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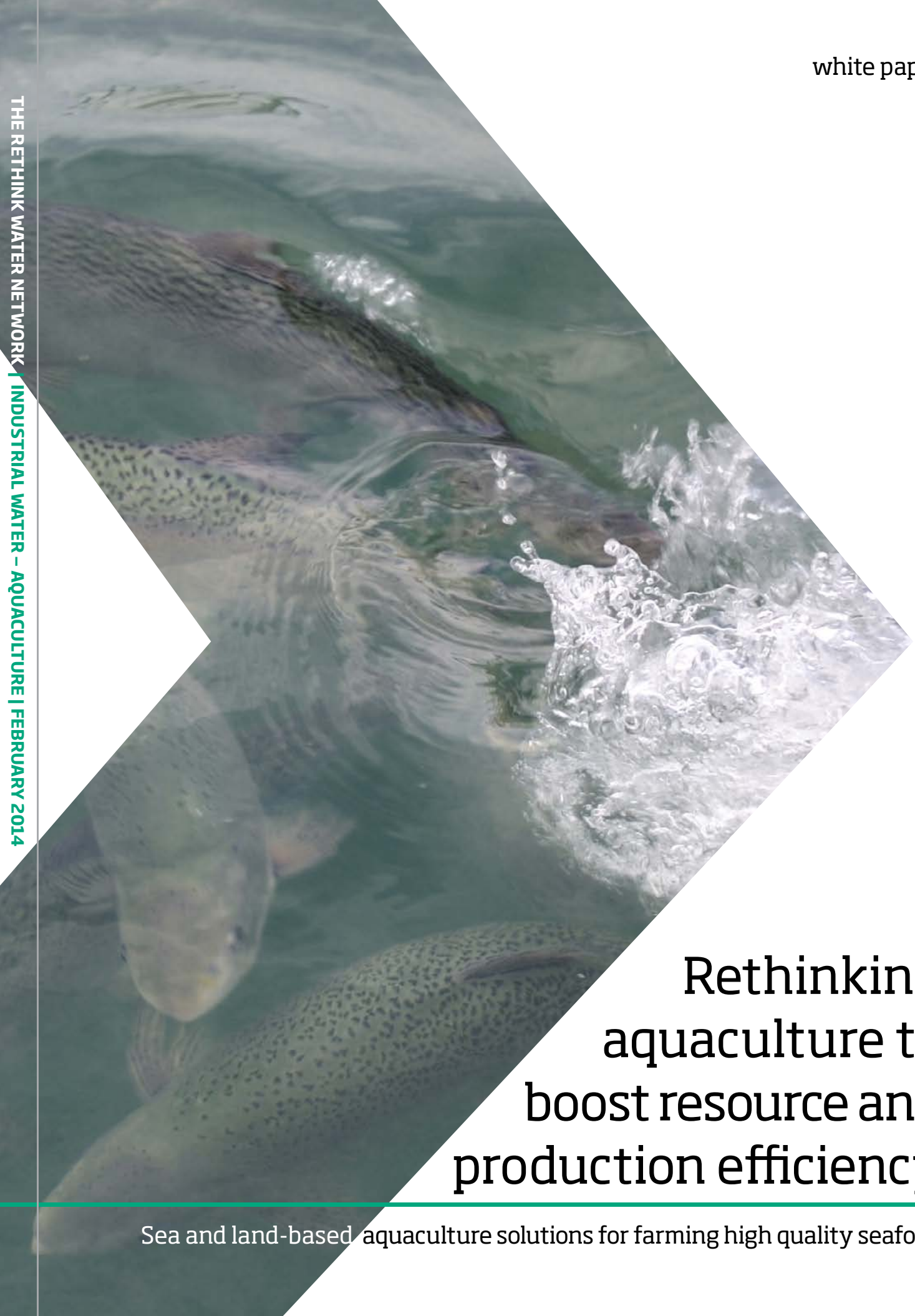

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Rethinking aquaculture to boost resource and production efficiency

Sea and land-based aquaculture solutions for farming high quality seafood

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Version 1.1

About this white paper
This white paper has been developed by the Rethink Water network in Denmark. The work is coordinated by the Danish Water Forum. The Rethink Water network consists of more than 60 technology and consulting companies, water utilities, water organisations and public authorities. It was established to support our partners internationally in developing the highest quality water solutions.

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Executive summary

Aquaculture, not the Internet, represents the most promising investment opportunity of the 21st century

PETER DRUCKER (1909-2005)
Writer, professor and self-described social ecologist

Besides the healthy aspects and seafood's great taste, life underwater is efficient in converting feed to protein. For more than four decades, the worldwide demand for fish has increased at almost twice the rate of the growth in global population. Today half of the fish consumed comes from aquaculture.

Avoiding impact on aquatic environments

Even if aquaculture has to some extent eased the stress on wild fish stocks, poorly located and poorly managed aquaculture production has significant negative impact on the environment. Some of the promising sustainable aquaculture solutions are off-coast marine production and modern land-based recirculation systems in which farming takes place at a safe distance from aquatic environments sensitive to aquaculture activities. The combination of smolt and fry production in land-based recirculation systems and grow-out undertaken off-coast in the sea ensure a resource and water efficiency that is second to none.

State-of-the-art recirculation systems

Farmers compete with other sectors for access to resources and space, whether at sea or on land. These factors can be important barriers against establishing or expanding conventional aquaculture farms. Looking into land-based recirculation systems, the advantage is that they use less than 500 litres of water per kilo of fish produced compared to the land-based flow-through systems, in which water intake is typically around 50,000 litres per kilo of fish produced. Other important benefits include the 24/7 monitoring and control that ensure consistently good water quality and feeding programmes tailored to the particular needs of individual species. These optimised conditions boost growth, minimise the risk of disease and mortality, and reduce medication to a minimum.

New developments in off-coast production

Looking into sea-based systems, the challenge is that oceans around the world will be subjected to new massive space-consuming marine infrastructures in the coming years. This includes sea-based aquaculture, which is expected to continue its boom. The European marine aquaculture sector is undergoing developments into off-coast aquaculture. The advantages are more stable conditions with regard to salinity and temperature. This means less stress on the fish and hence higher growth rates and reduced risk of disease. This also minimises the use of antibiotics and reduces the relative production costs. Furthermore, multi-use platforms will integrate off-coast renewables and cultivation of fish.

Farming salmon in the Gobi desert, China
High energy costs and strict environmental regulations have forced companies in Denmark to develop new and innovative solutions. One example is the intensive recirculation technologies that will now be used for an annual production of 1,000 tons of salmon next to the Gobi desert in north-western China, close to Mongolia. Water is pumped from a 100-metre deep borehole using only 250 litres (66 US gallons) of water per kilo of fish produced, whereas traditional flow-through technology uses 50,000 litres (13,000 US gallons) per kilo. Recirculation technology is thus an opportunity to produce high-quality seafood and become self-sufficient even when water resources are scarce. With regard to sustainability, however, it is important to be aware that recirculation plants use energy. But by using high efficiency pumps and other solutions to cut down energy use, salmon can be produced using just 2.5 kWh per kilo. (Courtesy: Billund Aquaculture and Grundfos).

The North Atlantic is one of the world's most productive oceans, but for decades it has been challenged by overfishing. Fishing is an important industry for Denmark, Greenland and the Faroe Islands, so the proud traditions of providing quality fish to the world are now supplemented with aquacultural production. In the North European region, aquacultural production of salmon and other salmonids now dominates, but because of space limitations, fish welfare and environmental concerns, smolt production increasingly relies on recirculation techniques, while grow-out of salmon at sea increasingly takes place in off-coast environments and areas with high water exchange where space is available and environmental conditions are more stable. This is a field of expertise for Danish companies and Denmark now exports not only seafood, but also consulting services and responsible aquaculture farming systems for both sea and land-based production. About 20 per cent of all land-based recirculation aquaculture systems worldwide are designed and delivered by Danish-based companies.

