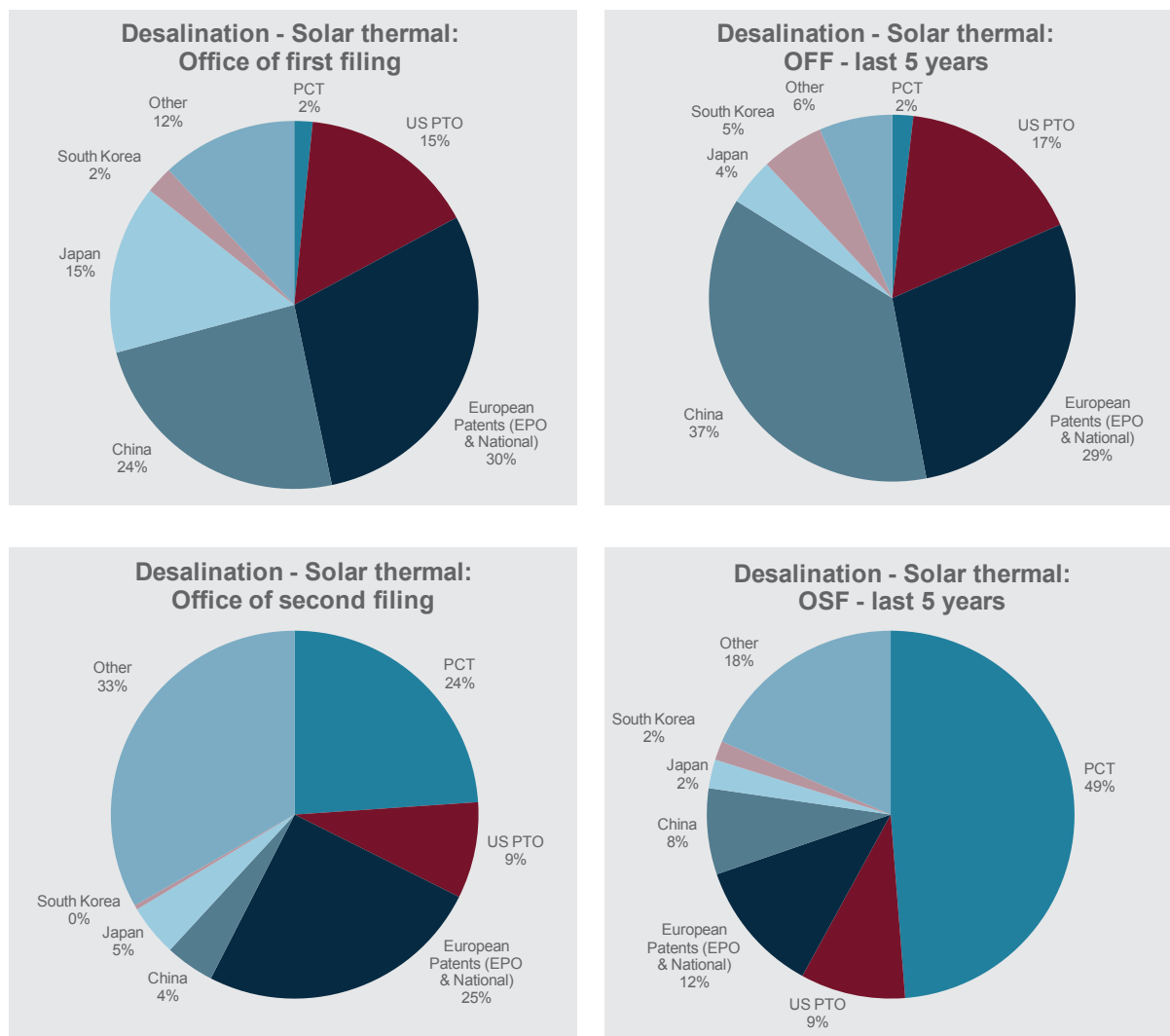


Figure 23: Analysis of patent filings by geography for desalination – Solar thermal integration

Japan has in this space also lost a lot of its share when comparing OFF and OSF over all time with that for the last 5 years. As in the overall dataset, Europe has lost some of its share as an OFF, but has more than halved the proportion of times it is used as an

OSF, shrinking from 25% over all time to 12% in the last 5 years. In the last 5 years, South Korea has also overtaken the PCT and Japanese filings to account for 6% of the OFF filings.

China doubled its share as an OSF, but has also grown considerably as an OFF to account for more than a third of the first filings in the last 5 years. PCT constitutes only 2% of the OFFs, but as OSF, PCT applications make up almost half of the applications filed in the last 5 years compared to the 24% of applications when considering OSF over all time.

As shown in Table 13, Australia makes up 14% of the OSFs in the desalination and solar thermal energy space, more than Japan, China and the US over all time. For patents filed in the last 5 years, it constitutes 8% of the OSF, which is equal to China's share but considerably more than Japan's.

Table 13: Geographic analysis of desalination–solar thermal space – number and % of filings

Geography	OFF	OFF – last 5 years	OSF	OSF – last 5 years
PCT	12 (2%)	4 (2%)	116 (24%)	58 (49%)
European Patents (EPO & National)	221 (30%)	62 (29%)	122 (25%)	14 (12%)
US PTO	116 (16%)	36 (17%)	41 (8%)	11 (9%)
Canada	5 (1%)	2 (1%)	14 (3%)	5 (4%)
Russia and USSR	44 (6%)	1 (0%)	2 (0%)	1 (1%)
China	180 (24%)	80 (37%)	21 (4%)	9 (8%)
Japan	111 (15%)	9 (4%)	22 (5%)	3 (3%)
South Korea	18 (2%)	12 (6%)	2 (0%)	2 (2%)
Other Asian Patents	9 (1%)	5 (2%)	10 (2%)	0 (0%)
Middle East	8 (1%)	0 (0%)	24 (5%)	2 (2%)
Africa	3 (0%)	0 (0%)	24 (5%)	1 (1%)
Australia and New Zealand	13 (2%)	3 (1%)	66 (14%)	10 (8%)
Central and South America	6 (1%)	3 (1%)	21 (4%)	3 (3%)

Africa: No ARIPO or OAPI filings were identified in this subspace. Individual African countries, however, constitutes 5% of the OFS over all time; this is more than both China and Japan. Patents were filed in South Africa (41%), Egypt (24%), Morocco (35%) and Algeria (6%). Only one patent filing in Morocco is from the last 5 years. The continent is however not very strong as an OFF, with only 3 families, none of which account for the last 5 years.

Middle East: The Middle East also overtakes Japan and China as OSF by accounting for 5% of the OSF filings. Like Africa, the Middle East is also not very strong as an OSF, with a number of patent families from Israel and one from the GCC, none of which were filed in the last 5 years.

Asia: Other than Japan and China, Asian patents did not account for a large proportion of the OFFs or OFS. Several patent families have Singapore, India, Taiwan or Malaysia as the OFF, most of these not in from the last 5 years. OSFs include India, Taiwan, Indonesia, Hong Kong and Malaysia.

Geographic analysis for desalination – Solar PV energy integration

When considering trend analysis in this space, one should bear in mind that it is a small space and a single company's strategy can have a visible effect on the trends. Figure 24 shows that Europe accounts for more than 50% of the OFFs, decreasing slightly in the last 5 years to 43%. In the last 5 years, the US and China has gained in their share of the patent filings, while Japan, as in the other desalination spaces, has drastically decreased its patenting activity. Other countries have also become more popular as OFFs in the last 5 years.

