# Industrializing land-based fish farming for a protein-hungry future: An interdisciplinary approach to environmental and economic success


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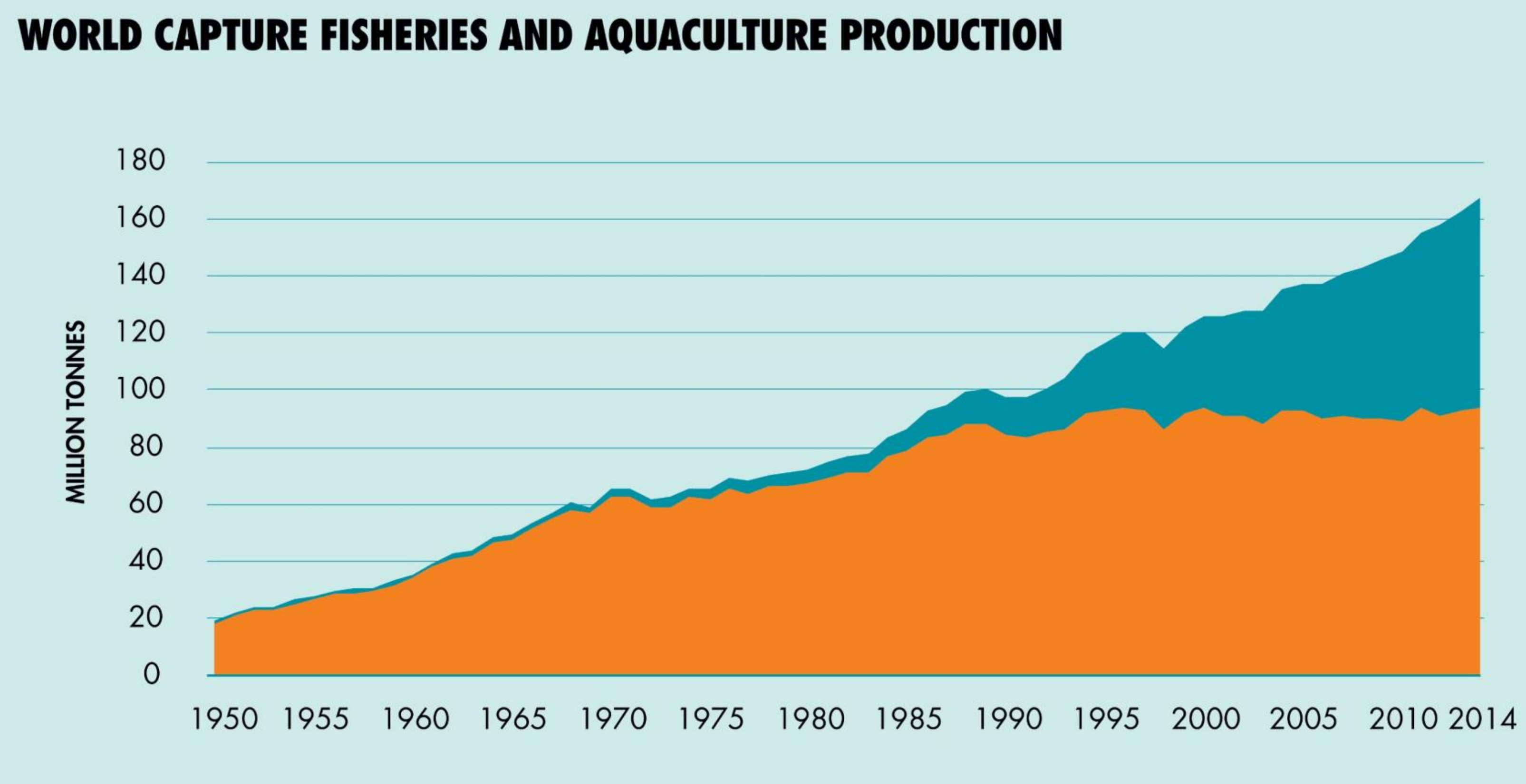
# Some context for recycling based systems today

# Global trend in fish capture and culture




Source: FAO (2016). *The status of world fisheries and aquaculture*
*http://www.fao.org/3/a-i5555e.pdf*

The volume of wild-caught fish has remained relatively stable since the 1990s, while the role of aquaculture has grown and continues to do so.

This does not mean that the world's fisheries are about to collapse; see the website CFOOD, by fisheries scientists, for balancing views: http://cfooduw.org/myths/

However, the fact remains that wild-caught fish is not increasing in volume to match the demand for seafood consumption. Wild-caught fish will also become increasingly expensive as the fishing industry responds to growth limitations by focussing on providing high quality catches to markets that are able to pay well.

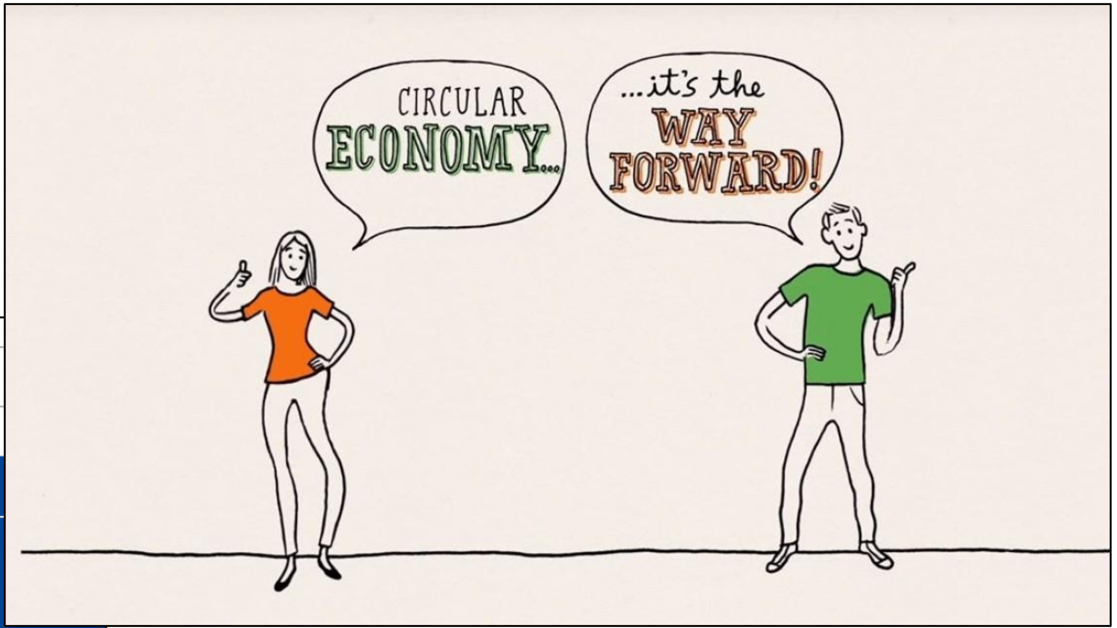
In technologically demanding aquaculture systems such as RAS land-based fish farming, investors' priority may also be expected to be focussed on high-value species for affluent markets.

From a food security aspect, limitations on wild-caught fish and investment costs in aquaculture may amplify the effects of a growing population.

There will thus be strategic differences between developing land-based RAS aquaculture to address:
*Food opportunities* - Farming for well-paying markets, which inevitably will continue to grow.
*Food security* – Farming to ensure *economic access* to seafood. For these consumers, sustainability is an absolute necessity; both to ensure predictable access to food and to prevent loss of ecosystem services and agricultural land available for food-, as opposed to feed-, production.

# International drive towards the Circular Economy

*“The proposed actions will contribute to "closing the loop" of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy. The plans will extract the maximum value and use from all raw materials, products and waste, fostering energy savings and reducing Green House Gas emissions.”* – **European Commission 2017**





English EN

European Commission › Priorities › Jobs, growth and investment ›

Towards a circular economy

Political priorities — Jobs, growth and investment

Commissioner — First Vice-President Frans Timmermans | Vice-President Jyrki Katainen | Karmenu Vella | Elżbieta Bieńkowska

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Documents

The European Commission has adopted an ambitious new Circular Economy Package to help European businesses and consumers to make the transition to a stronger and more circular economy where resources are used in a more sustainable way.