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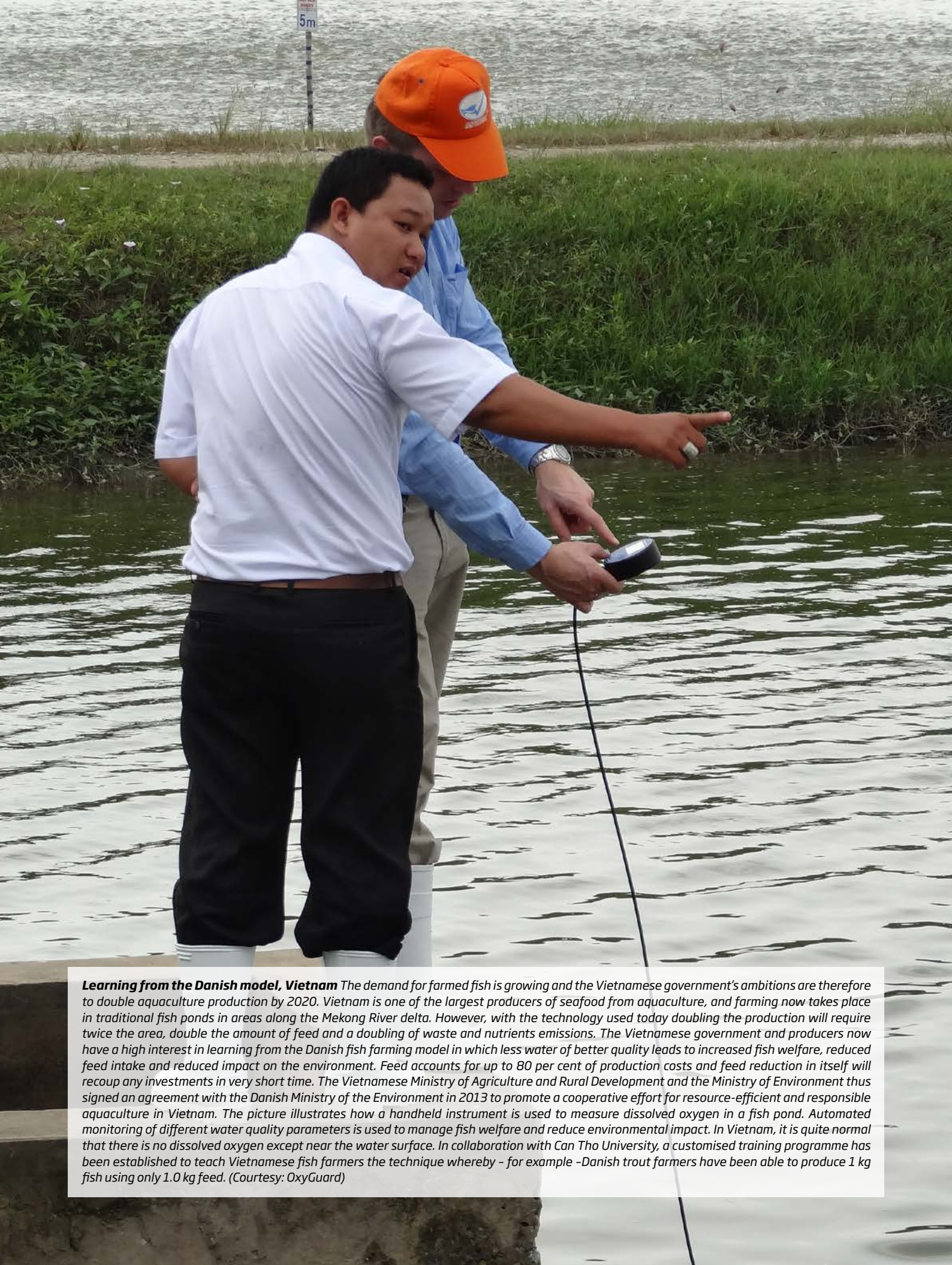

Learning from the Danish model, Vietnam *The demand for farmed fish is growing and the Vietnamese government's ambitions are therefore to double aquaculture production by 2020. Vietnam is one of the largest producers of seafood from aquaculture, and farming now takes place in traditional fish ponds in areas along the Mekong River delta. However, with the technology used today doubling the production will require twice the area, double the amount of feed and a doubling of waste and nutrients emissions. The Vietnamese government and producers now have a high interest in learning from the Danish fish farming model in which less water of better quality leads to increased fish welfare, reduced feed intake and reduced impact on the environment. Feed accounts for up to 80 per cent of production costs and feed reduction in itself will recoup any investments in very short time. The Vietnamese Ministry of Agriculture and Rural Development and the Ministry of Environment thus signed an agreement with the Danish Ministry of the Environment in 2013 to promote a cooperative effort for resource-efficient and responsible aquaculture in Vietnam. The picture illustrates how a handheld instrument is used to measure dissolved oxygen in a fish pond. Automated monitoring of different water quality parameters is used to manage fish welfare and reduce environmental impact. In Vietnam, it is quite normal that there is no dissolved oxygen except near the water surface. In collaboration with Can Tho University, a customised training programme has been established to teach Vietnamese fish farmers the technique whereby – for example –Danish trout farmers have been able to produce 1 kg fish using only 1.0 kg feed. (Courtesy: OxyGuard)*

1. A need for greater resource and production efficiency

Water is an increasingly scarce resource and more than 70 per cent of all water used globally goes into farming and the processing of food. This is an important advantage of aquaculture – producing a kilo of beef requires 15 cubic metres of water, whereas sustainably farmed fish takes only a fraction of this amount

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The demand for fish continues its insatiable rise and we now eat twice the amount of fish we did 50 years ago. In addition, a growing global population and a planet with limited resources makes seafood a genius source of food. Besides the healthy aspects and its great taste, life underwater is efficient in converting feed to protein.

Overfishing and environmental impact

Unfortunately, the world's oceans, lakes and rivers are no longer an unlimited source of human food because many of the world's fish stocks have been fished to their limits or are on the verge of collapse. This encourages the aquaculture sector to grow, and today about half of the world's consumption of seafood comes from aquaculture. However, when aquaculture farms are poorly located or poorly managed they have the potential for significant negative impacts on the environment. In addition, the pressure on wild fish stocks will continue if marine ingredients are used in the feed. An ever-increasing demand for fish thus calls for more sustainable and more efficient solutions.

Producing fish uses less water than beef

An important advantage of some types of aquacultural farming compared with other animal food production is that they do not necessarily need large quantities of water. Producing a kilo of beef requires an average of 15 cubic metres (4,000 US gallons) of direct and indirect use of water, according to the Water Footprint Network, whereas producing a kilo of farmed fish in sea-based aquaculture has almost no direct use of freshwater and can take as little as 500 litres (130 US gallons) if produced in a land-based recirculation system. By comparison, classic flow-through systems use around 50,000 litres (13,000 US gallons).

Expertise of Danish companies

The main challenge of running an aquaculture production system is to meet the fish's biotic requirements. When fish are farmed intensively in captivity, growth conditions quickly deteriorate if the right measures are not taken in time. The risk of disease and mortality is high, so knowhow and smart monitoring are of major importance. In this white paper consulting companies, system builders and technology providers of Denmark share some of their expertise to support customers and investors in adopting the right considerations. This expertise is born from of a strong business model in which the industry has benefited from strong cooperation between biologists and engineers, which has substantially encouraged the development of new technologies. Over the past 5-10 years, a transformation has taken place in Denmark to continuingly increased levels of recycling water, known as model farms, and successful off-coast production has proven its high cost efficiency. New sites will be scaled in the coming years.

Model farms, Denmark *While recirculation systems have been sold on export markets for decades, it is only in the last decade that the Danish production of rainbow trout was implemented. In 2005, the Danish government and the European Union allocated funds for 8 model farms that are currently demonstrating the benefits of recirculation technology, showing that investment is profitable for production volumes of over 1,000 tonnes. The Hallundbæk Fish Farm is one of these farms. Discharged water is filtered and the sludge is used for biogas or fertiliser on agricultural land. The reject water is treated in a plant lagoon for removal of nitrate. Water recirculation is over 96 per cent and water use is 500 litres (130 US gallons) per kg fish produced. (Courtesy: AKVA group)*

Large-scale caviar production, Moldova *Aquatir in Moldova is a unique, 30,000-square-metre large-scale industrial complex that breeds four different sturgeon species. The facility in Moldova produces five tons of black caviar and 200 tons of commodity fish per year, for both domestic and foreign consumers. The cultivation of fish takes place in recirculated systems to avoid any influence from external factors, and has its own scientific laboratory for water chemistry analyses and physiological-biochemical analyses, thereby allowing continuously qualitative scientific monitoring. Feeding is one of the very important factors in sturgeon breeding and advanced technology has improved the capacity of the facility and helped the company to reach planned targets. (Courtesy: Billund Aquaculture, OxyGuard)*

2. State-of-the-art recirculation aquaculture systems

The investment required for recirculated aquaculture systems, and the operating costs involved, are normally outweighed by the benefits of reduced needs for land, manpower, water and medication. Furthermore, production can be planned in detail, which is usually a major selling point for customers at the next levels of the supply chain

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Advanced recirculated aquaculture systems are one of the most promising methods for fish farming, as water consumption and medication are reduced to a minimum, while the feed conversion ratio optimal and environmental impact are reduced to almost zero. Additional benefits include full control of the production process, ensuring high quality products as well as virtually eliminating the risk of disease and mortality. The few basic needs are water, electricity, feed, oxygen and logistics. Skilled people trained to operate the plant are also particularly important because conditions involving large amounts of biomasses combined with small volumes of water mean that the staff only have a very short time to react in the case of oxygen shortages or similar malfunctions.