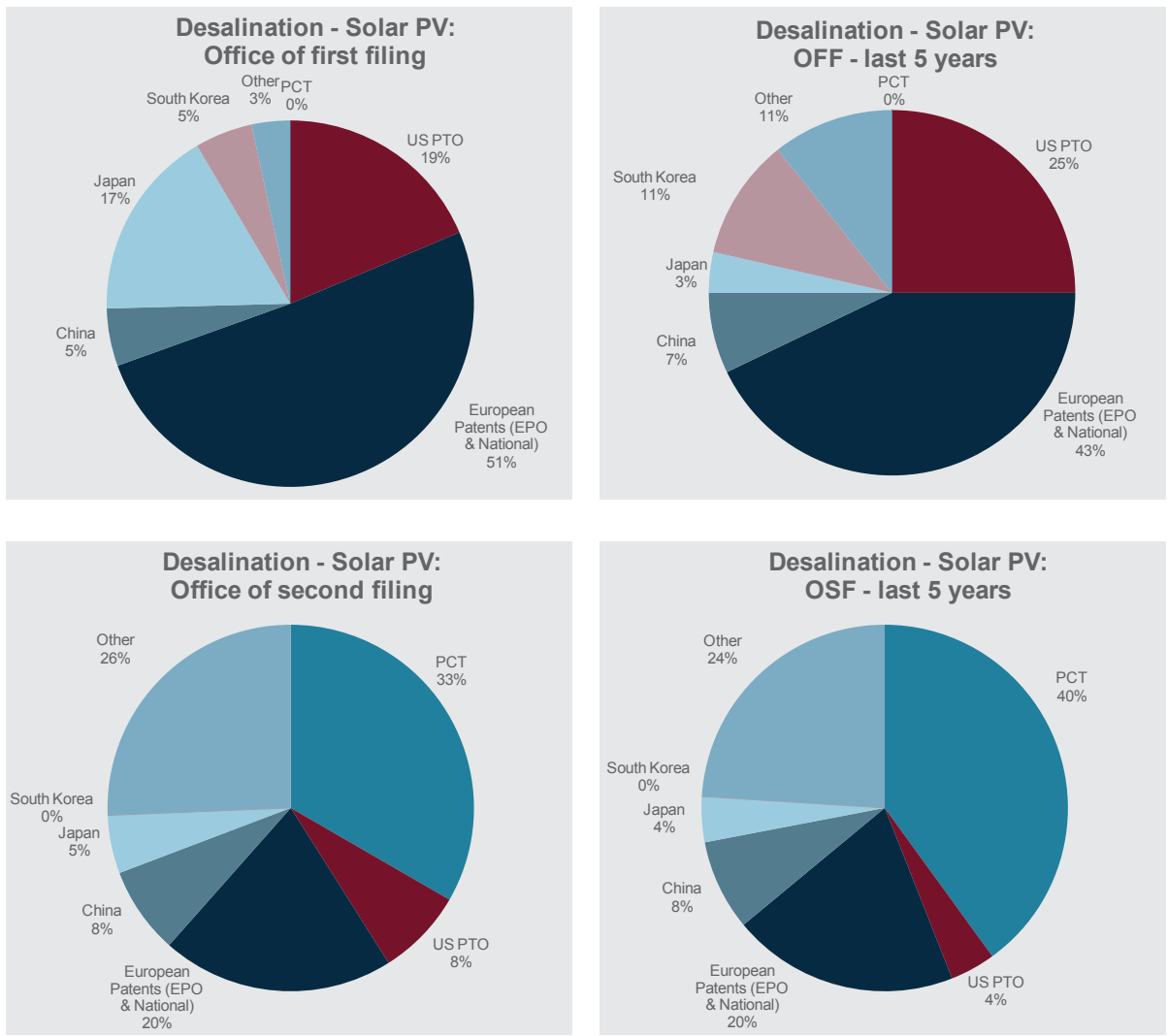


Figure 24: Analysis of patent filings by geography for desalination – Solar PV integration

PCT applications are only found as OSFs and have increased in share in the last 5 years. China has held a constant share, while Europe, the US and Japan have all decreased. China’s share as an OSF stays constant. As observed in the other renewable energy subspaces, Australia is a popular OSF, constituting 10% of the OSFs, more than China, Japan and the US (see Table 14).

Table 14: Geographic analysis of desalination–solar PV space – number and % of filings

Geography	OFF	OFF – last 5 years	OSF	OSF – last 5 years
PCT	0 (0%)	0 (0%)	13 (33%)	10 (40%)
European Patents (EPO & National)	30 (51%)	12 (43%)	8 (21%)	5 (20%)
US PTO	11 (19%)	7 (25%)	3 (8%)	1 (4%)
Canada	0 (0%)	0 (0%)	1 (3%)	1 (4%)
Russia and USSR	1 (2%)	1 (4%)	0 (0%)	0 (0%)
China	3 (5%)	2 (7%)	3 (8%)	2 (8%)
Japan	10 (17%)	1 (4%)	2 (5%)	1 (4%)
South Korea	3 (5%)	3 (11%)	0 (0%)	0 (0%)
Other Asian Patents	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Middle East	0 (0%)	0 (0%)	2 (5%)	1 (4%)
Africa	0 (0%)	1 (4%)	2 (5%)	0 (0%)
Australia and New Zealand	0 (0%)	0 (0%)	4 (10%)	3 (12%)
Central and South America	1 (2%)	1 (4%)	1 (3%)	1 (4%)

There are no OFFs or OSFs from Africa, the Middle East or Asia (other than Japan, China and South Korea), with the exception of two OSF filings in Israel and one in Algeria.

Geographic analysis for desalination – Wind energy integration

Figure 25 shows how Japan and Europe have both decreased as OFFs when comparing the applications over all time to those of the last 5 years. By contrast, the US and China have increased.

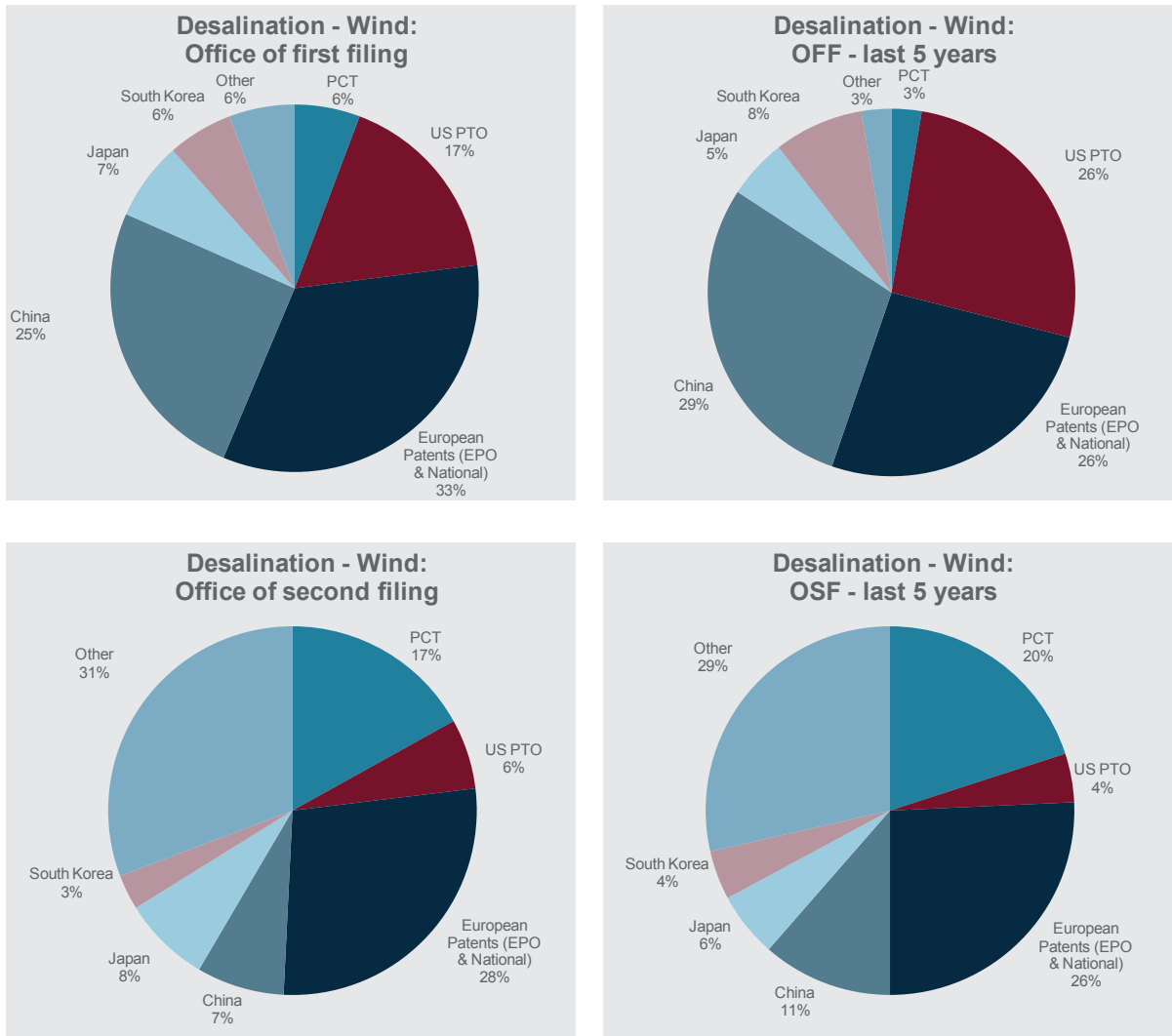


Figure 25: Analysis of patent filings by geography for desalination – Wind integration

In the wind space, although Europe is still the most common OSF, Australia accounts for 13% of the OSFs (see Table 15). This means that, after Europe and the PCT, it is the third most popular OSF. It is however interesting to observe that it is not the OFF on any of the families identified.

Table 15: Geographic analysis of desalination–wind space – number and % of filings

Geography	OFF	OFF – last 5 years	OSF	OSF – last 5 years
PCT	5 (6%)	1 (3%)	22 (17%)	14 (20%)
European Patents (EPO & National)	29 (33%)	10 (26%)	36 (28%)	18 (26%)
US PTO	15 (17%)	10 (26%)	8 (6%)	3 (4%)
Canada	0 (0%)	0 (0%)	6 (5%)	4 (6%)
Russia and USSR	1 (1%)	0 (0%)	0 (0%)	0 (0%)
China	22 (25%)	11 (29%)	10 (8%)	8 (11%)
Japan	6 (7%)	2 (5%)	10 (8%)	4 (6%)
South Korea	5 (6%)	3 (8%)	4 (3%)	3 (4%)
Other Asian Patents	2 (2%)	1 (3%)	1 (1%)	1 (1%)
Middle East	1 (1%)	0 (0%)	3 (2%)	0 (0%)
Africa	1 (1%)	0 (0%)	5 (4%)	3 (4%)
Australia and New Zealand	0 (0%)	0 (0%)	17 (13%)	7 (10%)
Central and South America	0 (0%)	0 (0%)	8 (6%)	5 (7%)

There is very little activity in Africa, the Middle East and Asia (outside Japan, China and South Korea). OFFs include one occurrence in Israel, one in Egypt and one in Taiwan. For OSFs, there is one occurrence in Taiwan, three in Israel and three in South Africa and two file through ARIPO.

Geographic analysis for desalination – Wave and tidal energy integration

Figure 26 shows the US and Europe being the most popular OFFs in this space, with Europe slightly decreasing when considering only patent families from the last 5 years. Japan shows a decrease while China shows an increases in popularity as an OFF.