Source: https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/towards-circular-economy_en

Recycling Aquaculture Systems (RAS) builds on re-use of purified and refreshed water, and also offers control with the mass flow into and out from the culture system. Sludge can be utilized in energy from waste (EFW) plants, or it can be treated in digesters to produce higher yields of biogas than sludge from livestock or chicken. Energy utilization can take place on-site or in energy facilities within reasonable transport distance. Nutrients from effluents can be used (with appropriate treatment and supplementation) as fertilizer or input to hydroponics. The industry is also seeing potential for using effluent nutrients to produce key constituents for fish feed. Intensive RAS fish farming on land thus offers opportunities for “closing the loop”, which is the overarching target of the circular economy.

# Nutrition and food security

Fish is an important source of protein and micronutrients, which will become increasingly important in order to provide nutrition for a global population of >9 billion by year 2050.

Apart from protein, the **nutrition value** of farmed fish depends on the **quality of the feed**. This is concerns certain fish oils, for example, that are not synthesized by fish but originate from marine algae. Without these components present in the feed, the consumers will not obtain them from the cultured fish. Realizing given nutrition targets for a consumer population thus depends considerably on the quality of fish feed. Feed is produced from agricultural areas or marine resources and feed procurement can therefore have greater implications for sustainability than the aquaculture activity itself. Tying up land areas and marine resources for feed production (for fish or livestock), disfavours the poor who have least economic access to fish, and who tend to lose access to ecosystem services in the wake of agricultural expansion and environmental degradation. Making effective use of feed is thus a major sustainability and food security matter.

**Properly farmed fish yields far more protein from a given quantity of feed than warm-blooded animals such as pig and chicken**.

Food Sec. (2015) 7:261–274
DOI 10.1007/s12571-015-0427-z

ORIGINAL PAPER

**Feeding 9 billion by 2050 – Putting fish back on the menu**

Christophe Béné · Manuel Barange · Rohana Subasinghe · Per Pinstrup-Andersen · Gorka Merino · Gro-Ingunn Hemre · Meryl Williams

Source: https://link.springer.com/article/10.1007/s12571-015-0427-z

Different demographics around the world consume either too much or too little food. Cardiovascular disease, diabetes and obesity are epidemics on one hand, while inadequate access to nutritious food is a threat to millions of poor.

Fish farming, and land-based recycling aquaculture in particular, can play a major in future food security. Achieving this does not follow automatically from increasing production. A main driver in global increase in fish consumption is growth of urban populations that can afford to buy fish. Fish farming to meet this demands does not necessarily improve food security (access) for those most in need for higher per capita consumption of fish.

Providing improved food security through land-based fish farming is a much broader issue than developing new aquaculture technology. For fish farming to contribute effectively to food security and nutrition for those who need it most, governments need to emphasize fish in national nutrition programs (Bene et al 2015).

*"Recommendation 8: Review national policies and investments and integrate nutrition objectives into food and agriculture policy, programme design and implementation, to enhance nutrition sensitive agriculture, ensure food security and enable healthy diets."*
ICN2 (2014) Framework for action (link below)

October 2014 ICN2 2014/3 Corr.1

Documents: http://www.fao.org/about/meetings/icn2/documents/en/

E

SECOND INTERNATIONAL CONFERENCE ON NUTRITION

Food and Agriculture Organization of the United Nations

World Health Organization

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| |
|---|
| **Second International Conference on Nutrition** |
| **Rome, 19-21 November 2014** |
| **Conference Outcome Document: Framework for Action** |

**FROM COMMITMENTS TO ACTION**

# Shortage of water itself

Climate change is threatening to upset the
rainfall patterns in parts of the world that
can ill afford to have greater shortages of water.

Even without regard to global climate change,
extensive dam building, ineffective irrigation,
changes in forest cover and hydrology as a consequence
of changes in land-use in river basins around the world
have created an international water crisis that looms large.

**Water-conserving aquaculture and agriculture systems are set to play an increasingly important role in food security in the future.**


**Newsweek cover 1 December 2017**
*The issue describes the critical water supply situation in Jordan, which according to the magazine may be the first country to run out of fresh water altogether.*

Functional principles

Opportunities

Challenges

General background

# Technical basis of land-based Recycling Aquaculture Systems (RAS)

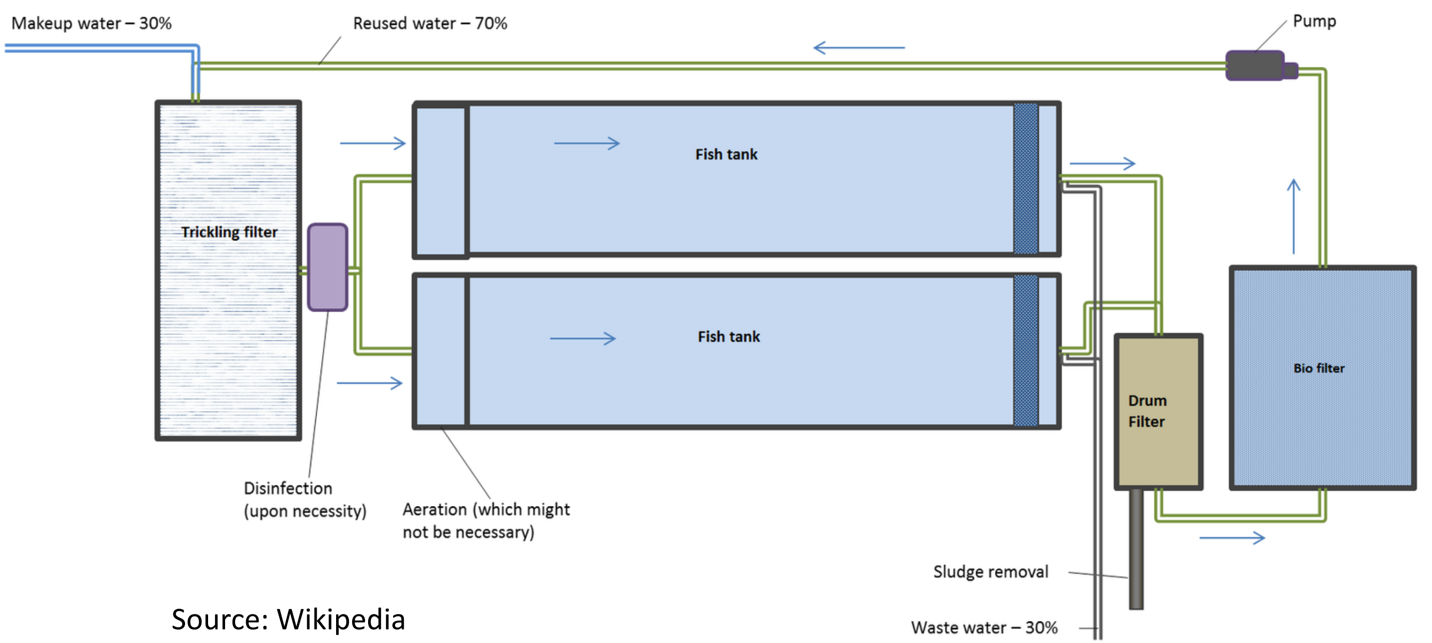
# Basic concept – land-based fish farming with water recycling

A great, **dense biomass** of fish that is fed for maximum growth, **rapidly influences** the **water quality** of the volume it occupies. The higher the density of fish, the more rapid the depletion of oxygen, build-up of carbon dioxide, accumulation of nitrogen waste, and feed spillage and fish droppings. In **conventional aquacuture systems**, whether land- or sea based, the living conditions for farmed fish depend on **flow-through** of clean, **unused water** from freshwater sources or coastal currents. Flow-through and open culture has many benefits, but also well-known drawbacks such their dependence on ample supply of high quality water (fresh or marine); external variation in seasons and temperatures have major influences. Along with a profuse flow of ambient water comes considerable risk for colonization by pathogens and parasites. Open culture systems (ponds and cages) leave open direct routes for spread of diseases and medicinal residues, as well as escape of cultured fish, to the environment. Good fish farming sites are in demand for other uses of fresh water or coastal areas, and as open culture systems have grown in numbers and farming intensities, conflicts with other user groups have steadily increased in many areas.