Strict legislation encouraged innovation

Modern recirculation aquaculture systems often become attractive investments when plant owners and investors are faced with constraints to reduce the consumption and emission of water from the farm. Looking back 25 years, aquaculture expansion with traditional flow-through systems stopped in Denmark due to very stringent environmental legislation. In that same period, Danish companies and research institutions developed the concept of the recirculation system. Aquaculture systems then developed from outdoor flow-through systems placed next to rivers or creeks into sophisticated in-house systems located away from natural watercourses. This involves a radical change because the water intake in recirculation systems is down to just 1 per cent of the water in flow-through systems and the production capacity of these modern systems is not limited by typical environmental constraints. The unique expertise of Danish system manufacturers developed over recent decades lies in the full control of the water environment. A pioneer company in water quality measuring and monitoring equipment is also Danish.

Farmed salmon a new commodity

The first commercial recirculation system in Denmark was developed for farming eels, but the concept has since been expanded to many new fresh water and marine species. In Northern Europe, North America, Chile and Tasmania salmon and trout are currently the most common species produced via fish farming. They are farmed in fresh water until they reach the smoltification process – the physiological

Converting process water to energy, Chile
Process water from aquaculture systems can easily be upgraded to a valuable by-product. In Chile, Chaicas Salmonos annually produces 50 million salmon eggs and 5 million Atlantic salmon smolt of an average of 100 gram per fish. To protect the very beautiful surrounding area and its aquatic system, the company is faced with very strict environmental regulations. All process water is therefore treated and the remaining sludge containing of around 0.3 percent dry matter is dewatered to a concentration of 30 percent dry matter. This dewatering process reduces transportation costs significantly and it is a useful fertiliser for local agricultural farmers. Later the concentrated sludge will prove even more valuable when converted into energy and Chaicas plans to invest in a biogas plant. (Courtesy: Billund Aquaculture)

Land-based salmon production, Denmark *A new 10,000-square metre state-of-the-art land-based recirculation salmon farm was established in the north western part of Denmark in 2013. Meeting the ever-more stringent environmental regulations on discharge of process water into the sea, rivers and lakes, it will produce 2,000 tons of salmon a year. The salmon grow to a market size of 4–6 kg with their full life cycle under the roof of this land-based installation. With a recirculation degree of more than 99 per cent, the system operates as a closed system using just 200 litres of new water from beach drains (salt water) and normal drainage water (fresh water) per kilo fish produced. The system is Denmark's largest fully recirculated aquaculture system, consisting of three halls with circular tanks where the salmon live from fertilised eggs until they are ready to be harvested. In addition, there are two large and three small treatment plants and a 150-square-metre administration building. The facility took just one yea from approval of detailed design to completion of the production system with equipment for water treatment, oxygen control, feeding system, etc. (Courtesy: AKVA group, OxyGuard, Grundfos, UltraAqua, RIA Aquatech, Orbicon).*

Photo: Axel Søgaard

A modern recirculation system will always include some kind of solution for process water treatment. Considerations regarding which level of treatment will be appropriate are alpha and omega, as this will minimise the time that public authorities take to process the application, and will protect the plant against stricter regulations in the future

JACOB BREGNBALLE
Business Director, M.Sc.
Land-based Aquaculture
AKVA group

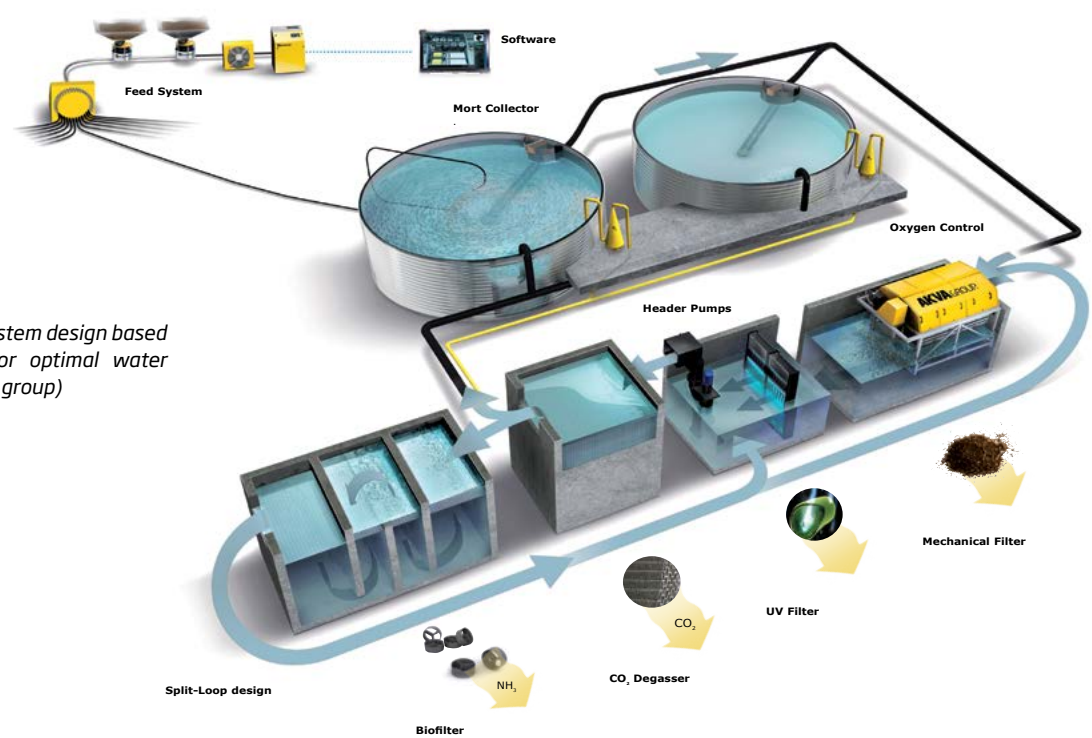
process undergone to allow the fish to migrate from freshwater to the marine environment as part of their life cycle. At a size of 150–200 grams, their growth continues in sea cages. The upper limit of sea-based salmon production has not yet been reached, and new recirculated smolt farms will be established to provide seed stocks for off-coast and offshore salmon farms in temperate seas. However, the latest development in recirculation technology is to grow salmonid fish species to full size on land in an alternated fresh/marine water environment. Monitoring and controlling temperature, light, pH, dissolved oxygen, CO_2, ammonia, nitrate, nitrite and other important water quality parameters give optimal fish welfare conditions. This leads to better feed utilisation and a shorter growing period compared to farming at sea and thus justifies the higher investment costs. Any introduction of parasites and pathogens from the marine environment is also avoided, making chemicals for de-licing unnecessary. As systems are constructed with several independent water treatment systems, the medication can be restricted only to infected section and the biofilter will break down possible residues.

Use of resources in figures

Even though recirculation systems can be built as closed-loop installations with no production water discharge, evaporation and sludge removal account for a certain water loss. The water consumption of 200–400 new litres per produced kilo of fish means a typical total water supply in the range of 10–25 litres/second for the whole installation, depending on the scale of the system. Besides water, an electrical consumption of 2.1–2.5 kWh per produced kilo of fish is needed to run the system and 0.8–1.0 kg fish feed per kg produced fish to make the fish grow.