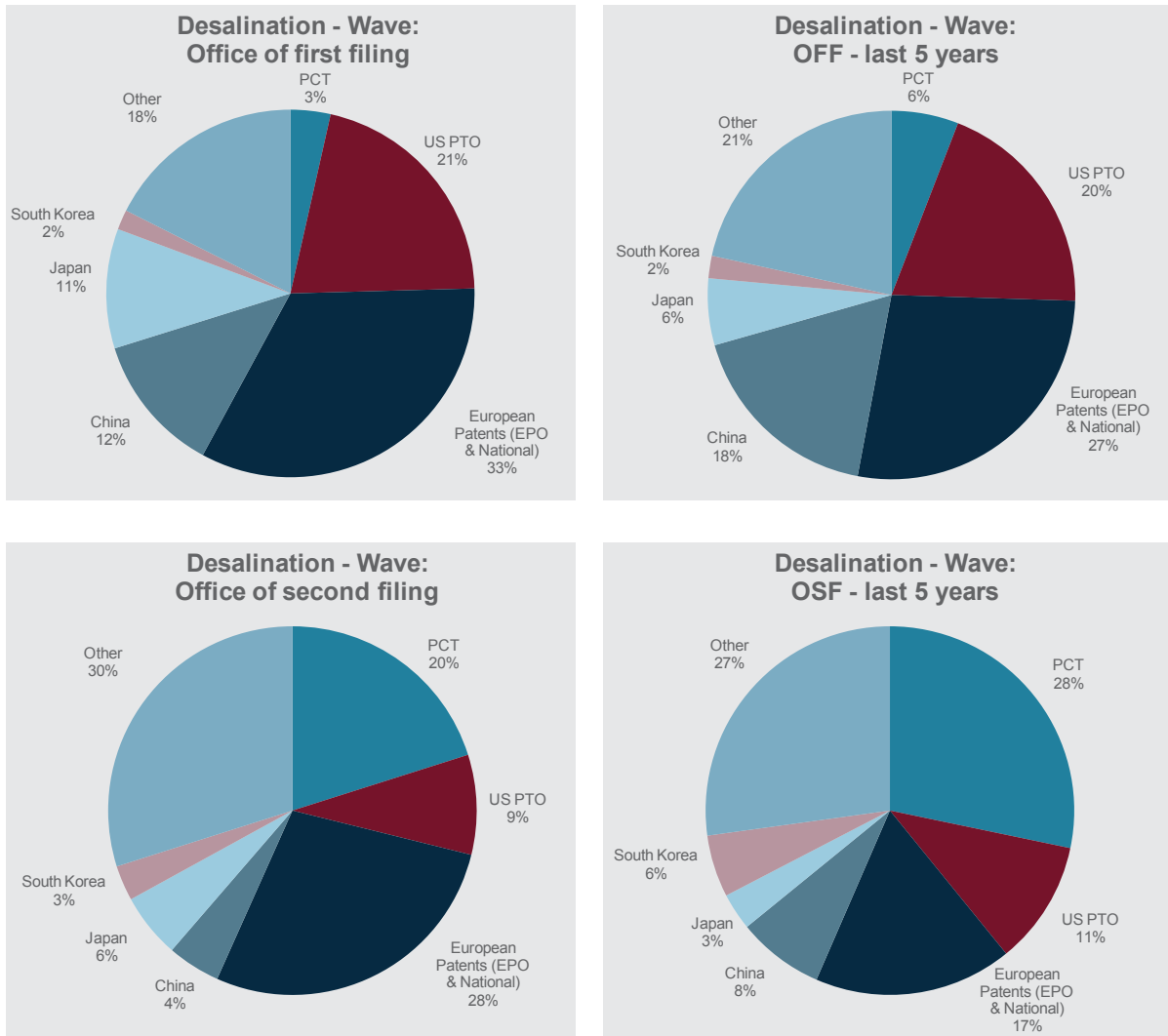


Figure 26: Analysis of patent filings by geography for desalination – Wave/tidal integration

The PCT is again the most popular OSF, increasingly so in the last 5 years. The US and China's shares have also slightly increased over time, while those of Europe and Japan have decreased.

As shown in Table 16, there is very little activity in Africa, the Middle East and Asia (outside of Japan, China and South Korea). OFFs include one occurrence in India, five in Israel and two in Egypt. For OSFs, there is one occurrence in Hong Kong, four in Israel, one in Egypt and four in South Africa as well as two filings through ARIPO and one through OAPI.

Table 16: Geographic analysis of desalination–wave/tidal space – number and % of filings

Geography	OFF	OFF – last 5 years	OSF	OSF – last 5 years
PCT	4 (4%)	3 (6%)	39 (20%)	26 (28%)
European Patents (EPO & National)	38 (33%)	14 (27%)	54 (28%)	16 (17%)
US PTO	24 (21%)	10 (20%)	17 (9%)	10 (11%)
Canada	2 (2%)	2 (4%)	12 (6%)	8 (9%)
Russia and USSR	1 (1%)	1 (2%)	0 (0%)	0 (0%)
China	14 (12%)	9 (18%)	9 (5%)	7 (8%)
Japan	12 (11%)	3 (6%)	11 (6%)	3 (3%)
South Korea	2 (2%)	1 (2%)	6 (3%)	5 (5%)
Other Asian Patents	1 (1%)	1 (2%)	1 (1%)	0 (0%)
Middle East	5 (4%)	2 (4%)	4 (2%)	1 (1%)
Africa	2 (2%)	0 (0%)	8 (4%)	3 (3%)
Australia and New Zealand	4 (4%)	2 (4%)	24 (12%)	7 (8%)
Central and South America	3 (3%)	2 (4%)	9 (5%)	6 (7%)

Geographic analysis for desalination – Geothermal energy integration

When considering trend analysis in this space, one should bear in mind that it is a small space and a single company’s strategy can have a visible effect on the trends. Figure 27 shows that the OFFs are only the US, China and Europe, with the US losing a large proportion of its share in this space to China in the last 5 years.

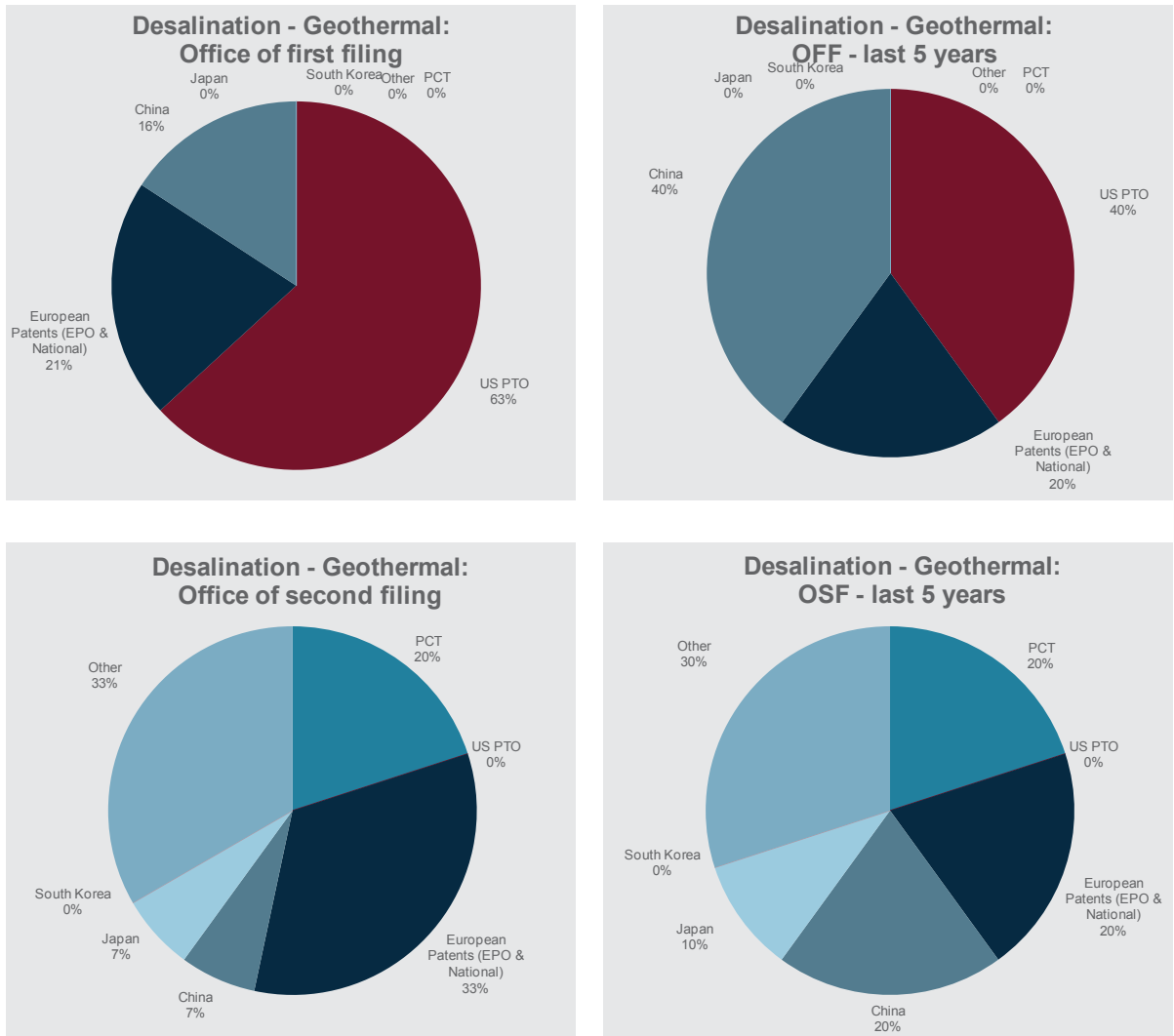


Figure 27: Analysis of patent filings by geography for desalination – Wave/tidal integration

Australia is also a popular OSF in this renewable energy integration space with a larger share than Japan and China (see Table 17). Canada has the same share (7%) as Japan and China when considering filings over all time.