In **Recycling Aquaculture Systems** (**RAS**), **effluent water** leaving the rearing tanks is **treated and refreshed** before being **returned** to the tanks, thereby radically **reducing** external **water requirements**. RAS have been used for **ornamental fish** and fish farming with **robust species** for many years, and in recent years for **early life stages** for more sensitive species (such as salmon smolt). Industrial scale RAS for full grow-out of sensitive species is **set to go mainstream** in the years to come, and will offer opportunities for increasing production volume in established fish farming nations as well as new opportunities for countries that would otherwise have far more limited options for intensive fish farming.

The specific set-up of RAS systems vary depending on the species being reared, the planned intensity of farming, as well as the experience and philosophy of system engineers. In general, they must address some fundamental challenges – and this list is partial:

1. Control of intake water (site- and water source selection, pre-treatment if necessary, and on-going monitoring and control; access to emergency supplies is a great insurance).
2. Tight biosafety controls to prevent introduction and internal proliferation of disease
3. Continuous removal of dead fish, particulate and dissolved solids (sludge removal, clarification)
4. Removal of nitrogen wastes (biofiltration)
5. Management of dissolved gases (oxygen, CO2, dissolved nitrogen, etc; requiring both oxygenation, aeration and degassing systems)
6. Management of pH, alkalinity and temperature (both for fish and biofilter bacterial requirements)
7. As dictated by the above: excellent operating expertise and –routines, supported by effective monitoring and control systems.




Source: Wikipedia

# Opportunities and challenges of RAS culture

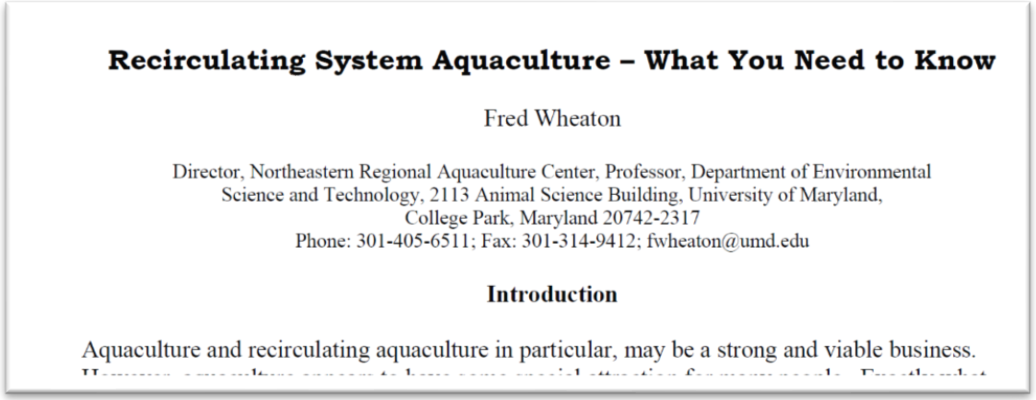
**Opportunities:**

- **Farming in a controlled environment**
  What comes in, and what goes out, is controllable, and the rearing environment can be kept stable and deliver consisten growth conditions year-round.
- **Flexibility in choosing locations for fish farming**. The limited water requirements changes the map of future fish production. Farming can take place inland, in arid areas, remote from large rivers and lakes and the coast. By siting farms near significant seafood markets, savings on transportation and logistics can contribute significantly to the overall project economy – both by cutting transport distances *per se* and by reducing the amount of ice that is flown around the world at airfreight rates.
- **Flexibility in choosing species for farming**. A controlled environment facilitates farming different species outside their normal climate zones, while closed, land-based farming technology eliminates risk of escape of fish into the natural environment. Preventing spread of pathogens .
- **High yield potential**. Farming with high fish density has become increasingly feasible and continues to do so; technology is maturing, experience is rapidly accumulating. RAS is set to enter the mainstream for intensive grow-out farming with species have not previously been economically viable.
- **Circular economy-ready**. Water conservation, control and utilization of waste and by-products, steadily improving know-how for integration with other land-based industry (utilization of waste and nutrients for energy, aquaponics, feed production, etc), are all features of RAS that are in line with principles of the circular economy.

**Challenges:**

- Most industrial experience with RAS has been with robust species such as tilapia or catfish, or early life stages of sensitive species such as Atlantic salmon. The more sensitive the species, the greater the requirements for planning, investments and highly stable operations.
- Access to qualified personnel. Careful operational management is required at high rearing densities; not just the fish, but also its environment, is under direct management. Access to supporting services and proper training of personnel is essential.
- Excellent monitoring and control systems are essential; response times and proper mitigating measures can leave a time window as low as 10-15 minutes to prevent total loss of stock (though it should be noted - short available response times are also prevalent in intensive cage culture and during live-carrier transport of farmed fish).

# General background on recycling aquaculture systems (RAS)



**Recirculating System Aquaculture – What You Need to Know**

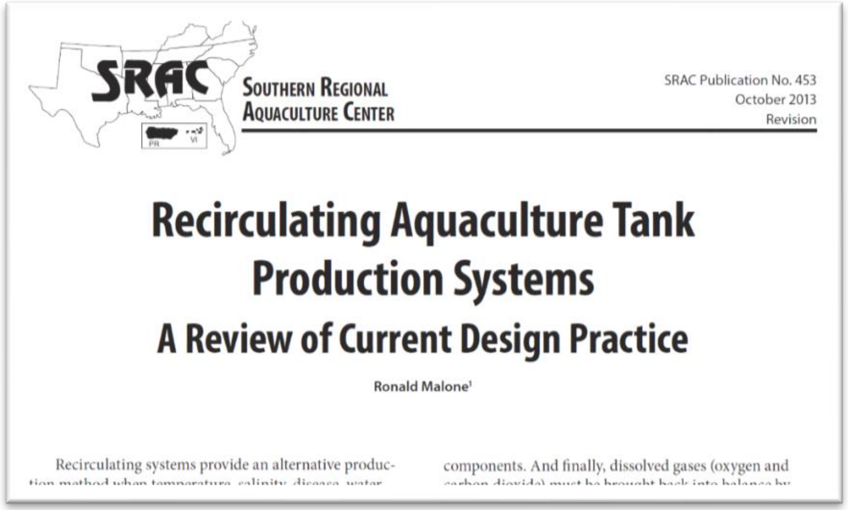
Fred Wheaton

Director, Northeastern Regional Aquaculture Center, Professor, Department of Environmental Science and Technology, 2113 Animal Science Building, University of Maryland, College Park, Maryland 20742-2317
Phone: 301-405-6511; Fax: 301-314-9412; fwheaton@umd.edu

**Introduction**

Aquaculture and recirculating aquaculture in particular, may be a strong and viable business.