Facilities vary with the breeding life cycle

The breeding is divided in sections spanning from production of eggs to full-size crop. At the first stages of the life cycle, the production facility is very different from where the fish are grown to full size. For salmonids, the cycle starts with an individual brood stock system, in which fully grown individuals periodically produce eggs and sperm, which are then manually mixed to ensure fertilisation. The fertilised eggs are then transferred to a hatchery facility



Recirculation aquaculture system design based on split-loop technology for optimal water purification. (Courtesy: AKVA group)

Valves and shut-off equipment tailored to aquaculture systems *In a recirculation system, up to 13,000 cubic metres of water are cleaned and pumped every hour. In addition, the aquatic environment is often very aggressive. On the other hand, fish demand a clean environment without inappropriate emissions from the equipment or a system attracting debris. These two things involve special demands, and the types of equipment used by Danish system builders are – in most cases – niche products tailored for aquaculture systems. This also applies to the valves and shut-off equipment used. The valves are produced in Denmark and are of very high quality. The material used is corrosion resistant plastic (HDPE), ensuring there is no risk of corrosion. (Courtesy: RIA Aquatech)*

Reliable and gentle feed dosing *Accurate, gentle dosing is an important element in a recirculated system. With increasingly complex dosing schemes, the need for intelligent dosing pumps grows. An intelligent dosing system ensuring precise pH value adjustment of the water, feeding live feed to fish-fry or algae to the living feed organisms, represents the ideal solution to these well-known challenges. Providing built-in flow control and optimised drive and adjustment mechanisms, the dosing system ensures precise, reliable and cost-effective processes. (Courtesy: Grundfos)*

As systems grow in size, UV water disinfection will become crucial in ensuring the necessary bio-security required to protect shareholders' investments. A properly designed and properly sized UV system can ensure higher growth rates, food conversion ratios and stocking densities, through reduced stress on the stocks

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Sales Manager
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and once the eggs are hatched, the fry are moved to a nursery section with many small tanks connected to a separate recirculating purification system. Here the fry are offered their first feed. For most marine species, natural spawning takes place in the water and the tiny fertilised eggs have to be recovered and treated properly until hatching. The fry most often need live prey, which therefore has to be produced at the hatchery/nursery.

Special attention to biosecurity

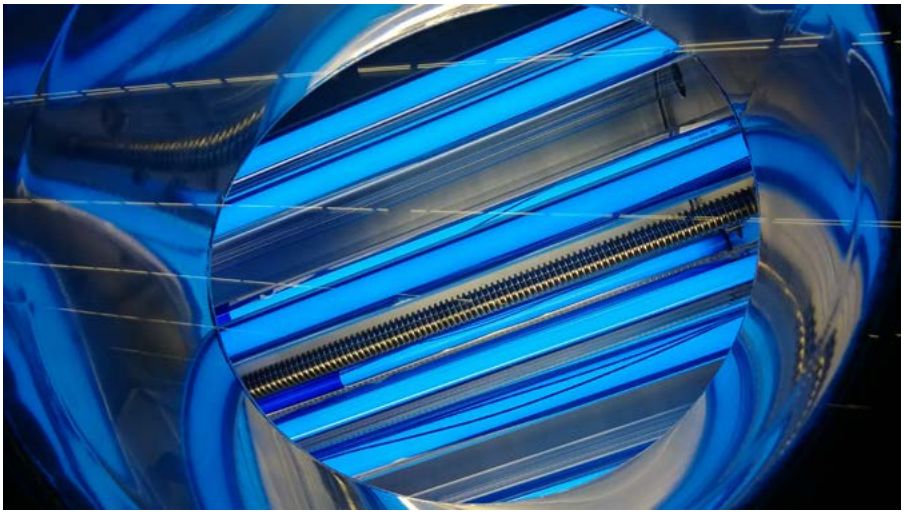
The production of eggs and fry is the most sensitive step in the beginning of the production life cycle. During this stage, the crop are particular susceptible to diseases and must be protected and cared for until vaccination can be carried out. In order to optimise the biosecurity and reduce the infection risks, nurseries are often completely isolated in separate buildings with independent water treatment systems and hermetically sealed buildings to which only staff have access, and these staff must wear special clothing and disinfect themselves before entering the facilities.

Continuous cleaning 40-50 times a day

In the on-growing facility, where the volume production starts, automated computerised feeding systems disperse the feed several times during the day corresponding to fish size, water temperature, the required growth rate, measured biomass, etc. As the biomass increases rapidly in recirculation systems, there is a risk of more significant excretion of ammonia and organic material from gills and faeces. Recirculation systems are designed to remove these pollutants and production water is pumped through sections with different treatment facilities for purifying the water, 40–50 times a day.

Mechanical and biological treatment

A combined mechanical and biological filtration of the production water is conducted to remove particles and soluble substrates generated from the fish. In the most intensive recirculation systems, special biological processes like denitrification are included as nitrate accumulates as a consequence of the mandatory nitrification process. Furthermore,



Disinfection of recirculated water *UV light destroys and/or damages the DNA of water-borne pathogens brought into recirculated water systems. With the structure of the microorganisms' DNA damaged, they can no longer reproduce thus rendering them harmless. The dose of UV radiation required to effectively disinfect water depends on the type of microorganisms present in the water. To size a UV system one must also consider the rate of water flow and the UV light transmission (UVT) (Courtesy: UltraAqua)*

Innovation consortium, Denmark *Supported by the Ministry of Science, universities and companies in Denmark have established an aquaculture innovation consortium called REFA to further improve the operational performance of recirculated aquaculture systems. Technologies and processes new to aquaculture, but well known in wastewater treatment, will be tested to increase the resource efficiency of land-based aquaculture. One research area is the improved removal of the fish faeces in a continuous process to enhance water quality, reduce stock mortality and improve feed conversion rate. Another area involves improving the quality of production water to increase the sanitation equipment (UV and ozonation) performance and reduce the emission of pollutants to the surrounding environment. Finally, advanced monitoring systems will be tested to identify whether fish movement suddenly becomes abnormal or if water quality parameters become critical. (Courtesy: OxyGuard, DHI, Orbicon, AKVA group, Billund Aquaculture, Grundfos, UltraAqua)*

The interaction between the process water treatment technologies in recirculation systems is extremely complex, and understanding this interaction is crucial for creating robust and efficient water treatment

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a special sanitation process like UV radiation is needed to keep unwanted waterborne microbial activity low.

Intelligent control of water quality

Monitoring the amount of dissolved oxygen, carbon dioxide and nitrogen is essential. These parameters need to be under constant surveillance, and if a malfunction of critical components in the system takes place it can be a matter of minutes before lack of oxygen can be critical to the stock. For this reason, recirculated systems are equipped with backup systems and automated emergency procedures such as the injection of pure oxygen, which can be triggered if redundant oxygen measurements indicate critical low levels in the fish tanks. A wide range of other relevant water quality parameters are also monitored in real time to fine-tune the water quality to the optimum level for the fish and the biological water treatment system.

A balanced symbiosis

The challenges in intensified recirculation systems are to optimise the interaction between each treatment process and still keep the water quality as constant as possible. Most critical is the nitrifying biological filtration process, where attached slow-growing sensitive bacteria transform the potential toxic ammonia into nitrate. To ensure a stable and fast nitrification process, the biofilm must be aerated and controlled efficiently so that ammonia and oxygen can diffuse deep into the biofilm where the nitrifying bacteria are located. The interaction between the fish that generate ammonia and the attached microorganisms in the nitrifying bio-filters that consumes the ammonia is a delicate balance, and it is important that the symbiosis between these two organisms (fish and bio-filter bacteria) thrives well.

The Danish export credit agency EKF helps buyers of Danish water solutions to obtain financing for greenfield and rehabilitation water projects. EKF has years of experience securing financing of water projects that utilise Danish water technology and services. A guarantee from EKF helps to persuade international or local banks to provide the financing needed for new projects on competitive terms, because the guarantee provides the banks with greater security.

Waste as fertiliser or for biogas production

The volume of thin sludge arising from micro-screen filtration is significant. Typical sludge production accounts for approx. 125 grams of dry matter per kg fish feed added. Depending on the subsequent utilisation of the sludge, different dewatering facilities are introduced. The sludge from the recirculation system is very rich in nutrients, which makes it suitable as an agricultural fertiliser agent and as such it has to be in liquid form. If the sludge contains high amount of organic material, it can be used in biogas facilities and to keep the transportation cost low further dewatering can be beneficial.