Table 17: Geographic analysis of desalination–geothermal space – number and % of filings

Geography	OFF	OFF – last 5 years	OSF	OSF – last 5 years
PCT	0 (0%)	0 (0%)	6 (20%)	2 (20%)
European Patents (EPO & National)	4 (21%)	1 (20%)	10 (33%)	2 (20%)
US PTO	12 (63%)	2 (40%)	0 (0%)	0 (0%)
Canada	0 (0%)	0 (0%)	2 (7%)	1 (10%)
Russia and USSR	0 (0%)	0 (0%)	0 (0%)	0 (0%)
China	3 (16%)	2 (40%)	2 (7%)	2 (20%)
Japan	0 (0%)	0 (0%)	2 (7%)	1 (10%)
South Korea	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Other Asian Patents	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Middle East	0 (0%)	0 (0%)	1 (3%)	0 (0%)
Africa	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Australia and New Zealand	0 (0%)	0 (0%)	5 (17%)	1 (10%)
Central and South America	0 (0%)	0 (0%)	2 (7%)	1 (10%)

There is almost no activity in Africa, the Middle East or Asia (outside Japan, China and South Korea) with only one occurrence in Israel as OFF.

6 Product and company case studies

Patents are a strong, but incomplete indicator of technology and innovation. It may take years for a patented technology to make its way to the market as a commercial product, or it may never be commercialised at all. Many products are protected by multiple patents, or a combination of third party technology (which may or may not be patented) and a company's own know-how or design. Finally, while it could be said that 'all patents are equal', the owners of those patents can differ significantly in size, commercialisation strategy and market positioning. In this section we provide a series of examples of how in *practice* desalination technologies are being deployed. We have investigated a cross section of companies including an industrial conglomerate (Mitsubishi), Universities (MIT and Yale), SME's and start-ups (Saltworks™, SwissInso Enis Windgen™, ecOcean renewable) as well as renewable energy companies which have developed applications in the desalination space (Aerodyn, Carnegie Wave Energy). We also show that some of the desalination - renewables integration is not backed by specific patents in this space, but rather has relied on the integration of separately patented desalination and energy technologies. These case studies are **not** exhaustive of all participants or technologies, and are **not** to be taken as recommendations about which technology is most appropriate.

6.1 Industrial conglomerate - Mitsubishi Heavy Industries

Background

Mitsubishi Heavy Industries (Mitsubishi hereafter) was the leading assignee in the overall desalination space, and remains a leading developer of desalination technologies, especially in the construction of large desalination plants. For instance, Mitsubishi has been involved in the construction of large desalination plants such as the RO desalination plant in Madina-Yanbu in Saudi Arabia (8,530 m³/day), and the world's first three-stage RO plant in Rabigh on the Red Sea (Saudi Arabia) with a total capacity of 192,000 m³/day.¹³ Figure 29 shows a schematic for an RO plant.

¹³ http://www.mhi.co.jp/en/products/category/desalination_plant.html



Figure 28: Plant schematic for a Mitsubishi-designed RO plant¹⁴

While Mitsubishi was the most prolific patenter of desalination technology (see Section 6), in the past 5 years its level of patenting activity has decreased substantially. Nevertheless, the company continues to be a leader in the desalination technology space, with the launch of various novel systems. Possible interpretations of the decline in their patenting rates in the space could be related to:

- exploitation of existing IP and iterative innovation around an existing technology platform
- increased reliance on trade secrets
- increased licensing-in of key technologies, or purchasing-in of components
- joint ventures (JVs) or collaborations with other partners
- focus of patenting activity around complementary systems (which were outside the scope of the project)

Desalination – Renewables integration

Our research did not show Mitsubishi to have a very high focus on desalination–renewable energy integration. Most of its patent families referring to the use of solar thermal or waste heat energy date from the 1970s or 1980s. One exception is a patent family with priority date 2005 which is focused on providing small-scaled freshwater production at a low cost with the use of exhaust combustion gas and seawater. The patent family (JP 2005349299A, Figure 29) does not appear to include a granted patent, but includes EPO and US applications in addition to the Japanese one.

Our website search found no matching product around this patent, or indeed any other products that showed desalination–renewable energy integration. Perhaps that should not be surprising, as Mitsubishi is primarily focused on large system deployment and, as discussed earlier, desalination technology is not yet at efficiency levels that can be deployed at utility-level plants.

At the same time, industrial conglomerates such as Mitsubishi have activity across multiple industries, and may be in a position to implement system-wide integration. For instance, Mitsubishi’s wind turbine or steam turbine generator businesses means that it

¹⁴ <http://www.mhi.co.jp/technology/review/pdf/e461/e461012.pdf>

is in the position where potential synergies with integration of waste heat or wind renewable energy could be piloted and ultimately deployed.

Freshwater production apparatus
CAMBRIDGE

Publication Number: JP2005349299A
Publication Date: 2005-12-22
Assignee: MITSUBISHI HEAVY IND LTD
Inventor: OGURA KAZUMASA; IJIMA MASAKI

Abstract: PROBLEM TO BE SOLVED: To provide a small-scaled freshwater production apparatus at a low cost. ; SOLUTION: The freshwater production apparatus using exhaust combustion gas 11 and seawater 12 comprises a sprinkler 15 which sprays the seawater 12 onto the exhaust combustion gas 11 to evaporate water in the seawater and to humidify and cool the exhaust combustion gas to a saturation temperature, and a freshwater recovery device 17 which cools the humidified and cooled exhaust combustion gas 16 to condense and recover freshwater. Water in the exhaust combustion gas is recovered together with the water in the seawater to efficiently produce the freshwater. ; COPYRIGHT: (C)2006,JPO&NCIP

Figure 29: Mitsubishi patent integrating desalination technology with waste heat energy

Inventor network and collaborations

Patent-based inventor network diagrams can illustrate ‘research clusters’ within companies, and visualise knowledge flows within and across companies. High connectivity, based on co-patenting, may be closely linked to collaborative working environments, thus decreasing duplication of research and resources. The patent-based inventor network map in Figure 30 is based on Mitsubishi inventors’ co-filings of more than 4 patents (reducing the complexity of a very rich inventor network map). The map shows that Mitsubishi has somewhat intensive collaborations (more than 4 patents) with several companies, each in a different part of the technology value chain of desalination:

- **membranes:** Nipon Rensui co, a Tokyo-based membrane and water treatment chemicals company with 279 employees and ¥13bln in sales in 2009.
- **reinforced plastics:** Arisawa MFG, a manufacturer of reinforced plastics for the aerospace, medical, desalination and other industries
- **power pumps:** Aqua Systems k.k., a relatively minor collaborator, most likely around its core area of expertise of fluid power pumps
- **automation:** Ryomei Engineering, a co-assignee, a robotics specialist that is a subsidiary of Mitsubishi

Expanding the patent-based network analysis can also show who Mitsubishi-affiliated inventors have worked with prior to or after Mitsubishi. These include Toray Industries, Aqua Systems, the Mechano-Chemical Research Institute, Kyusho Electric and other companies.

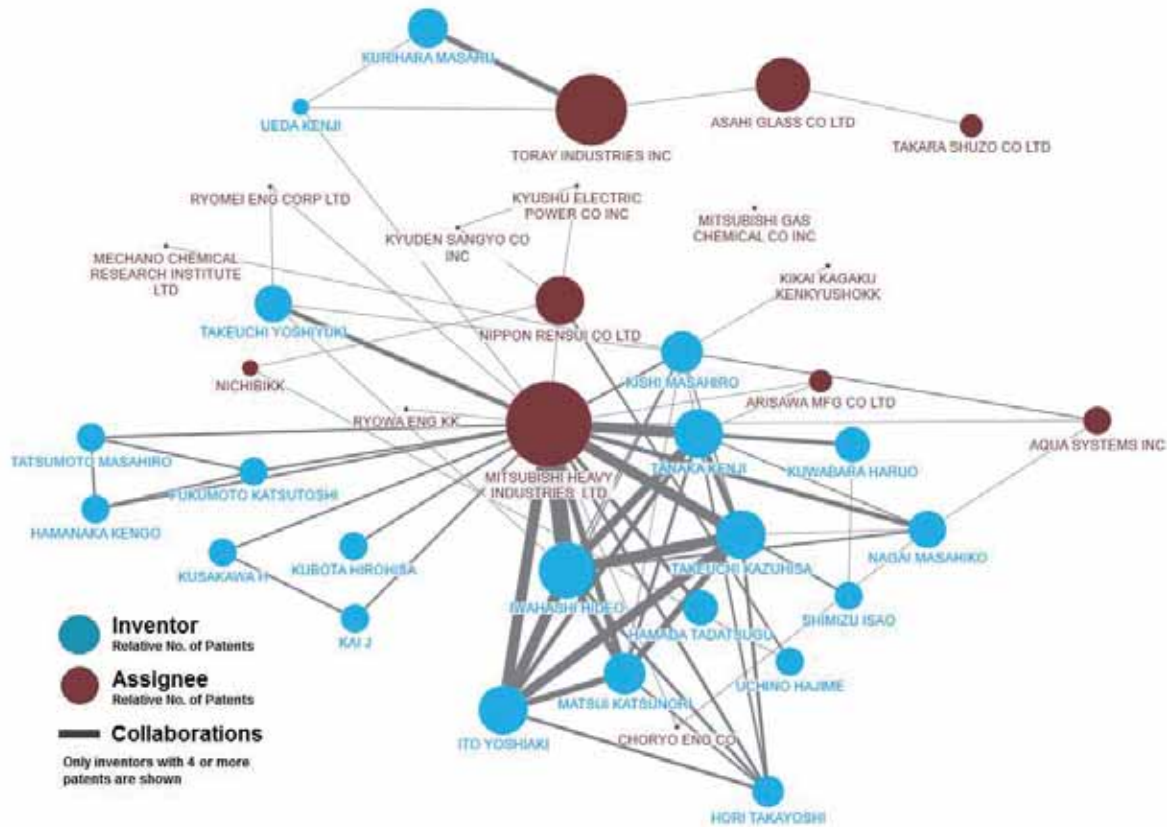


Figure 30: Mitsubishi assignee–inventor network diagram for desalination technology

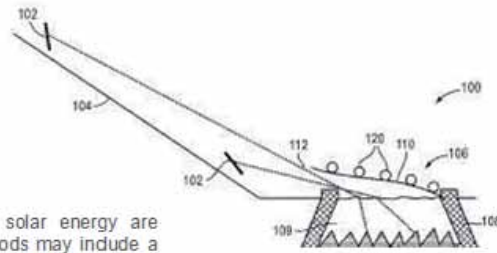
6.2 Desalination – Solar thermal energy integration products

Massachusetts Institute of Technology

A 2010 patent family by MIT that we identified covers concentrated solar thermal power, and also its integration with desalination systems in claim 33 (WO2011035232A2, Figure 31). MIT is developing a technology for the combination of concentrated solar thermal power and desalination.¹⁵ This technology is being developed through a collaboration with King Abdullah University in Saudi Arabia, and more recently with the Cyprus Institute.