Source:
http://www.aces.edu/dept/fisheries/aquaculture/documents/Wheaton.pdf



SRAC SOUTHERN REGIONAL AQUACULTURE CENTER

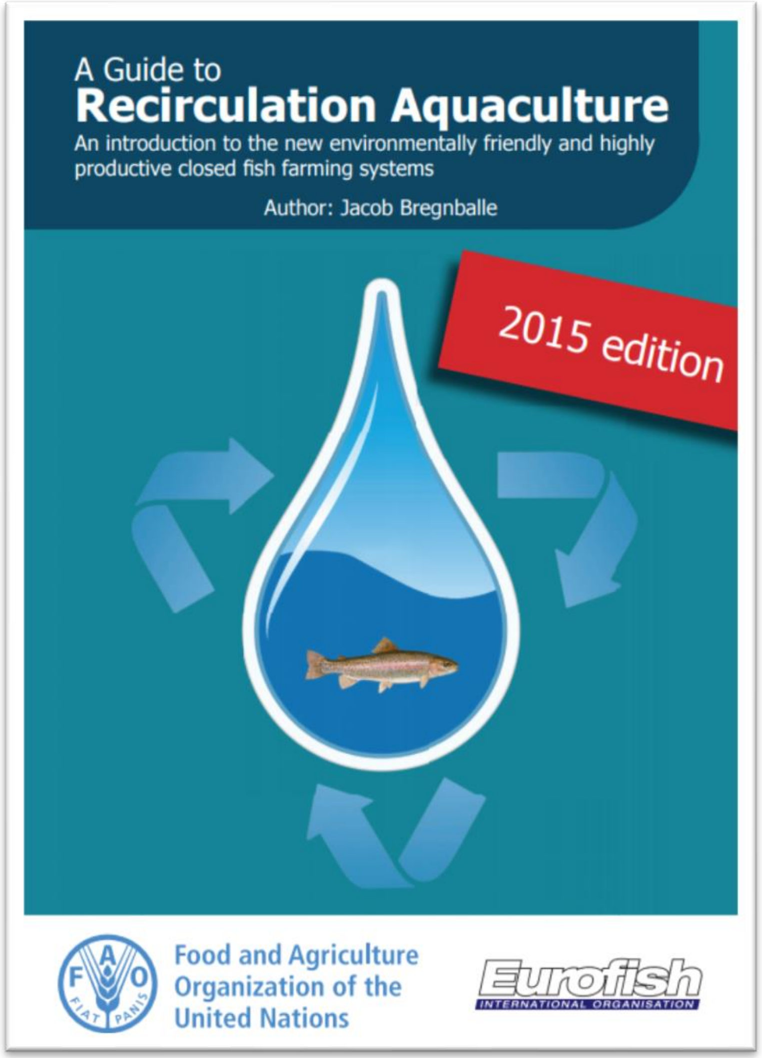
SRAC Publication No. 453
October 2013
Revision

**Recirculating Aquaculture Tank Production Systems**
**A Review of Current Design Practice**

Ronald Malone[1]

Recirculating systems provide an alternative produc- ... components. And finally, dissolved gases (oxygen and

Source: https://srac.tamu.edu/serveFactSheet/104




Source: http://www.fao.org/3/a-i4626e.pdf

# Additional resources:


Up-to-date presentations and videos from the Conservation Fund's Freshwater Institute «Aquaculture Innovation Workshop» **Nov 29-30, 2017**, where 180 participants from 10 countries gathered to discuss status and challenges in RAS aquaculture.
Source:
https://www.conservationfund.org/our-work/freshwater-institute/aquaculture-innovation-workshop


Published in 2011, and as the name implies, the proceedings from the FAO Technical workshop on *Aquaculture in desert and arid lands* reflect the need for better fish farming solutions for regions with little water supply.
Source: http://www.fao.org/docrep/015/ba0114e/ba0114e.pdf

Experiences from fisheries and aquaculture in Norway

# Some general hurdles in moving from a technology platform to an industry

# Technology Readiness levels – Getting over the hump

| Technology Readiness Level | Description |
|---|---|
| **TRL 1** | Basic principles observed |
| **TRL 2** | Technology concept formulated |
| **TRL 3** | Experimental proof of concept |
| **TRL 4** | Technology validated in lab |
| **TRL 5** | Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) |
| **TRL 6** | Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) |
| **TRL 7** | System prototype demonstration in operational environment |
| **TRL 8** | System complete and qualified |
| **TRL 9** | Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space) |

**Technological Readiness Levels** are useful scales for characterizing the maturity of enabling technologies in industry development. Niri evaluates its technology using the TRL scale of the European Economic Commission (left).

In purely technical terms, at moderate rearing densities or for early life stages of fish, TRL9 has been achieved for RAS technology, including for sensitive species such as salmonids.

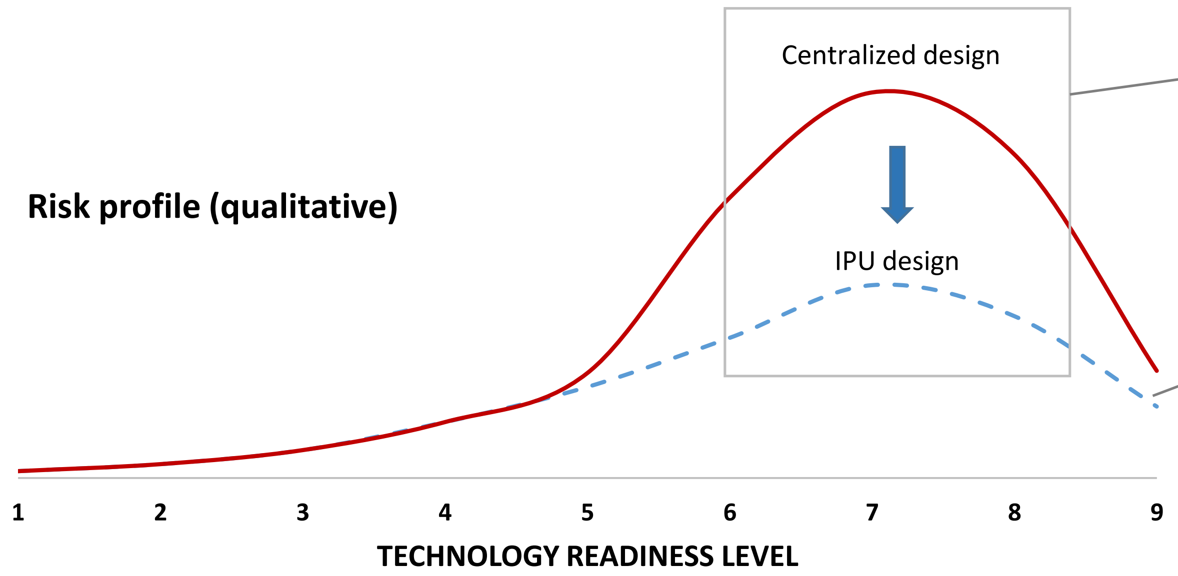
Taking into account crucial targets for economic competitiveness such as sustaining **high rearing densities** during **full grow-out cycles** and with **adequate operational stability**, the industry is currently moving through TRL 7-9.

As technology is moved from the «laboratory» into a phase of verification in industrial use, economic risk shifts from costs associated with time-expenditures and prototype building at small scale, to the risks associated with investments in much larger facilities combined with the possibility of losing industrial-scale rearing stock - a far more costly proposition than experimenting with small batches of fish in prototype systems.

Maturation of technology to tackle industrial-scale operations thus often faces a steep «hump» of financial risk to be overcome (next page); at times this may work more like a wall than a hump. Many innovative technologies in fishing and aquaculture remain frozen in their tracks at TRLs 4 to 5, being neither rejected nor verified for years. RAS technology for sensitive species has idled at these stages for many years until recently.

An important success criterion for rapid industralization is therefore **early-stage planning** of the core technology **to minimize and compartmentalize risk**. This is one of the considerations beind Niri's technology that is based on Independent Production Units (IPUs), each of which integrates the backbone of a self-contained RAS system.

# Getting over the «hump» towards industrialization through innovation




Industrialization requires verification from operations of **scale** and **intensity,** which inevitably entails increased financial risks until both technology and operations are well tested under representative conditions. Moving past this stage requires capital and government incentives. Several RAS technology providers are moving through these stages at the moment, and intensive RAS culture with sensitive species is about to enter the mainstream.