Modular systems *Modular concepts used for recirculation systems make even the most advanced recirculation technology easy and flexible to install on site. The modular concept is also developed to minimise transportation costs. (Courtesy: AKVA group)*

Restocking and stock enhancement, Denmark *The advantage of flow-through systems normally lies in the supply of fresh and oxygen-rich water and the easy removal of contaminated production water. Furthermore, energy consumption is normally low because the transport of water is powered by gravity. The disadvantages are that pathogens and other contaminants easily are brought into the farm. Furthermore, the discharge of wastewater with nitrogen, phosphorous and organic material pollutes the rivers, lakes and seas. In Denmark, strict environmental regulations protect the rivers from untreated waste streams from intensive aquaculture. In fact, fish are today bred to improve wild fish stocks. Funen Salmonids is a breeding farm producing 700,000 individuals of different trout species annually. The farm is part of a project whose goal is to increase angling tourism. The parent fish are electrofished from the rivers and then brought to the farm to spawn and later they are returned to the rivers where they were caught. The fertilised eggs are placed in the hatchery and then later transferred to the production facility. The fish are ready for release when they are 4–25 cm long. Funen Salmonids is an advanced recirculation aquaculture farm. So the sport fisherman is a happy man – not only are there plenty of fish in the rivers, but the water in these rivers is also of a good unpolluted quality. (Courtesy: Billund Aquaculture and AKVA group)*

3. Increasing water quality and breeding conditions step by step

Reduced needs for land and water are often important arguments for converting a classic flow-through aquaculture farm to a recirculation system, but the best overall argument lies in the boost to production. A high, stable level of dissolved oxygen in the ponds assures healthy, growing fish – and room for more of them in same pond

PAW PETERSEN
CEO
OXYGUARD

In most places, land-based aquaculture competes with other sectors for land use and access to freshwater. These two factors can be important barriers against establishing or expanding conventional flow-through farms. Another important barrier lies in increasingly stricter environmental regulations, since untreated process water can contain ammonia, antibiotics and organic material, and its discharge can critically upset the balance of the ecosystems of rivers, lakes and the sea. This brings about increasingly stricter production license criteria that might limit production and can create investment uncertainty.

Increased recirculation to boost capacity

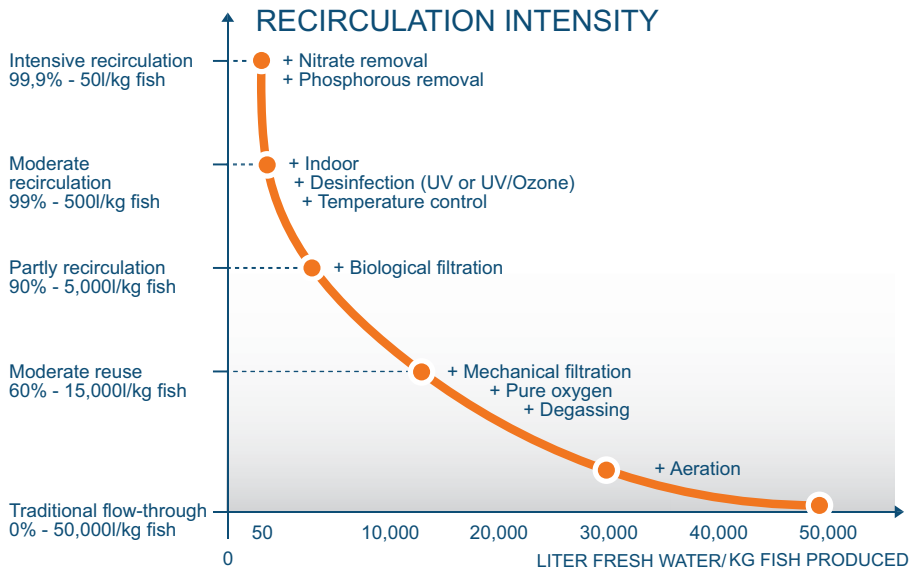
These barriers can often be overcome by upgrading conventional flow-through systems into partial, moderate, or even full recirculation systems. The advantages of a flow-through system are, of course, the easy supply of fresh and oxygen rich water, and the possibilities for flushing contaminated production water back to the natural water course. Energy consumption is normally also low because gravity drives the movement of the water. Converting a classic flow-through farm to recirculation provides more benefits than just overcoming barriers like high water consumption and use of land. The effective water treatment used in recirculation systems reduces the risk of disease and mortality, and a stable temperature regime can boost production considerably in the same or even a smaller area.

Stable oxygen level first important step

Conversion is possible as a step-by-step process in which more and more features are added to increase farming efficiency and outcome. High, stable levels of dissolved oxygen are a prerequisite for low feed conversion rates and healthy, growing fish. In some periods, the natural oxygen levels in the water intake can be very low, so the addition of oxygen is necessary. Using aeration increases and distributes oxygen in the water. Another option is oxygenation, i.e. adding pure oxygen to the water. With monitoring equipment, it is possible to ensure that aeration and oxygenation only take place when needed, thus ensuring that conditions are stable and the use of energy is kept to a minimum.

Removing particles and organic material

Organic material comes from intake water and is also generated in the pond, mainly by



Biological treatment of process water *Apart from initially filtering the intake water, farms must continuously filter and treat the recirculated water using methods that include biological treatment, as known from nature. A biological filter uses a media with sufficient surface area for the bacteria to grow on. It converts ammonium to nitrate, and for most species nitrate is harmless up to high concentrations. Over time, different kinds of bio-media, such as stone and sand, have been used, but today plastic bio-elements are used due to their large surface area and low water resistance. With a surface area of 750 square metres per cubic metre, the conversion rates are 530 grams TAN (Total Ammonia Nitrogen) per cubic metre per day. The unique design at the farm on the picture uses a moving-bead filter for nitrification, followed by a fixed-bead filter to polish the water by catching small particles. (Courtesy: RK Plast)*

Boosting production with oxygenation, United Kingdom *In the 1990s, the Test Valley Trout company, located next to the rivers of Hampshire in the United Kingdom, started using oxygenation control equipment. This allowed production to be greatly increased without using more water or land, making it possible to meet strict environmental regulations. The company has recently installed a new measuring, monitoring and control system at each of its four farms. This system is easy to use and the improved measurement and control gives savings in oxygen use. (Courtesy: OxyGuard)*

Biofiltration is a naturally occurring process that does not require any use of chemicals. Fixed or moving plastic media in a unique design create ideal conditions for the bacteria to grow, and thus makes it possible to make this cleaning process controlled and very effective

ROBERT KNUDSEN
Sales Manager
RK PLAST

undigested feed in fish faeces and uneaten food. These particles easily irritate the gills of the fish and act as transport media for pathogens and parasites, causing reduced fish health, slower growth, poorer feed conversion and hence a poorer financial return. As bacteria also use oxygen to decompose organic material, removing them helps maintain oxygen levels. If not removed, most of the particles will sink to the bottom of the pond, creating a layer of sludge with associated oxygen depletion. A simple method of removing organic materials from intake water is sedimentation, where water is left in a pond for some time to allow particles to settle before leading the water to the ponds. Another rapid, effective way of removing particles is by mechanical filters such as drum filters. In modern land-based systems, circular tanks with a central outlet are kept clean by centrifugal force. In rectangular raceways, sludge traps are used to remove waste.

Neutralising toxins in the pond

A high density of fish requires clever husbandry to balance the physiological needs of the fish. Fish excrete ammonia when digesting proteins in the feed. Ammonia is toxic to the fish but can be converted to nitrate, which is harmless to most fish up to quite high concentrations. This nitrification process will naturally take place in the ponds, but can be enhanced and controlled in a biofilter. Different kinds of media such as stones and sand have been used in such filters, but today plastic bio-elements distinctive for a huge surface/volume ratio, low water resistance and being easily cleanable, have proved more effective. Biofilters can be of two types – moving bed, where the bio-elements are constantly moved around in the water, and a version where the bio-elements are fixed. Fixed bed filters are also applied as a polishing filter because they catch very small particles in the water. Two more forms of water treatment are also common. One is letting the water flow through UV units that contain lamps producing UV light. The second is to add ozone to the water. Both these kill pathogens. Ozone (O_3) is a more active form of oxygen that can also oxidise organic compounds. One or both of these are always used to treat recirculation water, and they are also valuable in treating intake water.