¹⁵ <http://web.mit.edu/newsoffice/2011/mit-and-cyprus-institute.html>

Publication Number: WO2011035232A2
Publication Date: 2011-03-24
Assignee: MASSACHUSETTS INST TECHNOLOGY
Inventor: SLOCUM ALEXANDER H; BUONGIORNO JACOPO; FORSBERG CHARLES WINFIELD; CODD DANIEL S ; PAXSON ADAM T



Abstract: Systems and methods for concentrating and storing solar energy are provided. A solar energy receiver for use with the systems and methods may include a container for holding a solar absorption material, such as a phase change material, and a cooled cover disposed above the container for condensing and collecting vaporized phase change material collected along an underside of the cover.

Figure 31: MIT desalination technology integrated with concentrated solar thermal and other waste heat sources

The patent-based inventor network map in Figure 32 shows that there is collaboration between MIT and King Fahd University of Petroleum and Minerals (Saudi Arabia) through one research cluster. It also appears that there are other distinct clusters at MIT working on desalination technology, although two of these are linked through John Lienhard, a professor of mechanical engineering.¹⁶

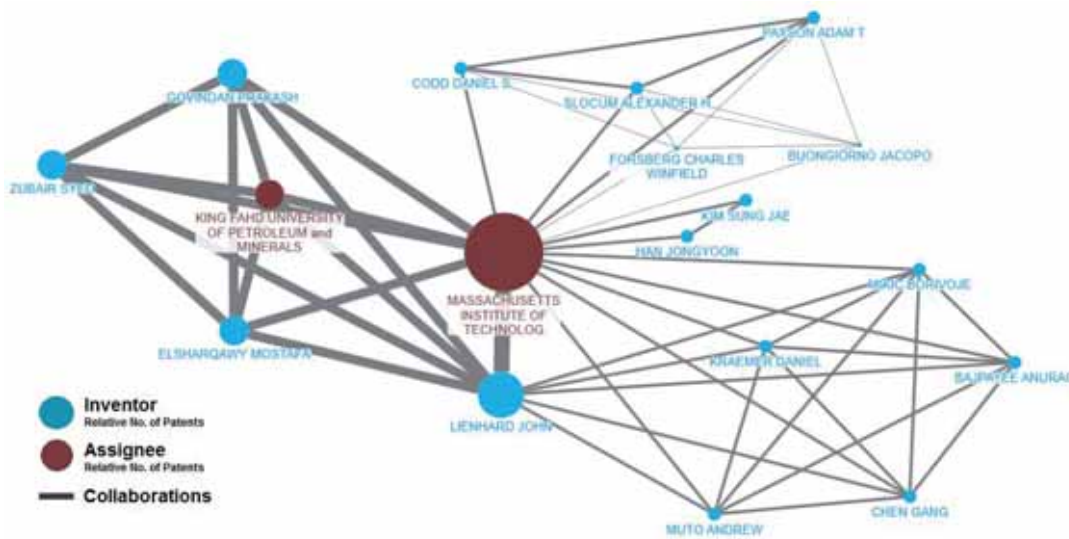


Figure 32: MIT assignee–inventor network diagram for desalination technology

Saltworks™ Technologies

Saltworks™ technology is a Canadian company with a technology that is based on the concentration difference between salt water solutions through their thermo-ionic (TM) process. In this technology, low temperature waste heat of solar heat helps to drive the

¹⁶ <http://meche.mit.edu/people/?id=53>

system.¹⁷ The patent application (US2011068008A1, Figure 33) describes the use of solar power with their technology in the abstract.

Method, apparatus and plant for desalinating saltwater using concentration difference energy
CAMBRIDGE IP

Publication Number: US2011068008A1

Publication Date: 2011-03-24

Assignee: SALTWORKS TECHNOLOGIES INC

Inventor: SPARROW BENJAMIN STUART; TANG JAMES; ZOSHI JOSHUA

Abstract: A method and apparatus for desalinating saltwater using concentration difference energy is disclosed. In order to desalinate saltwater that is contained within a product chamber, a drive cell is used to generate a drive voltage. The product chamber has a desalination voltage such that when a sufficient voltage is applied to the product chamber, anions and cations migrate out of the product chamber, thereby desalinating the water. The sufficient voltage, which includes the drive voltage and which is equal to or greater than the desalination voltage, is applied to the product chamber, consequently effecting desalination. Beneficially, concentration difference energy can be generated using a concentrated solution, which can be generated using, for example, solar energy.

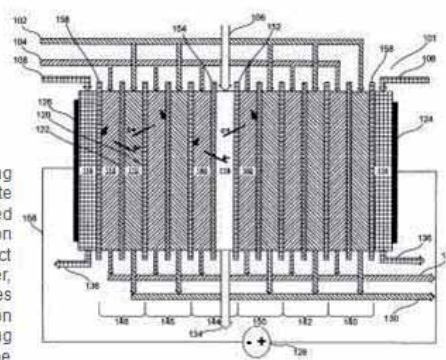


Figure 33: Saltworks' desalination technology integrated with solar thermal energy

The desalting device is modular and designed for rapid deployment. Building from electro dialysis, Saltworks' stack uses ion exchange membranes to separate solutions and transfer salt (see Figure 34). Unlike electro dialysis, Saltworks' device does not require external power. Instead, it harnesses energy captured in concentrated salt solutions to initiate salt transfer.

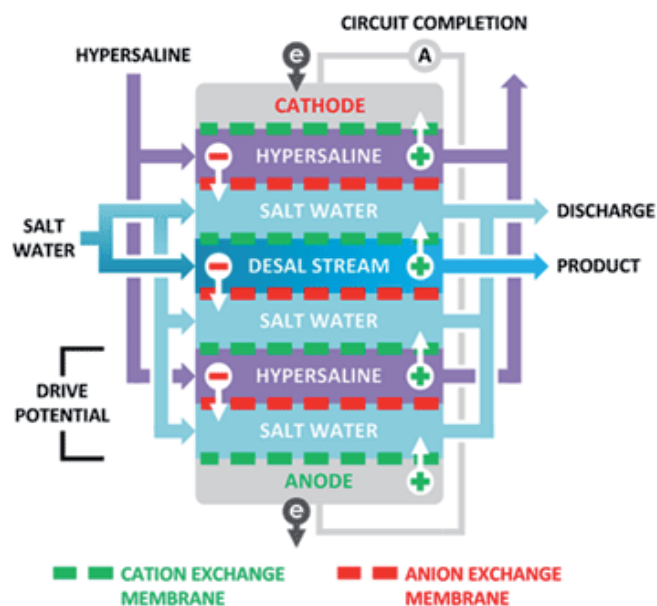


Figure 34: Saltworks technology – product outline¹⁸

The patent-based inventor network map in Figure 35 shows that Saltworks does not have any collaborations that are apparent from its patent portfolio.

¹⁷ http://www.saltworkstech.com/press_20110614.php

¹⁸ <http://saltworkstech.com/technology.php>

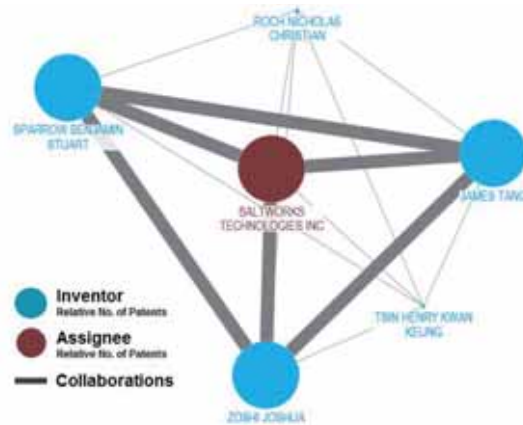


Figure 35: Saltworks assignee–inventor network diagram for desalination technology

6.3 Desalination - Solar PV integration products

SwissINSO

SwissInso has developed a solar powered RO water purification system capable of producing up to 100m³ p/day of pure drinking water from Brackish or Seawater (the Krystall™ system, see Figure 36)¹⁹. This is a complete product which can be readily deployed in rural or remote locations, and has already been deployed in some areas of West Africa and the Middle East. The container based product is modular and mobile, and contains all necessary components on delivery that can be assembled locally. It also contains a back-up diesel generator in case of Solar PV failure or insufficient power. It is based on 'indirect' integration via electricity generated from the solar panels or generator.

It is important to note that we did not identify any patents owned by SwissInso related to desalination or Solar PV. The product is based on the integration of a third party desalination technology and solar PV kit. The case study highlights the importance of combining patent landscaping techniques with non-patent research to develop an accurate product and technology map in an industry. It also suggests that much of desalination - renewables integration may be led by 'technology integrator' companies.



Figure 36: SwisINSO Krystall™ product

¹⁹ <http://www.swissinso.com/en>

6.4 Desalination – Wind energy integration products

Aerodyn

Aerodyn is a leading wind turbine technology company. It has developed an integrated wind turbine desalination unit, using mechanical vapour compression (MVC) technology, as illustrated in patent WO02097265A1 (see Figure 37). The MVC uses the kinematical energy of the wind turbine directly to drive the compressor of the evaporation plant. It raises the temperature and pressure in the evaporator that is integrated in the tower up to the required level. This integration is anticipated to keep down costs compared to a conventional wind energy convertor (WEC) with a downstream electrically run desalination plant.