Niri's core technology based on largely self-contained (except the limited flow of intake water) **Independent Production Units** (IPUs) has been developed with this view. The IPU approach compartmentalizes risk during technology verification (arrow). An IPU technology core also allows individual commercial projects to be developed in planned stages, permitting staff training and experience to keep up with investments and scale of operations. IPUs also offer biosafety benefits as batches do not share centralized water treatment infrastructure.

# Risk & industrialization – good public research is priceless

**1: Commercialization of proprietary research**
- Return on prior investments
- Outcome known – risk reduced
- Patents/IPR protection possible
- Rarely highly interdisciplinary

**2: Fundamental and applied research**
- Returns on taxpayer money
- Outcome known – risk reduced
- Patents mainly held by research institutions
- **A major reducer of risk**

| | Research execution | |
|---|---|---|
| **State of research** | **Internal** | **External** |
| **Completed** | 1 | 2 |
| **Pending** | 3 | 4 |

*TI Kvernevik/Fiskevegn*

**Long-term, public domain, basic and applied research,** are **major catalysts** for successful industrialization. Enabling intensive land-based aquaculture to meet the objectives that lie outside the immediate scope of fish farming core technology - such as success criteria raised by consideration of **food security/-access**, **nutrition** and **sustainability** – lies beyond the R&D capacities of most corporations.

**3: New industrial research**
- Outcome unknown – high risk
- Investment of own time – liquidity benefit
- Builds internal expertise -> strategic benefits
- Patents/IPR protection possible
- Often compartmentalized – limited exchange of know-how slows industry growth

**4: Commercial sourcing of basic research**
- Outcome unknown – high risk
- Payment for all time and material in cash
- Builds little internal expertise, expert depenencies
- Patenting/IPR protection problematic
- SMEs can rarely afford to buy multidisciplinary, institutional research for prolonged periods of time

# Developing industrial RAS fish farming: an analogy from performing music professionally

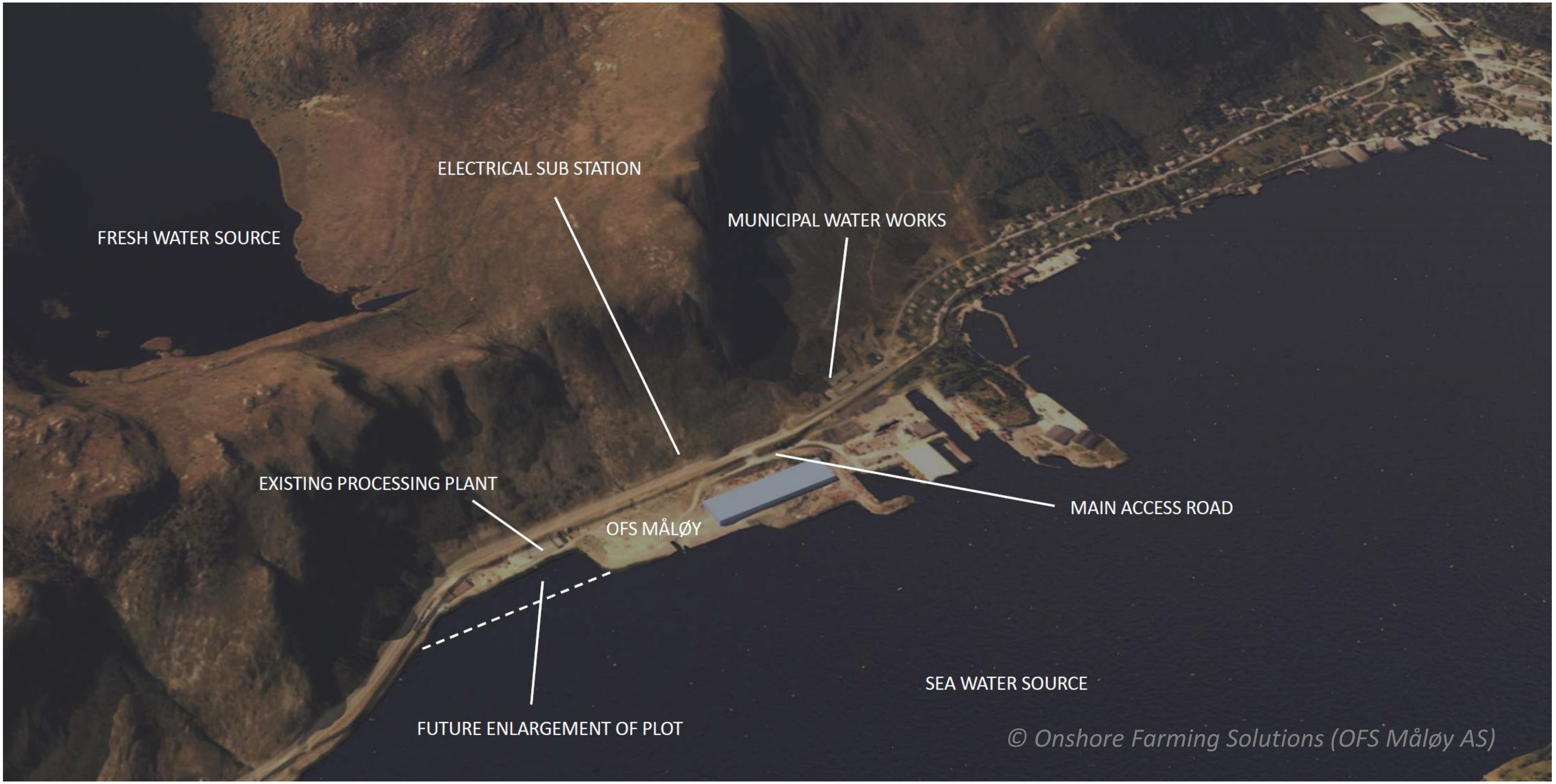
- **Buying the instruments is the easy bit**

  -> ***Technology core***
- Tuning, preparing, choosing what to play

  ->***System configuration and context***
- You still need trained musicians

  -> ***Operations know-how and experience***

# Case: Industrializing with good risk management
## Scaling up and intensifying operations in flexible stages




In 2018 construction begins of a large-scale salmon RAS facility using NIRI technology in Vågsøy, Norway. The project builds on NIRI's flexible IPUs concept to compartmentalize investment-, operational- and biosafety risk, whilst allowing investments to be made in several stages towards high production capacity.

With a production capacity of the first stage of 6000MT/yr and 15000MT/yr at full capacity, this will be one of the world's largest RAS facilities for full grow-out farming of Atlantic salmon.

To further manage risk, the site has backup access to large volumes of highly quality controlled and UV-treated fresh water, as well as proximity to seawater for use in off-taste treatment prior to harvesting.

Coverage (in Norwegian): https://www.nrk.no/sognogfjordane/vagsoy-far-50-nye-arbeidsplassar-1.13826007

System Engineering approach

Scoping for sustainability

Feedback loops between criteria and solutions

# What are success criteria for industrialization of land-based culture?

Defining success criteria for nutrition, food security and sustainability success criteria, (as opposed to technical and economic feasibility of individual fish farming projects):