Microorganisms added to solve problems *Adding microorganisms to a pond can help maintain the water quality and limits the need for water exchange. Such microorganisms help remove the ammonia and nitrite that cause eutrophication (algae blooms), and prevent and control the hydrogen sulphide that occurs when organic material is broken down in oxygen-free environments. This smells like rotten eggs and is seen as black sludge at the bottom. In Asia, one in three shrimp ponds is estimated to be affected by this problem, and studies show that a concentration of as low as 0.051 ppm in seawater can lead to mortality rates of 50 per cent or more of the shrimp population in just four days. When adding microorganisms, they multiply until they become part of the natural pond bottom material, forming a thin biofilm. Hydrogen sulphide is then converted to harmless gases. (Courtesy: Novozymes)*

Advanced monitoring of recirculation aquaculture systems *Operating a modern recirculation aquaculture system means extensive measuring, monitoring and control. The operator has a full overview of all parameters on a computer display and dissolved oxygen, temperature, pH, dissolved carbon dioxide, salinity and total dissolved gas pressure as well as equipment like pumps, blowers, UV systems, etc. are constantly monitored. Customised software controls feeding and artificial daylighting schemes that can be set up to emulate daylight anywhere in the world anytime of the year, with gradual dawn and dusk transition periods. Feeding can also be set to follow any desired feeding pattern and to keep track of growth and level of biomass. Video cameras give the operator instant information on the fish behaviour and welfare. And on top of it all these parameters are logged. (Courtesy: OxyGuard)*

4. Safeguarding the stocks and high return on investment

Keeping in mind that fish only die once, operational reliability is crucial. If technology doesn't measure up, it can lead to the death of hundreds of thousands of fish. A recirculation system that easily employs up to fifty pumps calls for reliable, energy-efficient pumps and superior control

MIKAEL ZACHO JENSEN
Sales engineer, Industry
GRUNDFOS

Modern recirculation systems incorporate intelligent monitoring and control of the production, which is a major improvement compared with traditional aquaculture farms. Ensuring a high return on investment has both a technical aspect, which is fixed once the installation is up and running, and a human aspect that consists of skilled and well-trained staff.

Taking feed conversion ratio down

Modern systems maintain water quality parameters within close limits and this enables very low feed conversion ratio (FCR), which is the first important factor for a high return on investment. The ratio to aim for depends on species and growth conditions, but obtaining 1 kg of fish using 1 kg of feed is in fact possible for some species. Consistently good water quality, high dissolved oxygen levels and optimal temperatures are required, and other important parameters to be kept within limits include pH values, dissolved CO_2, salinity and total gas pressure. However, the really clever husbandry of modern systems is performed with automatic programming and control of feeding and lighting patterns as the fish grow, taking into account variations in parameters such as dissolved oxygen and temperature. The systems with such a degree of control can be used to adjust the growth of the fish so that fish of the optimal size can be harvested at the best possible point in time, thus adjusting the product to current market conditions at any given time.

Safety and bio-security systems

A second important factor for safeguarding one's investment lies in the alarm system and emergency measures. The cost of an entire measuring, monitoring and control system is only a fraction of the value of the stock that it protects. It is done setting up the system with suitable alarm set points and establishing effective communication to the on-duty operator. An alarm system also has a human aspect, which includes focusing on which emergency measures the operator should undertake in any given situation. It is important that personnel are trained in performing the necessary tasks.

Operating efficiency

Good system design will ensure high energy efficiency, thereby keeping operating costs to a minimum. Here the choice of components and the sensitivity, accuracy and stability of the monitoring and control system are the important factors in ensuring a high return on investment. Secondly, settings should be chosen by the control system engineers, marine biologists and operators working together to ascertain the best settings for each system.

Minimum energy use with speed control
High-quality water environments are not without costs, and the high level of energy use for fish produced in recirculated systems is an important sustainability issue. Operating costs stem in part from large quantities of energy used simply to recirculate the water and keep production running. However, pump solutions can help minimise this energy consumption – not least due to unique variable speed functionality. A pump solution suited for aquaculture systems provides the freedom to tune the water flow perfectly to the biomass in the system and to adjust speed to suit current flow and demand – ensuring that energy is never wasted. Such pump solutions, built to lift large amounts of water with a low head, are available in a broad range of materials, incl. saltwater-resistant materials, and operate in even the most corrosive environments. (Courtesy: Grundfos)

5. Understanding seafood markets to see new market potentials

With more people globally there are strong arguments for increased and sustainable seafood production to meet public demands not least for polyunsaturated fatty acids. Moreover, seafood is a rich source of flavour and deliciousness, and it meets humans' natural craving for umami. Umami-rich food from the sea will in turn help us to regulate food intake and improve nutrition and health

OLE G. MOURITSEN
Professor of biophysics
UNIVERSITY OF SOUTHERN DENMARK
Author of articles and books with a scientific view on seafood

The demand for fish is continuing its insatiable rise. Since 1961, the worldwide demand for fish has been increasing at almost twice the rate of the growth in global population, and we now eat more than twice as much fish as we did 50 years ago. Aquaculture is set to remain one of the fastest-growing animal food-producing sectors, rising to an anticipated 230 million tonnes by 2050.

Growth from an expert's perspectives

In a world challenged by resource scarcity, population growth, obesity and poor nutrition many experts – such as scientists, politicians, economists and nutritionists – see the growing demand for seafood as a very positive trend. Taking a water expert's perspective, and being aware that around 70 per cent of global water consumption relates to primary production of food and the food processing industry, the benefit of farmed fish is clearly that the rearing of fish can be very water efficient. Water is an increasingly scarce resource challenged by urbanisation with half of the global population now moving into the larger cities and by climate changes with less evenly balanced distribution of precipitation. A growing market for aquaculture systems can help slow down the trend of increasing global water consumption. Producing a kilo of beef requires an average of 15 cubic metres (4,000 US gallons) of direct and indirect use of water, according to the Water Footprint Network, whereas producing a kilo of farmed fish in sea-based aquaculture has almost no direct use of freshwater and can involve as little as 500 litres (130 US gallons) if produced in a land-based recirculation system.

Consumers do drive the market

Looking into market trends is important if one's business should stay profitable. While experts give their recommendations, all companies in business know that consumers only spend their money on the food they want and can afford. It is thus essential for farmers aiming for a sustainable and profitable business – and for the experts who want to influence how seafood markets develop – to understand what drives consumers' and retailers' demands. In other words – as with consumer expectations that to a great extent control the world economy – consumer demand for fresh, well-tasting seafood to a great extent controls developments in local and global seafood markets.

New Nordic cuisine favouring local food

One very interesting example of how food markets develop is to be found by looking into a trend like the New Nordic cuisine, which in recent years has influenced food market of Scandinavia. This concept is an attempt to promote local seasonal food and nowadays many of the best restaurants in Denmark feature dishes prepared in new ways, emphasising purity, simplicity and freshness. The restaurant Noma in Copenhagen, which today ranks second on the list of the world's 50 best restaurants, builds entirely on this idea. Based on the New Nordic cuisine, a wide range of new high-quality food products have also been introduced on the food markets in Scandinavia, along with some of the older Scandinavian techniques of marinating, smoking and salting. The seafood market is also influenced by new high-quality salmon products, for instance.

Photo courtesy: www.letzminis.dk

Searching for sensation of deliciousness

A broader concept influencing many of the world's food markets is the concept of sensationally tasting food. As human beings, we are to a large extent driven by the craving for the fifth basic taste, which is called umami, and is described as the sensation of deliciousness. The term umami was coined in the context of a basic Japanese soup broth based on fish and seaweed, and it has since become clear that the deliciousness of many seafood products is due to their high contents of umami-inducing compounds. The unique molecular mechanism behind umami is now partly understood as an action on the umami receptors in the taste buds. According to professor Ole G. Mouritsen – a Danish author of many articles and books with a scientific view on seafood – the lack of deliciousness and umami (savoury) flavour in many prepared meals is a possible reason for poor nutritional management and excess intake of salt, saturated fats and sugar. Umami has also recently entered as an element of the New Nordic cuisine, where chefs use it to understand how to combine old and new Nordic ingredients based on fish and seaweeds to infuse a range of different dishes with umami taste. So even if it is obvious that umami always has been of importance for consumers' taste, scientific support will now play a role for developing and bringing new sensationally tasting seafood products to food markets around the world.

New upmarket fish farm, Denmark

The Danish fish farming company AquaPri, which specialises in sustainably farmed fish and trout caviar of luxury quality, is now investing in new facilities for pikeperch farming based on advanced recirculation technology. Pikeperch is a luxury freshwater fish and a new species in Danish aquaculture. For this company, full control over all stages of the farming process is the main argument for choosing recirculation technology. The new plant will be built in stages and finished over three years, to be completed in 2017.