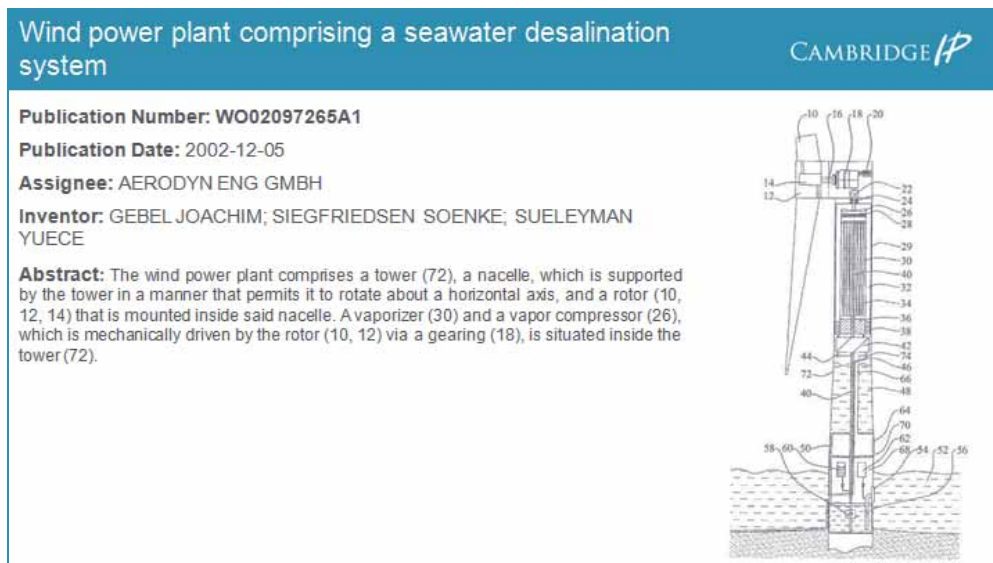


Figure 37: Aerodyn’s desalination technology integrated with wind energy

The patent-based inventor network map in Figure 35 shows that Aerodyn has not undertaken any collaboration in this technology space.

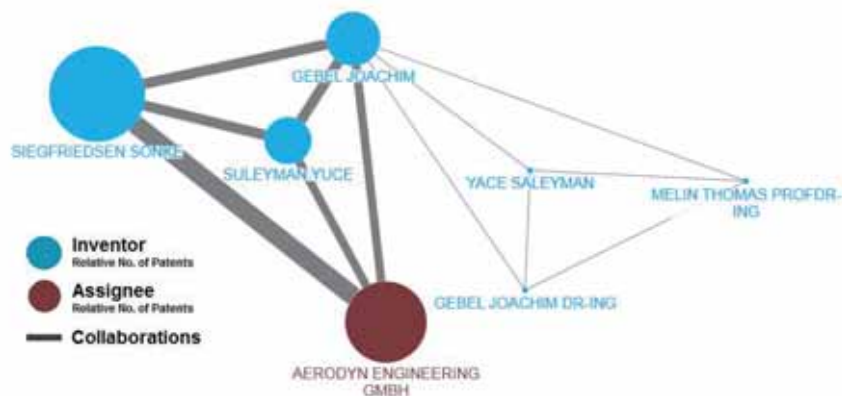


Figure 38: Aerodyn assignee–inventor network diagram for desalination technology

Enis Windgen™

Enis Windgen™ is currently developing a novel wind-powered desalination system using eutectic freeze crystallisation (EFC),²⁰ and using wind power combined with compressed air energy storage (a patent relating to this technology is WO2008013870A2, Figure 39). The website of the company also does not seem to suggest that the technology has been commercialised, or that prototypes of the technology have been developed.

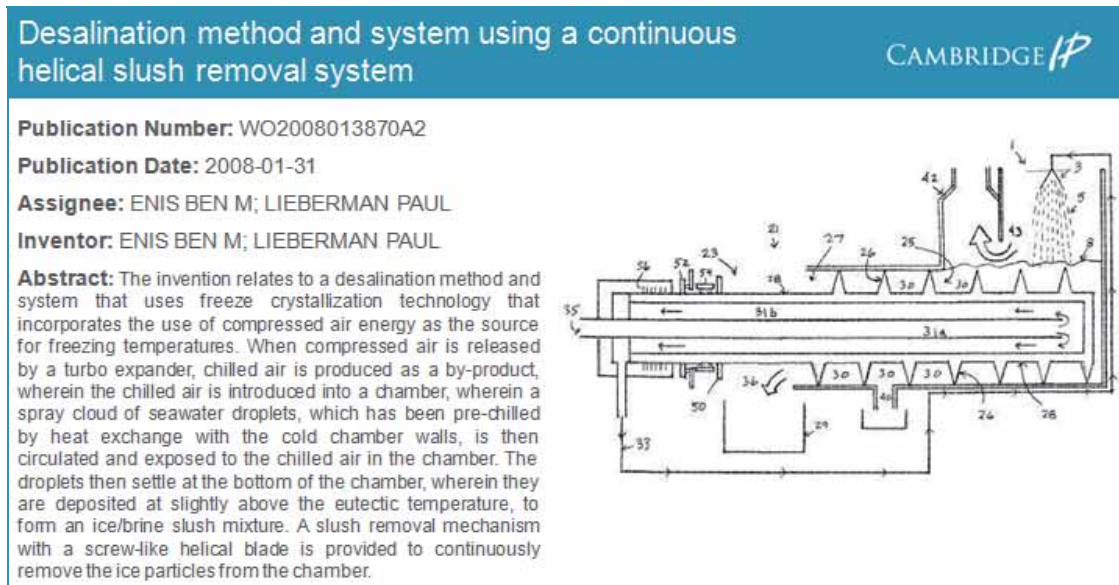


Figure 39: Enis Windgen’s desalination technology integrated with wind energy

The patent-based inventor network map in Figure 40 show not collaborations in this space that is apparent from their patent portfolio.

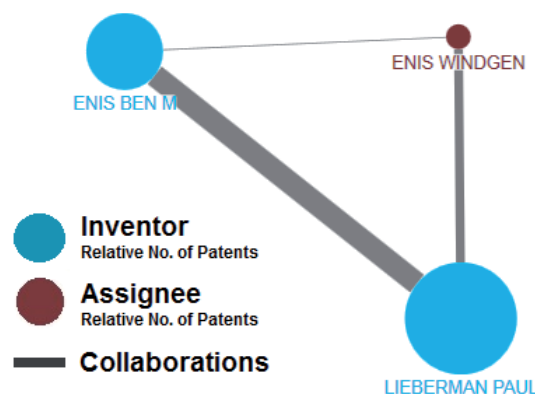


Figure 40: Enis Windgen assignee–inventor network diagram for desalination technology

²⁰ <http://www.eniswindgen.com/FlyerDesalination.pdf>

6.5 Desalination – Wave energy integration products

Carnegie Wave Energy

Carnegie is an Australian wave energy company, with commercially deployed wave energy turbines, tested in real offshore conditions. Carnegie has also developed combination of RO desalination technology, integrated with its wave energy technology using pressure. We did not identify specific patents related to the integration, most likely due to its use of third-party RO technology.

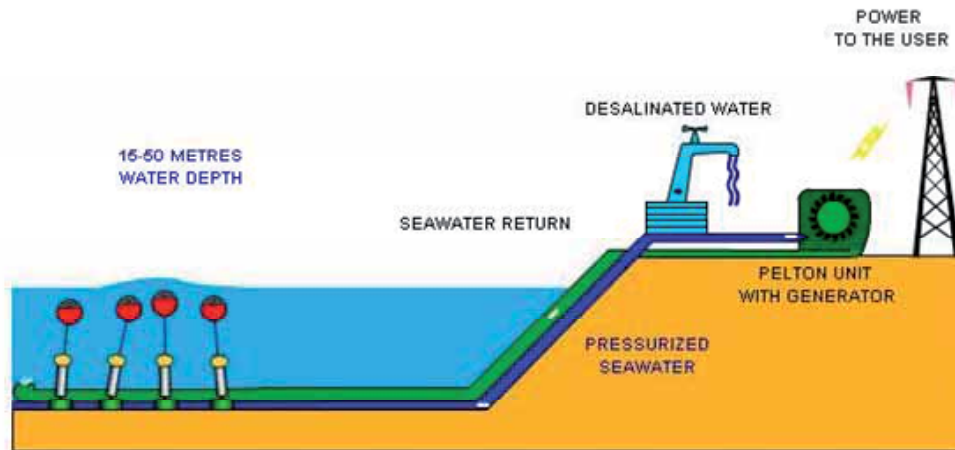


Figure 41: Carnegie's wave-desalination integration

ecOcean renewables

ecOcean renewables is a company that focuses on producing potable water from renewable energy resources,²¹ specifically wave and tidal. Its technology appears to be at an early stage of development. One patent relevant to its main product is WO2008074810A2 (Figure 42).

²¹ <http://www.ecocean.eu/index.php/home>

System for generating electrical power and potable water from sea waves

CAMBRIDGE IP

Publication number: WO2008074810A2

Publication Date: 2008-06-26

Assignee: ECOCEAN RENEWABLES LTD

Inventor: PAPADOPOULOS CHRISTOS F

Publication Date: 2008-06-26

Abstract: The invention pertains to a device and method for generation of electrical power from sea waves, with either simultaneous or no desalination of seawater. The device comprises of a seaborne portion and a shore - side portion. The seaborne portion of the device comprises a float (1), an anchor (2) and a pumping mechanism (27). Seawater and air are drawn in and pumped through pipes (29) and (30) respectively to a shore - side compressor system (33). The compressor system is adapted to provide pressurized water of constant pressure to the next stage, which is either the desalination assembly (36) through which potable water is produced using the reverse - osmosis method or the water - motor (24), which drives a generator that provides electrical power or both.