# Early adoption of a systems engineering approach with appropriate scope

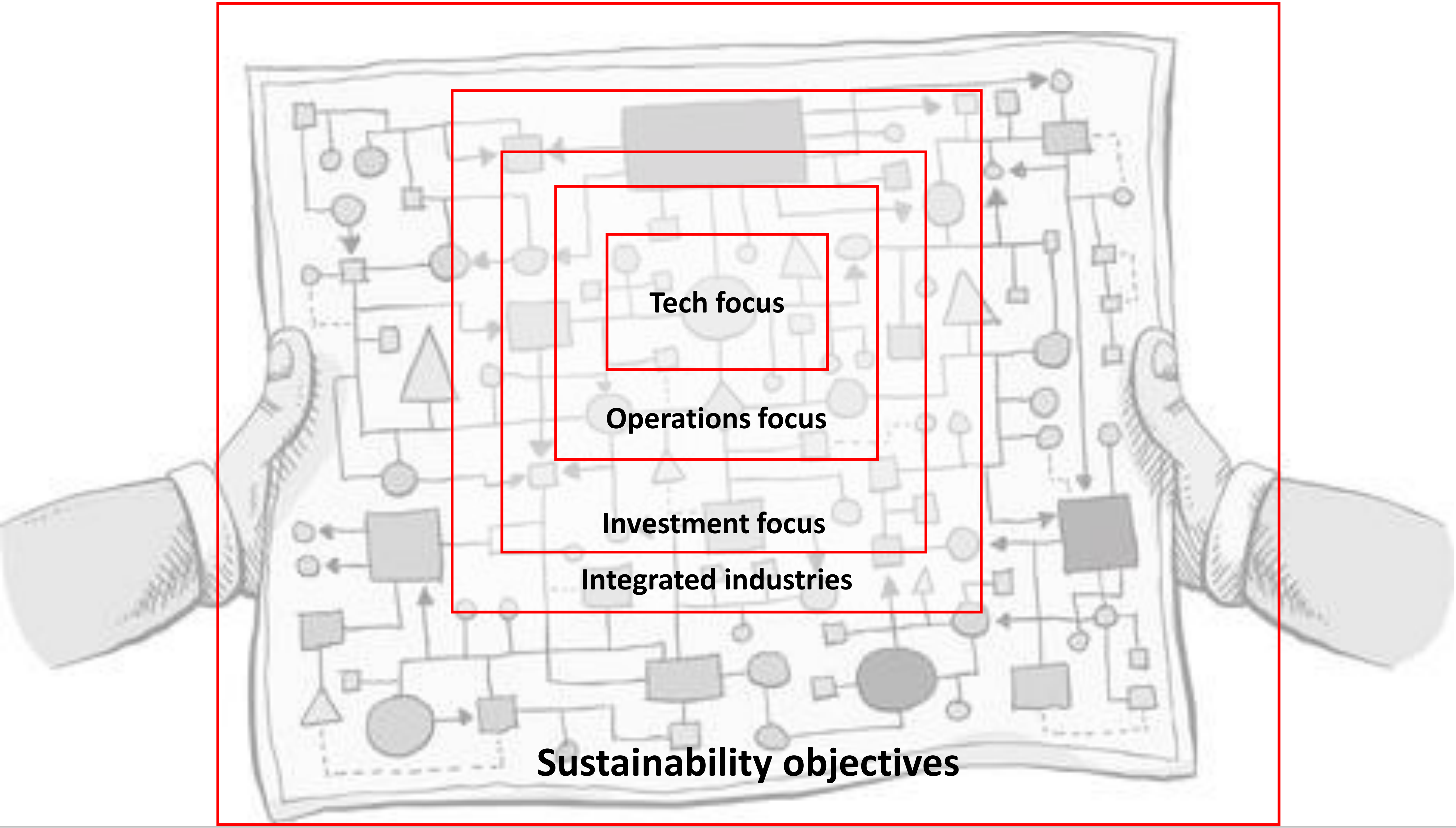
As a new industries emerge based on relatively new technologies, the shared insights and experience of scientists, regulators, area planners, industry consultants and operators typically become formalized in a systems engineering framework, about which there exists a fair level of professional consensus. If such a framework is not established, this is in itself a strong indicator that a technology is not ready for mainstream industrial application. At the very least, one should be able to define a basic architecture for the system in question on the appropriate scale:

- **System definition** – What are the boundaries of our system? Is it a single fish farm, or a whole range of value chains, from feed procurement and water management, to seafood consumers and their different economic access to produced food; waste utilization, and public health risk from antibiotics use?
- **System components** – Given the system boundaries, what components does the system comprise? What are the additional elements to be included when "sustainability" is not part of a branding strategy, but rather an actual operational requirement?
- **Component properties** – We may discuss the properties of biofilters and CO2-strippers at length; but what are the functional properties of agricultural land and marine resources that feed comes from; the carbon emissions from supply and distribution, and so forth?
- **Component interactions** – As we move beyond the boundaries of the installations on the industrial estate of a given fish farm, do we have the capabilities for explicit assessment of mutual interactions and dependencies among the wider system's components?
- **System properties and system level behavior** – Our ability to plan and control system level performance is immensely influenced by the scoping implications of moving beyond a single fish farm (technical, operational and economic viability) - to the macro-level considerations that popular tags such as "nutrition", "food security" and "sustainability" acutally require.

To facilitate informed choices for industrial fish farming solutions aimed at population level nutrition targets, food security and sustainability, NIRI advocates the early adoption of a **sustainable engineering approach** among planners and industry.

Inspirations on sustainable systems engineering / sustainable engineering
https://en.wikipedia.org/wiki/Sustainable_engineering
https://www.engineering.unsw.edu.au/study-with-us/postgraduate-degrees/sustainable-systems

# Planning for sustainability widens scope greatly



# Sustainable systems engineering – effects on planning

As we zoom out from classic technical/economic feasibility planning (the focus of most corporate entities and their investors) the main focus shifts from **solving technological issues** to meeting **large-scale environmental and social economics objectives**. Sustainable industry development requires success on all these levels.

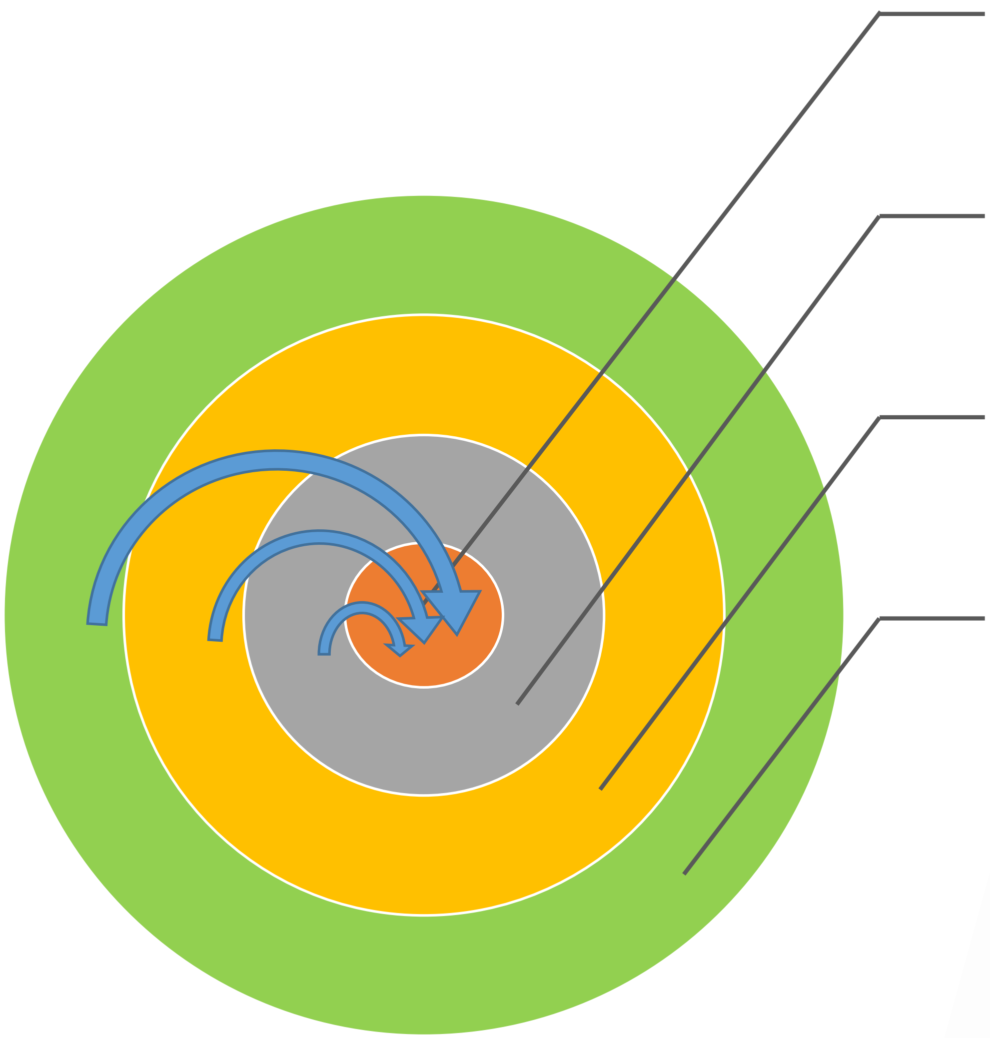
Planning for **technical and economic feasibility** is obvious for any industry, though challenging in its own right. As planning is widened to consider population-level **nutrition targets** and **food security**, criteria for successful industry development grow more complex. As **sustainability** criteria are applied, the scope widens still.