6. Gaining consumers and retailers trust through certified farming

Besides producing high quality salmon, responsible farming is important to us. The coming ASC certification and a dedicated effort to form retailer partnerships ensured us orders for our first batch two years ahead of delivery

THUE HOLM
CEO
LANGSAND SALMON

Inadequate or poor aquaculture practices often lead to over-use of antibiotics and – depending on the production volume – excessive loss of waste and residues can harm the aquatic environment and its natural inhabitants. This is why aquaculture calls for sustainability measures, and certification schemes will become increasingly important for farmers seeking to assure shelf space with retailers.

Increasing attention from retailers

The World Wildlife Fund meets increasing demand from retailers for purchasing consulting. One example is one of Denmark's largest retailers, Danish Supermarket, which signed a three-year contract to create a list of 45 to 50 sustainable seafood products. Hence, as documented traceability is needed to assess whether the fish are sustainable or not, information is now gathered from all suppliers of products containing seafood. Suppliers must, among other things, indicate what types of products they provide, which species are included in the products and when and where the fish are caught or farmed. The goal is to motivate suppliers to be innovative and develop more responsible products. The easy way is to drop the problematic species here and now, but this will not change things significantly in the long run. So the conditions for this collaboration with suppliers are to apply over the next three years, doing as much as possible to move suppliers in the direction of sustainability.

Success of the Marine Stewardship Council

The opportunity for the seafood industries is thus to meet retailers' demands by getting fisheries and products sustainable certified. One option is the Marine Stewardship Council (MSC), which has increased consumer awareness of wild caught fish and shellfish from well-managed stocks. It has been successful in influencing retailers and consumer preferences and research shows that across 10 larger countries 30 per cent of adults who buy fish at least once every two months were aware of the MSC label. This is an increase from 23 per cent in 2010 and today 7 per cent of all seafood originating from wild catches is certified to the MSC standard and MSC-labelled products are used in 106 countries all over the word.

Aquaculture Stewardship Council

Looking into aquaculture, the Aquaculture Stewardship Council (ASC) is a promising label as sustainable measures are specific and

quantitative. It was founded in 2010 by the World Wildlife Fund and the Dutch Sustainable Trade Initiative (IDH) as an independent non-profit organisation and as a global certification scheme to support and ensure socially and environmentally responsible farming of fish and shellfish. The organisation manages a set of global standards and institutes a certification process using independent third-party entities to certify farms.

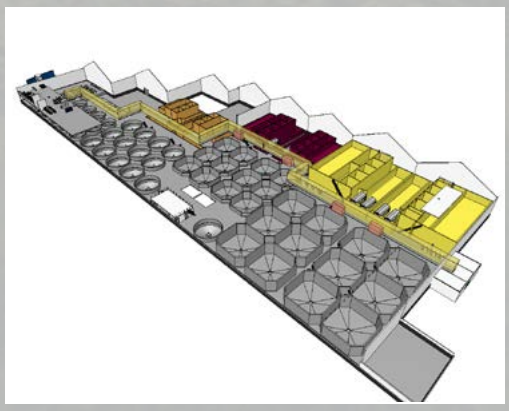
70 per cent of salmon to be ASC-certified

The ASC certification standards came out of a comprehensive multi-stakeholder process that addressed innovative approaches to salmon farming's environmental and social impacts. Farming standards for species like salmon, trout, pangasius, tilapia, warm water shrimps, abalone and a number of shellfish have been developed and more is on the way. Within sea-based aquaculture the Global Salmon Initiative is a recent commitment from 15 of the world's largest salmon producers in Chile, Scotland, Norway and Canada. Together, these companies represent 70 per cent of the global production of farmed salmon and all of their production facilities will be ASC-certified by 2020.

Standards for land-based aquaculture

The quantitative measurable standards for individual species also apply when reared in recirculated aquaculture systems. Within land-based aquaculture, an ASC certification assures that the water intake is in balance with surrounding environmental needs and that nutrients and organic matter in the effluent are within the limits of the standard. The standards also contain measures for the welfare of the farmed animals and for combating illegal or improper use of drugs and chemicals. The use of feed and origin of feed ingredients must be documented as well. Expansion in wild catch fisheries is restricted, as most of the fish stocks globally have been exploited to their limits. Some aquaculture production of mainly marine species may be challenged by this restriction, as marine ingredients, like fish meal and fish oil, are needed in the fish feed. However, in 2010 about 36 per cent of the fishmeal produced globally came from trimmings and other residues from the preparation of fish fillets, and fish feed manufacturers now put great efforts into finding alternative ingredients like algae, seaweed, mussels and land-based crops.

First system will be ASC-certified in 2014
One of the largest commercial land-based recirculating aquaculture systems in the world started its production of Atlantic salmon in 2011. The company, Langsand Salmon, decided to pursue ASC certification by participating in a pilot programme. The facility is expected to receive its ASC certification in 2014, as the first land-based recirculation aquaculture system in the world.



Lerøy Seafood Group, Norway *1.2 million tonnes of salmon are produced annually in the fjords of Norway. The tradition is to farm the salmon fry in land-based installations until smoltification at a weight of 60–150 grams and the salmon are then moved to cages at the fjords to grow for another 16 to 18 months, obtaining a slaughter weight of 4–6 kg. However, as licenses for salmon farms in Norway are issued based on the maximum amount of biomass from individual farms, advanced land-based aquaculture recirculation technology allows manufacturers in Norway to double production within the same license period. The smolt is then farmed to a size of 500 to 1,000 grams on land instead, so it only needs 7 to 8 months at sea. Besides boosting production, recirculation aquaculture systems also help manufacturers avoid biological or chemical treatment against salmon lice. The Lerøy Seafood Group plant illustrated here produces 14 million Atlantic salmon smolts from egg to an average of 100 grams per fish. The building covers 12,500 square metres and includes 11 separate intensive recirculation systems. Total capacity of the biological filters amounts to 8,500 kg feed per day and water consumption is 400 litres per kg salmon smolt. (Courtesy: Billund Aquaculture)*

7. Promising developments in sea-based aquaculture production

Minimising environmental footprint is very important and in Denmark we have achieved this with aquaculture at sea. Data and quantitative models have been used to define the operational requirements, making environmental management a rational decision rather than an emotional choice

MADS JOAKIM BIRKELAND
Marine Biologist
DHI

In the years to come, oceans around the world will be subjected to new massive marine infrastructures as aquaculture at sea is expected to boom, as are other set-ups that include off-coast wind farms and wave energy farms. This will unavoidably exert pressures on marine ecosystems. Environmental management, new technology and smart concepts will thus also be an important part of the future – for instance off-coast platforms combining many functions creating an industrial symbiosis with benefits in the form of logistics, environment and revenue.

Environmental protection based on data

The dispersion and sedimentation of feed and faeces around the cages are some of the environmental impacts of sea-based aquaculture. Deciding the right balance between environmental protection and investment/operational costs in a marine area is today more easy to answer. In-depth knowledge, advanced methods and quantitative models are available to help investors assess the economic and environmental benefits as well as the costs of new developments, new sites or new methods in sea-based production. Applying such tools provides a more secure basis for decisions when planning new marine aquaculture facilities and, at the same time, improves governmental bodies' ability to assess the environmental impact of the expected expansion of aquaculture production and thus speed up the licensing time.

Space at sea, away from coasts

In the marine aquaculture sector there is now reason to believe that Europe will follow the global growth trend in aquaculture since there is a great potential for an economically feasible sector with limited environmental impact. Although marine areas are huge, other stakeholders also apply for space. As on other continents, shipping and industrial fishing are intense, the tourist industry sees pristine beaches as a key selling point and the citizens enjoy the recreational activities in coastal areas, not leaving much space or tolerance towards new marine aquaculture. Combining these barriers with probably the world's most strict marine environmental legislation and slow licensing procedures, the options for moving off-coast where the conflicts with other sectors will be limited are now being investigated.