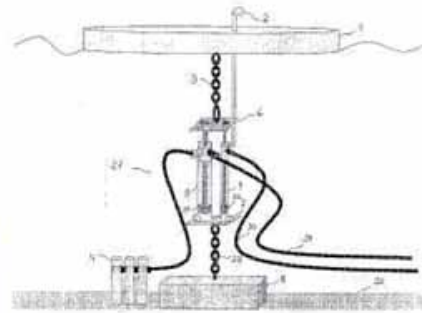


Figure 42: ecOcean renewables' desalination technology integrated with wave and tidal energy

6.6 Desalination – Geothermal energy integration

Yale University

Patent WO02060825A2 (Figure 43) from Yale University relates to a membrane process patent. Claim 13 of the patent lists possible integration with geothermal energy, but also waste heat and solar heat. This highlights the fact that many companies in the solar thermal and waste heat dataset could also be developing technologies that could be integrated with geothermal energy. It also demonstrates that for many of the patents identified, 'integration' may mean an awareness or intent by the inventor for integration, rather than specific innovation related to integration.

Osmotic desalination process

CAMBRIDGE IP

Publication number: WO02060825A2

Publication Date: 2002-08-08

Assignee: UNIV YALE

Inventor: MCGINNIS ROBERT

Publication Date: 2002-08-08

Abstract: An energy efficient desalination process that does not produce waste products involves the extraction of water from a first solution, such as seawater, by using a second concentrated solution to draw the water from the first solution across a semi-permeable membrane. By manipulating the equilibrium of the soluble and insoluble species of solute within the second solution in favor of the soluble species of the solute, a saturated second solution can be used to generate osmotic pressure on the first solution. Also, by adjusting the equilibrium in favor of the less soluble species after the water has been drawn from the first solution, a portion of the solute can easily be precipitated out. Heating the second solution decomposes the solute into its constituent gasses.; The constituent gasses and precipitated solute may be recycled through the process to affect the changes in equilibrium and eliminate waste products. Additionally, by using the waste steam from industrial sources and a heat pump to effectively distribute heat through the present method, the present method exhibits greater energy efficiency than prior art methods.

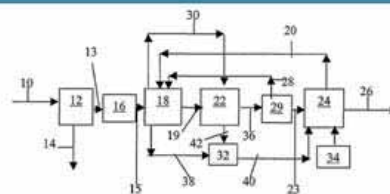


Figure 43: Yale University's desalination technology integrated with wave and tidal energy

The patent-based inventor network map in Figure 44 shows that the Yale University patents all relate to the Robert McGinnis work, with him as the assignee on some of the later patents, but no co-assignee on any of the Yale University patents. The inventor on the Yale University patent is Robert McGinnis, who is now part of Oasys Water, a novel desalination company creating the Engineered Osmosis™ technology.²²

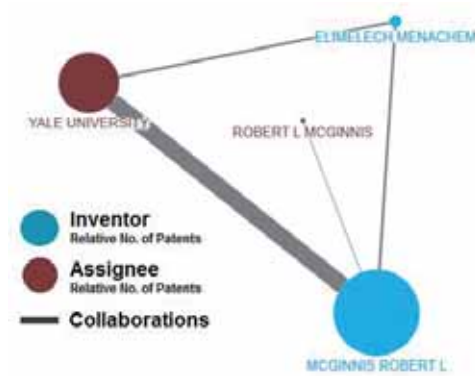


Figure 44: Yale university assignee–inventor network diagram for desalination technology

²² <http://www.oasyswater.com/index.php>

7 Key findings and implications

In comparison to the overall desalination technology space, the renewable energy integration subspace is relatively small. It is important to bear in mind that this space only accounts for direct integration of renewable energy. Indirect integration will typically be covered by separate patents in the renewable energy and desalination spaces.

Of the desalination-renewable integration technologies, the most developed are thermal integration solution. These integrations are frequently relevant to integration with solar heat, waste heat as well as potential integration with geothermal energy. It is likely that integration technologies developed in this space will have the most routes to market

The number of solar PV desalination integration patents was relatively small. This is to be expected, as the energy integration would either be through waste heat from the PV installation, in which case the technology would fall in the solar heat space, or alternatively the technology would relate to indirect integration.

For wind as well as wave and tidal technologies, the patenting spaces are relatively small compared to solar thermal integration. However complete integrated products in this space do exist. These products could be particularly applicable in coastal or island areas.

There are different types of companies owning patents in the desalination space, from large multinationals to Small and Medium Enterprises (SMEs), Universities and Government research laboratories. There are also a number of individual inventor patent owners.

In the case studies, particularly those of Carnegie Wave Energy and SwissINSO, it is clear that technology ownership and patent ownership are not always the same. Further technology landscaping or more in depth patent landscaping focussed on a specific technology aspect could enhance these general patent landscape results, particularly towards creating more product based or FTO type analyses.

There are very few patent filings in Africa and the Middle East compared to North America, Europe and Asia. This was somewhat surprising, given that these areas are some of the most important *deployment* geographies. The limited number of patent filings could be related to market perceptions of the potential market size, strength of IPRs, or indeed the commercial value of technologies. Further analysis could focus on key motives behind the patenting strategy of key companies, and choices between geographies.

A particular area of growth in technology and innovation is around the design of mobile, modular and saleable desalination systems which are integrated with renewable energy sources. Such systems can be transported and assembled easy to off grid remote areas and island locations. This will allow products to be installed on a small scale in remote locations where they are needed and these installations can help companies to further develop their technologies. Such smaller systems can support the generation of potable water for consumption and sanitation in remote locations, and support small-scale

industrial operations. The economics of water in such locations are such that desalination - renewable integration may already be economically superior to other solutions. Scale-up of usage of desalination technologies in such market niches could help the technology move down the experience curve, increase adoption rates, lead to further innovation and ultimately help bring down the costs of desalination technology more widely.

The patent landscaping exercise did not consider the issue of brine disposal. Yet mass deployment of desalination technologies is likely to result in a drastic increase in the potential environmental impact of brine disposal using current techniques. We would recommend further study of the emerging technology solutions to this problem, as brine disposal technologies would need to be transformed to accompany mass deployment of desalination.

The three main application of clean water are personal use (drinking and sanitation), industrial use and agricultural use. Most of the desalination systems in operation currently address shortages of drinking water and sanitation. There has also been growth in the use of these systems for small-scale industrial purposes in remote areas. Agricultural applications are viewed as an important market for desalinated water in the long term, although this is already practiced in Israel, who is the current leader in the development of desalination solutions for agricultural use.

It is important to continue monitoring this space, and in particular to focus on understanding better the inter-relation between desalination technology and the 'indirect integration' with renewable energy sources through the grid or small scale power generation. This would require integrating information from the IP Landscape with product and technology mapping using wider techniques. Where the patent landscape is very relevant for assessing the innovation trends in the space, a more in depth correlation with products will provide policy makers with a more complete picture. A systematic monitoring of this space could allow key stakeholders to benchmark infrastructure investment and technology acquisition programmes not only with the latest technology in the market place, but also to identify close-to-market technologies which can be accelerated further through volume deployment.

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Appendix 1: Definition of desalination technologies

Membrane technologies

Reverse osmosis (RO)

Reverse osmosis (sometimes called hyper filtration) is a membrane filtration technique. The osmotic membrane allows water molecules through, but not the salt and mineral molecules. Osmosis is defined as the diffusion of water through a semi-permeable membrane from a solution with low total dissolved solids (TDS) to a solution with high TDS. In reverse osmosis, saline feed water, a high TDS solution, is pumped at high pressure through permeable membranes to produce a solution with low TDS, thereby separating salts from the water and producing freshwater (UN ESCWA, 2009).

The pressure needed is closely related to the TDS of the feed water. This means that the energy requirements of the system are also closely related to the TDS of the feed water.

The reverse osmosis membranes are prone to scaling and fouling. This can be reduced by filtration of the water to reduce the larger particles in the feed water. Membranes can be protected from this by pre-filtration processes, most commonly by using sand filtration and/or nano-filtration membranes (Younos, 2005).

Forward osmosis (FO)

In the forward osmosis technique, a draw solution is used on the opposite side of the membrane to the feed water. Fresh water is drawn towards the draw solution, creating a solution of fresh, potable water. Typically, a draw solution is chosen such that it can easily be extracted to produce fresh water.

Electrodialysis (ED) and electrodialysis reversal (EDR)

Electrodialysis uses electromotive forces to separate dissolved ions from the feed water. An electric charge is applied over a water stream. The water moves along a series of membranes pairs, called a membrane stack. Each membrane pair consists of a cat-ion transfer membrane (which lets cat-ions and not anions pass through) and an anion transfer membrane (allowing only anions through). As water moves along the membrane stack, cat-ions and anions pass respectively to the cathode and anode. This creates streams of brine and desalinated water (Younos, 2005).

Thermal technologies

Solar distillation

A pond of feed water is subjected to solar radiation, which causes pure water to evaporate and condensate on some condensing surface provided. The condensate is

guided away as potable water, while the concentrated salt water left in the pond constitutes the brine (Younos, 2005).

This technique is generally low cost, but requires a large footprint and has low productivity.

Multistage flash (MSF)

This process is made up of multiple flashing stage. Each flashing stage sees feed water travel into the system in a tube, the tube (and feed water) is heated by warmer water vapour around it which simultaneously pre-heats the feed water and causes the vapour to condensate. Once the feed water pipe reaches the last flashing stage, it has been pre-heated enough to enter the brine pool of the first flashing stage. Here it evaporates to heat the feed water intake pipe. The water left in the brine pool then forms the feed water for the next flashing stage where the temperature is increased and more water evaporates (Younos, 2005).