There are inevitable **feedback loops** among the different levels of planning. Findings on the macro-level can easily **call for changes** in the assumptions a **technology core** builds on. A simple example is planning aquaculture that is economically viable in isolation, but that can be unsustainable and of net cost to society due to unsustainable feed procurement and evolution of antimicrobial resistance.

**Industrializing sustainable, large scale food production based on new technology requires an iterative planning process. It also requires an open and broad-base discourse among industry, government agencies, research institutions and NGOs.**

***The good news is that «planning is cheap».***

The potential costs to society from failures to develop good nutrition, food security and a sustainable value chain, far exceed the expenditures required to incentivize research and planning for the bigger picture.




# Where is the feed to come from?

Assessment of sustainability must, among other concerns, cover the value chain from feed to waste.

From a «cynical perspective», intensive fish farming could be seen as an industry that uses a large biomass of terrestrial and marine raw materials to manufacture a smaller biomass of high value fish, and with a significant mass of feed spillage and organic sludge as by-product.

If all the feed used in farming of Atlantic salmon were of vegetable origin, feeding a single salmon to harvest weight of 4kg requires an agricultural area of 25m$^2$. Feed procurement does have a footprint. In absolute terms, massive growth in both land-based and marine aquaculture will put increasing pressure on land areas and marine resources for feed procurement.

On the other hand, **fish** has a more **effective conversion of feed to biomass** than alternative livestock such as pig an chicken. To continue the biomass-to-area example above, rearing 4kg of pig requires 50m$^2$; chicken slightly more. Thus, in relative terms, it is better to respond to the world's increasing protein demand by culturing fish, than livestock, which are homeotherms and have less effective feed conversion ratios. This will have comparative benefits on the area/resource footprint of protein production. For these assumptions to hold, the species chosen for cultivation, rearing temperatures and several other factors must be managed; yet, fish culture offers significant potential to **limit the footprint of protein production**.

Sludge from land-based fish farming also has significant biogas potential (more so than sludge from marine culture as salt content inhibits methane yields), including as a mixed-in booster of biogas production from manure from livestock. The digestate from biogas reactors is better suited for use as fertilizer than raw sludge, though the nutrient content is not «crop ready»; for effective aquaponics or use as terrestrial fertilizer, certain nutrients must be supplemented to fish sludge.

Future visions for **integrated industry solutions** that cover both fish farming, feed production and energy utilization are **attractive**, though they are **challenging** and **highly interdisciplinary** ambitions. They nonetheless represent a natural evolution of large-scale protein procurement towards greater compliance with the principles of the circular economy.

# Antibiotics use in aquaculture is a major public health concern.

Aquaculture is a major contributor to public health professionals' concerns regarding evolution of antimicrobial resistance.

**Limited research has so far been carried out on the antimicrobial resistance threats from RAS aquaculture** (**Watts et al 2017**).

Large biofilters, populated by bacteria, are cornerstones in RAS systems, and water recycling could lead to accumulation of antibiotics inside the system over time if antibiotics are used.

**The best strategy for avoiding evolution of antimicrobial resistance in RAS fish farming is a Zero Antibiotics Policy.**

This has implications for technology planning. Strict biosafety protocol must be followed to **prevent introduction of disease** in the first place. **Sterile intake water** and rearing fish from **disease-free eggs** rather than sourcing external fish fry is advisable. **Compartmentalization** of rearing batches in Independent Production Units facilitates adherence to a zero antibiotics policy, by containing bacterial disease if it occurs. Infection risk must be continuously managed - a crucial aspect of **personnel training**.

Nations that wish to secure long-term socioeconomic benefits, such as improved nutrition and food security, from investments in industrial aquaculture, should allocate adequate and ongoing funding for public research on biosafety and antimicrobial resistance.

**See review by Watts et al (2017), Marine Drugs 15(6):**
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5484108/#!po=2.17391

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Mar Drugs. 2017 Jun; 15(6): 158. PMCID: PMC5484108
Published online 2017 Jun 1. doi: 10.3390/md15060158

**The Rising Tide of Antimicrobial Resistance in Aquaculture: Sources, Sinks and Solutions**

Joy E. M. Watts,[1,*] Harold J. Schreier,[2] Lauma Lanska,[1] and Michelle S. Hale[3]

Allen Place, Academic Editor, Rosemary Jagus, Academic Editor, and Paul Long, Academic Editor

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## Abstract

Go to:

As the human population increases there is an increasing reliance on aquaculture to supply a safe, reliable, and economic supply of food. Although food production is essential for a healthy population, an increasing threat to global human health is antimicrobial resistance. Extensive antibiotic resistant strains are now being detected; the spread of these strains could greatly reduce medical treatment options available and increase deaths from previously curable infections. Antibiotic resistance is widespread due in part to clinical overuse and misuse; however, the natural processes of horizontal gene transfer and mutation events that allow genetic exchange within microbial populations have been ongoing since ancient times. By their nature, aquaculture systems contain high numbers of diverse bacteria, which exist in combination with the current and past use of antibiotics, probiotics, prebiotics, and other treatment regimens—singularly or in combination. These systems have been designated as "genetic hotspots" for gene transfer. As our reliance on aquaculture grows, it is essential that we identify the sources and sinks of antimicrobial resistance, and monitor and analyse the transfer of antimicrobial resistance between the microbial community, the environment, and the farmed product, in order to better understand the implications to human and environmental health.

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Planning for:

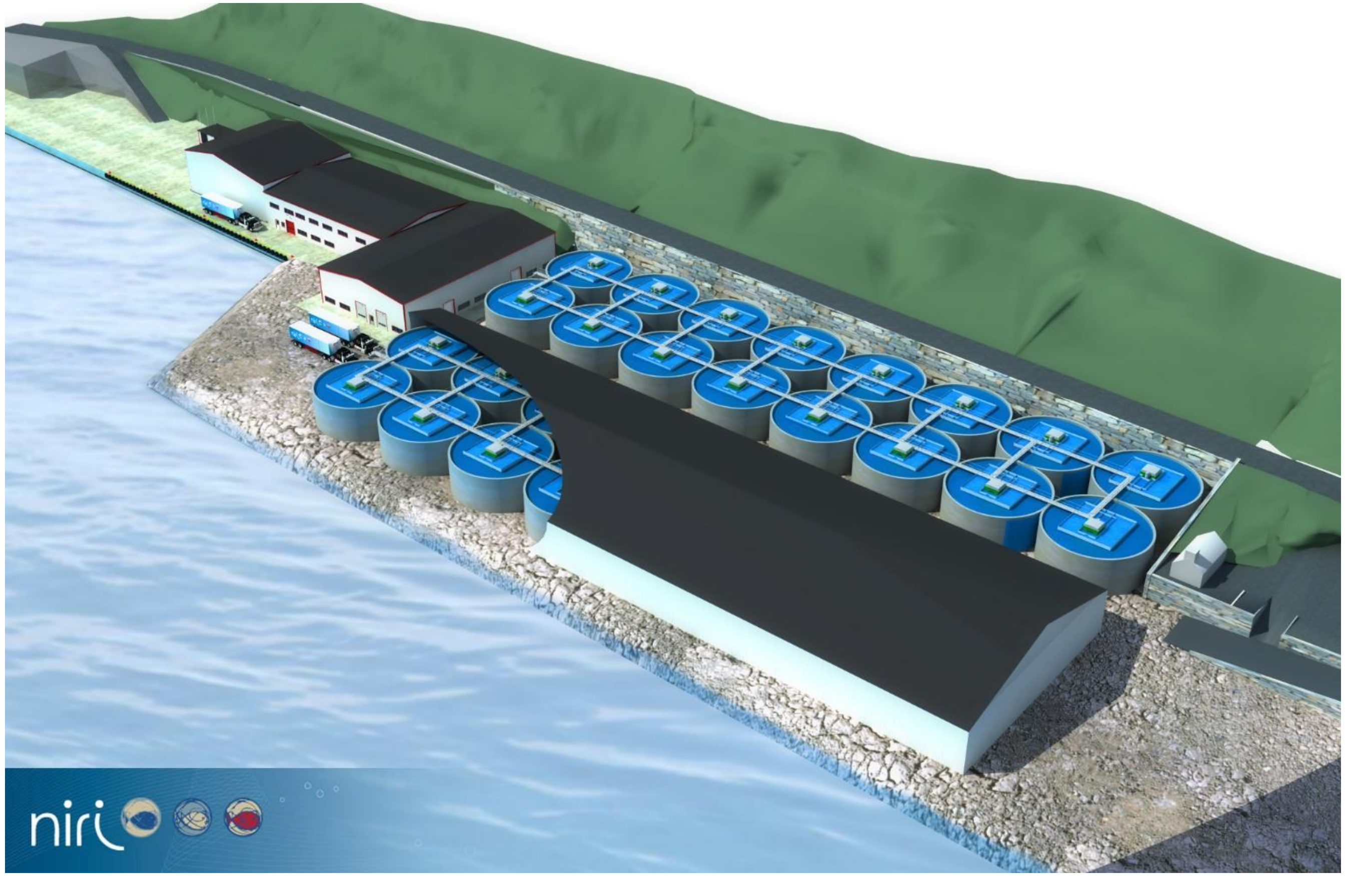
**Seafood opportunities**

**Integrated industries**

**Food security and sustainability**

# Contrasting visions

# **Seafood opportunities visions**:
# Industrial scale RAS facility (building start Q2 2018)
# Capacity up to 15 000 tonnes/year



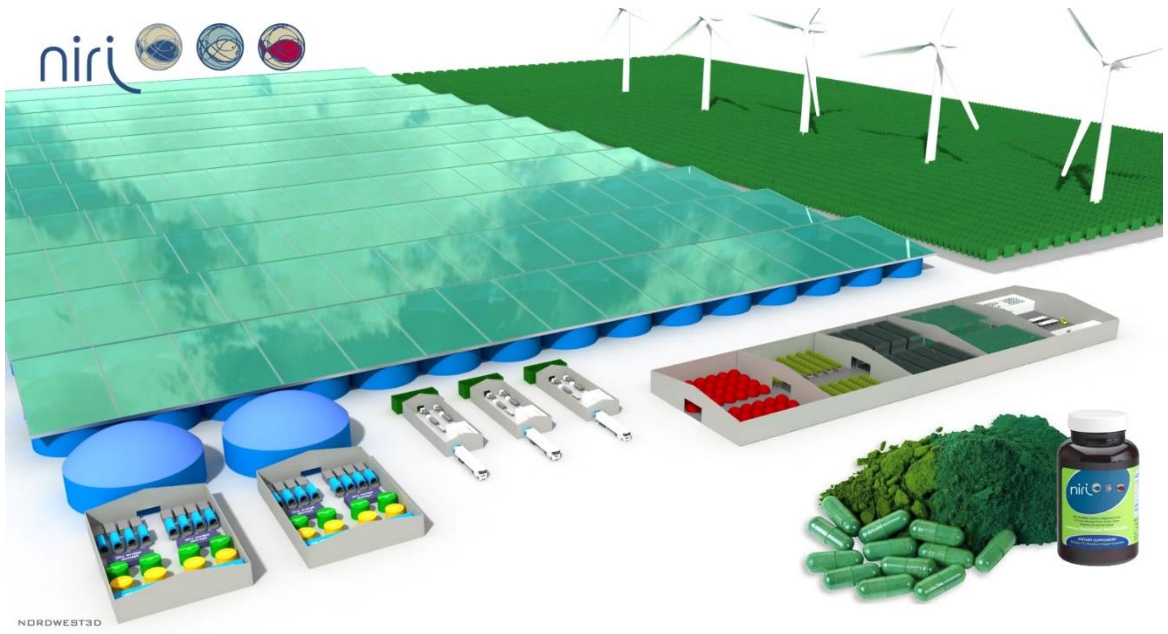

Sucess criteria:

- Technological readiness
- Sufficient density of fish
- Stable operations
- Profitable investment
- Competitive farming
- Comparative environmental benefits

Early version of OFS Måløy AS facility

# Integrated industries visions:

## Industrial scale RAS facility capacity 40 000 tonnes/year + energy (EFW/solar/wind) – nutrition - aquaponics




**Sucess criteria for industrial integration**:

- Technological maturity in each sector to be combined
- Realization of comparative environmental benefits on the relevant scales and when whole value chains are considered
- Each business area must make business sense when integreated (for example, energy production must be competitive with paying gate fee for waste and buying power off the grid; agriculture production must be competitive against alternative investments and operations)

Economic incentives that reward industry integration will help enable industry combinations that realize the objectives of the circular economy on large scale.

# Sustainable seafood visions – a work in progress

- Sustainability must be evaluated throughout the entire food value chain and its branches (clear strategies for feed procurement and management of public health risks from antimicrobial resistance are key examples; how to realize positive impacts on landuse, water resources and energy conservation, positive effects on logistics/transport and carbon emissions; and so forth)
- Capabilities for planning with appropriate scope must be nurtured. A sustainable engineering framework offers clarity and helps governments and industry home in on good strategies. Including objectives for nutrition, food security and sustainability has major effects on the scope of system definition. From a planning perspective, this relatively simple tool help point to existing knowledge bases in disciplines that tend to live separate lives in spite of having mutual relevance, and helps identify priorities for research and development.
- Emerging Circular Economy frameworks (EU commission and other sources) offer strong guidance for further industrialization of aquaculture. Intensive land-based RAS fish farming in inherently preadapted to circular economy objectives by offering potential for control with in- and outflux of water and other resources.
- The various potential nutrition benefits from fish are not automatically achieved. Much depends on the chosen species, feed quality and how fish is utilized as food. Realizing specific nutrition benefits require that nutrition targets are defined for given demographics, and these differ widely by locations and economic circumstances. National nutrition plans should be revised to define such targets and how fish is envisaged to help reach them (as recommended by Bene et al 2015); in turn industry can address these challenges with sufficient clarity.
- To make a dent in global challenges within nutrition, food security and the sustainability of protein procurement, production capacity has to be sufficient to make a difference in on relevant scale whilst giving economic access to the consumers that are in need of those benefits. Developing industrial fish farming to realize seafood market opportunities vs solving food access- and sustainability issues are not equivalent challenges.
- The road towards large scale seafood production from intensive RAS fish farming as commercially viable ventures *per se* now appears comparatively short – if this helps large consumer groups consume more protein from feed-efficient cultured fish and less from livestock and poultry, the footprint from feed production and water consumption should be reduced in relative terms.
- RAS farming of fish has the potential to make major contributions towards healthy nutrition, food security and sustainable protein procurement, but is in itself, as every food industry, in this broader context a cog in a much larger machinery that must be optimized as a whole.
- Obviously, no single corporation has the capabilities or reach to solve this challenge. Moving from visions for food security and sustainability to operational reality is a interdisciplinary, collective challenge for governments, scientific institutions, visionary investors, technology developers and dedicated industry players.

# THANK YOU

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