European ambitions to grow off-coast *The ambitions to grow the European aquaculture sector are clearly shown in three projects funded by the European Union's Seventh Framework Programme (FP7). One is the MERMAID project entitled 'Innovative multi-purpose off-coast platforms: planning, design and operation concepts' for the next generation of off-coast platforms for multiple purposes, including energy extraction, aquaculture and platform related transport. From a theoretical point of view, new concepts combining structures and building new structures on representative sites under different conditions will be examined. The 28 partners in the project consist of 11 universities, eight research institutes, five industries and four enterprises from different regions in Europe representing a broad range of expertise in hydraulics, wind engineering, aquaculture, renewable energy, marine environment and project management, and socio-economics. This project will cost 7.4 million euro and the European Union has granted a contribution of 5.5 million euro. (Courtesy: DHI – www.mermaidproject.eu)*

Monitoring of sea cage systems *Monitoring production is also important in net-cage aquaculture, and the use of wireless networking makes communication easy. Alarms are sent to mobile phones and advanced systems enable someone on one side of the Earth to see what is happening in a fish farm on the other side. Wireless probe transmitters also enable easy communication between probes on the cages and an on-shore unit or a unit on the feed barge, which can normally be a challenge due to the conditions at sea. Feeding can be optimised to suit the actual temperature and dissolved oxygen levels (DO), and action can be taken if very low levels are detected. Measuring DO at different depths gives an extra degree of safety. (Courtesy: OxyGuard)*

It is crucial to find the right combination of physical, chemical and biological conditions to achieve cost-effective production. By combining advanced modelling techniques with environmental and hydrodynamic expertise, it is possible to find sites most suitable for off-coast aquaculture production

MADS JOAKIM BIRKELAND
Marine Biologist
DHI

Benefits from producer's point of view

However, it is not only a matter of marine space and conflicts across sectors. There are a number of clear advantages of moving the production off coast. From the producer's point of view, moving off coast means more stable environmental conditions – especially temperature, salinity and oxygen content – which leads to higher growth rates and reduce the risk of disease. This minimises the use of antibiotics and reduces production costs. Furthermore, multi-use platforms combine the off-coast production of renewable energy and the cultivation of fish. Polyculture, including mussels and seaweed, shows clear advantages. The greater water depth also allows for greater production volume and a constant, steady flow of water ensures sufficient availability of phytoplankton and nutrients for mussels and seaweeds. Hydrodynamic and water quality models are used in site selection and optimisation of farm design and crop density.

Solution to environmental impacts

From an environmental point of view, moving off coast means a higher volume of water – resulting in higher dilution of waste products such as dissolved nutrients and organic particles. Taking into account that many off-coast areas are characterised by relatively low background concentrations of nutrients, the advantage of off-coast production from an environmental point of view becomes even clearer. Another environmental concern connected to coastal aquaculture is the risk of negative interactions between farmed and wild fish stocks. Transmission of diseases and parasites, along with escapees and the subsequent risk of farmed fish species' genetic interference with wild populations are key critical issues, jeopardising not only the health of wild stocks but also growth of the aquaculture sector. Moving off-coast reduces this risk dramatically, since the risk of interactions between farmed and wild fish stocks are minimised or even neutralised.

Denmark now to proof off-coast concept

Convincing manufacturers to move production into high-energy off-coast environments will only be achieved by investments proving the concept. Denmark takes the first step with an off-coast aquaculture project financed by the Danish Ministry of Food, Agriculture and Fisheries and the European Union. The goal is to develop floating net-cages that can be submerged during extreme weather conditions and are able to withstand the physical energy at an off-coast site. The project combines expert knowledge from fish producers, producers of hardware for off-coast installations and researchers applying advanced modelling and monitoring because the Danish aquaculture sector has a long tradition of developing net-cages and other hardware needed in the installation of off-coast facilities. The environment and the production are further secured by the application of advanced knowledge-based tools such as three-dimensional models, sensors, data management systems, forecasting and satellite observations. The new fish cage concept was successfully tested when a hurricane of historical dimensions passed Denmark in October 2013, with wind speeds exceeding 50 metres/second and wave heights of up to 8 metres at the test site.

Off-coast aquaculture *Global aquaculture production has grown by 8.8 per cent per year over the last three decades, an exceptionally high growth compared to all other food-producing industries. Denmark, and Europe in general, have so far failed to deliver the same growth because aquaculture production is located in coastal areas where expansion opportunities are limited. Development of new equipment will pave the way towards an off-coast and off-shore expansion of the Danish and European marine aquaculture sector. The new generation of marine farming equipment consists of plastic floating rings and large net-cages anchored to the seabed. This equipment, which can be lowered beneath the sea in bad weather, will be tested under high-energy conditions in the North Sea.*

World's second best innovation, Australia *Bluefin tuna is a new aquaculture species that can be farmed based on sustainable principles. The breakthrough in full lifecycle farming of southern bluefin tuna took place in the Danish-designed facilities of Clean Seas Ltd. in Australia back in 2009. The concept was awarded the world's second best invention of the year by TIME Magazine. For the first time, southern bluefin tuna successfully spawned in a controlled environment in captivity. The fully recirculated aquaculture system was designed and delivered by a Danish-based system builder. Clean Seas Ltd. is currently hatching and rearing fingerlings in the tanks, after which the fish are transferred to ocean farming in cages for grow-out. (Courtesy: AKVA group and OxyGuard).*

If your goal is water efficiency, Denmark is ready as a partner

Danish water companies have shown their courage and drive by working with their competitors in order to create the Rethink Water platform. They are showing the world that Denmark is ready to take responsibility and contribute to finding solutions to the major water challenges the world faces

KIRSTEN BROSBØL
Minister for the Environment
DENMARK

Denmark is surrounded by water, yet freshwater is still a scarce resource for us. For 30 years, we have been rethinking water and building expertise within water efficiency. Today, our tap water is as pure as the finest spring water and the water in the harbour of Copenhagen, our capital, is so clean that people swim in it.

Denmark knows water

The knowledge we have about water resources, water security and water efficiency is no coincidence. Successive governments have addressed our country's limited natural resources, concentrating on using them efficiently, and as a nation we strive to provide a safe, pleasant and healthy environment for people to live in.

Knowledge transfer

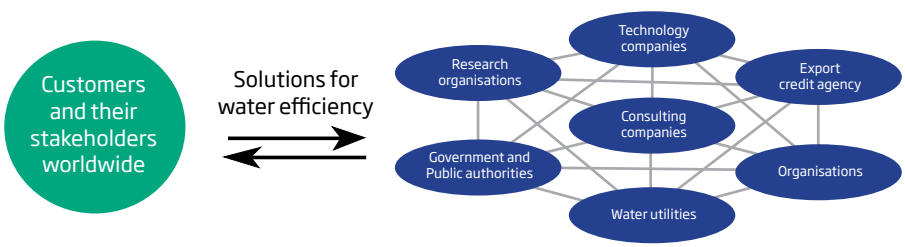
Denmark is not physically powerful, but knowledge is power. Long ago we as Vikings spread fear across the seas. Today, we want to spread something entirely different: knowledge and collaboration on how to globally protect water resources and improve water efficiency. Water is an increasingly scarce resource in most parts of the world. We need to rethink how we use it.

For mutual benefit

As a country, we see great opportunity for mutual benefit in the transfer of knowledge and the growth in both partners' business. Our expertise is in assisting customers and stakeholders reach safe and effective water solutions, while developing their ability to profit from that knowledge. In our work we maintain a healthy respect for different perspectives and agendas, as well as for the environment.

Rethinking water together

Rethink Water is a global network specialising in water efficiency. So far, we are over 60 consulting companies, technology providers, utilities, research institutes and governmental bodies. The network brings together an unusually diverse and valuable mix of clients, consultants, researchers, technology experts and governmental bodies. We have joined forces to share knowledge and create even better water solutions, in Denmark and around the world. We invite you in to collaborate on solving your water challenges and to explore our expertise at www.rethinkwater.dk/whitepapers



Find more white papers, learn more about the Rethink Water network and get in touch with us at:

www.rethinkwater.dk

Consulting companies

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Wavin	wavin.com
Aarhus Geophysics	aarhusgeo.com
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Research institutes & demonstration projects

Danish Technological Institute	teknologisk.dk
DHI	dhigroup.com
Geological Surveys of Denmark and Greenland	geus.dk
Kalundborg Industrial Water Demonstration Site	symbiosis.dk

Water utilities

Greater Copenhagen Utility	hofor.dk
VCS Denmark	vcsdenmark.com
North Water	nordvand.dk
Aarhus Water	aarhusvand.dk

Organisations related to water

Association of Waterworks in Denmark	fvd.dk
AquaCircle	aquacircle .org
Copenhagen Cleantech Cluster	cphcleantech.com
Confederation of Danish Industry	di.dk
Danish Water Technology Group	dk-water.com
Danish Water and Wastewater Association	danva.dk
Danish Water Forum	danishwaterforum.dk
Danish Water Services	danishwater.dk
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