Multi-effect distillations (MED) (also known as multi-effect evaporation (MEE))

Feedwater is sprayed on hot tubes which cause it to evaporate; the water vapour is fed into the next set of pipe to heat them. The spraying of the cool saltwater on the hot pipes not only causes the water to evaporate, but also the vapour in the pipes to cool down and condensate (Younos 2005).

Thermal vapour compression (TVC)

This works similar to MEE, but uses steam jet ejectors to compress the vapour entering the tubes, improving the performance (Younos, 2005).

Mechanical vapour compression (MVC)

MVC works in the same way as TVC, but employs mechanical compressors instead of steam jet ejectors (Younos, 2005).

Adsorption vapour compression

A pressure difference is created between two reservoirs, which drive the evaporation and condensation process for potable water production. Typically, this difference is created through an exothermic reaction by adding a substance such as LiBr to the feed water reservoir (Younos, 2005).

Other technologies

Membrane distillation

A hydrophobic membrane is placed between water streams at different temperatures. The difference in vapour pressure drives vapour to move through the membrane. As the salt does not vaporise, it cannot pass through these membranes.

Electrodeionisation (EDI)

EDI is a combination of ion exchange and electrodialysis. An electric charge is applied to plates which are outside membranes separated by resin beads. Salt water passes between the membranes. Salt ions are caught by the resin and pulled out through the membranes. The water passes through the resin beads and produces a clean stream of water. This procedure can also be used to produce ultra pure water.

Capacitive deionisation (CDI)

The feed water is passed between plates that are coated with a carbon aerogel. This material absorbs the salt ions in the water and so produces potable water (Younos, 2005).

CDI technology is still under development and there are a number of groups working on it worldwide. In the current level of development, it is not a feasible solution for seawater desalination, but more focused on the desalination of brackish water.

Freeze separation (FS)

This technique, which is still in development, uses the freezing or partial freezing of feed water to create pure water crystals. These crystals are then separated from the brine and subsequently melted to produce clean water.

Rapid spray evaporation

Feedwater is sprayed at high velocity. The mist allows water to evaporate, while the salt ions do not. The water vapour is collected to form potable water. This technique has potential to be used for recovery of potable water from brine solutions.

Vacuum distillation

When water is in a vacuum, the evaporation temperature is significantly reduced, which means that distillation can occur at much lower temperatures.

Gas hydrates

The chemical structure of a gas hydrate includes only water and a given gas molecule (e.g. methane or carbon dioxide). When hydrates form, the chemical structure excludes all salts and other impurities. When the hydrate is dissociated, only gas and pure water remain.²³

Complementary technologies for desalination processes

Various processes and chemicals are used during the pre- and post-treatment of water during the desalination process. Certain membrane processes can be used as pre-treatment of feed water before the desalination process. Microfiltration (MF) is sometimes used to reduce the turbidity of feed water and remove suspended solids and

²³ <http://sps.esd.ornl.gov/desalinationpage.html>

bacteria. Additionally ultrafiltration (UF), where the membrane pores is slightly smaller than microfiltration, can be used in the removal of high weight dissolved organic compounds, bacteria and some viruses. Probably the most commonly used pre-treatment membrane process for RO desalination is nanofiltration (NF). It is used for water softening and removing sulphates, organics and viruses. The water softening in particular helps to protect the RO membranes from scaling and helps improve their lifetime. In addition to processes, chemicals typically used in pre-treatment include NaOCl, FeCl₃/AlCl₃, H₄SO₄/HCl/NaHSO₃ and scale inhibitors. (Mezher, 2010)

Ion exchange, which uses resins to remove undesirable ions from water, is used sometimes used as a final step after other desalination processes have been used to remove most of the salt content. In addition, chemicals commonly used in post-treatment of potable water from desalination processes include enzymes, detergents, surfactants, caustics, biocides and acids. (Mezher, 2010)

Another consideration is the disposal of brine solution, which can be done in one of six ways (Mezher, 2010):

- Surface (surface water or submerged)
- Sewer system blending
- Land application
- Deep well injection
- Evaporation ponds
- Zero liquid discharge

The selection of the most appropriate method of disposal is based on a number of factors, including (Mezher, 2010):

- Volume of the brine concentrate
- Chemicals present in the discharge
- Geographical location of the discharge point
- Availability of the receiving site
- Public acceptance
- CAPEX and OPEX

Ability of the facility to be extended

Appendix 2: Patents and business strategy

In practice, there are a number of ways in which companies use IPRs to shape their business strategy. This section summarises the most important aspects.

Licensing

Patent owners can licence their IP to a third party in return for a fee or some other arrangement between the relevant parties. A specific case is a cross-licensing agreement, where is pre-defined arrangement by which the partners can use one-

another's IP. The licensee is then free to use the licensed IP for the time agreed. In some cases the agreement will only cover licensing for production, which means that the IP is licensed by the owner to only be used in a certain predefined way. In cases where a licensee oversteps the agreements of the licensing contract, or where someone is infringing on a patent owner's IP, they may seek enforcement licensing. This generally takes place out of court and targets companies that have already commercialised their technology.

Financing and investment

A company's patent portfolio can be an important consideration during fund-raising (such as through Venture Capital funding). In R&D_ intensive industries, a strong patent portfolio can be a strong signal of quality and market potential. In some industries strong patent protection may be seen as *the* critical factor in being able to commercialise a technology successfully.

Blocking market entry by other players

Patents can be used to block market entry and prevent the sale of products that infringe on the rights of the patent holder. Patent owners can decide whether or not to assert their rights through a patent lawsuit. This decision is based on strategic and economic considerations.

Technology standards bodies

These are industry associations administering key technology standards on behalf of the market. Cross licensing often forms part of these associations as many of the partners will contribute IP for mutual use through some pre-defined arrangement.

Technology transfer

This is often associated by university-to-industry transfer, where universities license the use of their spin-off businesses or other industrial partners.

Risk pooling

Risk pooling involves consortia of major industry players seeking to pool their resources for highly capital intensive and risky ventures. IP is pooled or shared through a predefined arrangement.

Strategic leadership

It may be beneficial for companies to licence their technology to partners and other market players at a less economic rate in order to influence the technology development path favouring the adoption and potential lock-in of their technology.

Patent banks/libraries

Some IP owners keep banks of patents which they do not enforce of use for manufacturing. These patent banks can be used in a number of ways , depending on the

owner. Some of these are used as a reference library for smaller players to find IP protecting them against possible litigation by larger players or providing them a platform on which to develop their product. In an extreme case, the patents are accumulated by non-practicing, non-manufacturing entities which seek financial gain through enforcement licensing.

Appendix 3: Detailed patent coverage

Table 18: Detailed patent data coverage

Patent dataset	Date
INPADOC	1900 - present ²⁴
US (Granted)	1971 - present
US (Applications)	2001 - present
Europe (Granted)	1980 - present
European (Applications)	1979 - present
PCT publications	1978 - present
Japan (Title, Abstracts)	1976 - present
German (Granted)	1968 - present
German (Applications)	1968 - present

Appendix 4: Patent terminology

Patent applications vs. granted patents

Patent landscaping is based on the development of a patent dataset specific to a particular technology space, application area or problem focus. This dataset can be made up of patents and patent applications, as well as patent families, as explained below. Patent applications may be published even though a patent has not been granted yet, which provides early information about innovative activity. Differences in the rates between granted and non-granted patent applications can also provide proxies for the level of genuine inventiveness in a technology space, or provide an insight into industry players' patenting strategy.

Patent families

Patent documents are geographically specific, while technologies can flow across countries. Consequently an inventor seeking patent protection over the same technology in more than one country will end up having multiple patents protecting the same

²⁴ For more detailed information about exact INPADOC coverage, refer to <http://www.epo.org/searching/essentials/data/tables.html>

technology or invention. This is broadly referred to in the patent literature as ‘patent families’²⁵.

Patent families can therefore be viewed as a proxy for a number of innovations around a technology space. In addition, analysis of the size and composition of individual patent family can help to understand better companies’ patenting strategies. One patent family can include more than one patent in a single country, each protecting a different aspect of the invention.

Technology classification codes

Patents are tagged by various classification codes by the patent examiners dealing with their application, e.g. IPC (international patent classification) codes, ECLA (European classification), US classification codes. By looking at the various trends we can see how the research focus in a field has changed from one aspect to another. IPC codes are most frequently used, as it is associated with the most patents.

Office of first filing (OFF)

The country where the first application was filed – this is taken to be the earlier priority country.

Office of second filing (OSF)

This is the jurisdictions where subsequent family members of a patent were filed. Here each application/patenting country in a family of counted only once, even when more than one patent from that family is filed in the country. The office of first filing is also not included here.

Appendix 5: Focus dataset

Refer to accompanying dataset in Excel spreadsheet.

Appendix 6: LDCs investigated

A list of the least developed countries investigated in the geography analysis. No patents, offices of first or second filings were identified in these countries. Except for Malawi and Zambia, our databases do not contain filings for these countries.

²⁵ For more on the different types of patent family definitions you can refer here: <http://www.espacenet.dk/dk/dk/help/161.htm> and http://www.intellogist.com/wiki/Patent_Families

Table 19: Least developed countries investigated

Least developed countries	
Afghanistan	Lesotho
Angola	Liberia
Bangladesh	Madagascar
Benin	Malawi
Bhutan	Mali
Burkina Faso	Mauritania
Burundi	Mozambique
Cambodia	Myanmar
Central African Republic	Nepal
Chad	Niger
Comoros	Rwanda
Democratic Republic of the Congo	Samoa
Djibouti	São Tomé and Príncipe
East Timor	Senegal
Equatorial Guinea	Sierra Leone
Eritrea	Solomon Islands
Ethiopia	Somalia
Gambia	Sudan
Guinea	Tanzania
Guinea-Bissau	Togo
Haiti	Tuvalu
Kiribati	Uganda
Laos	Vanuatu
	Yemen

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