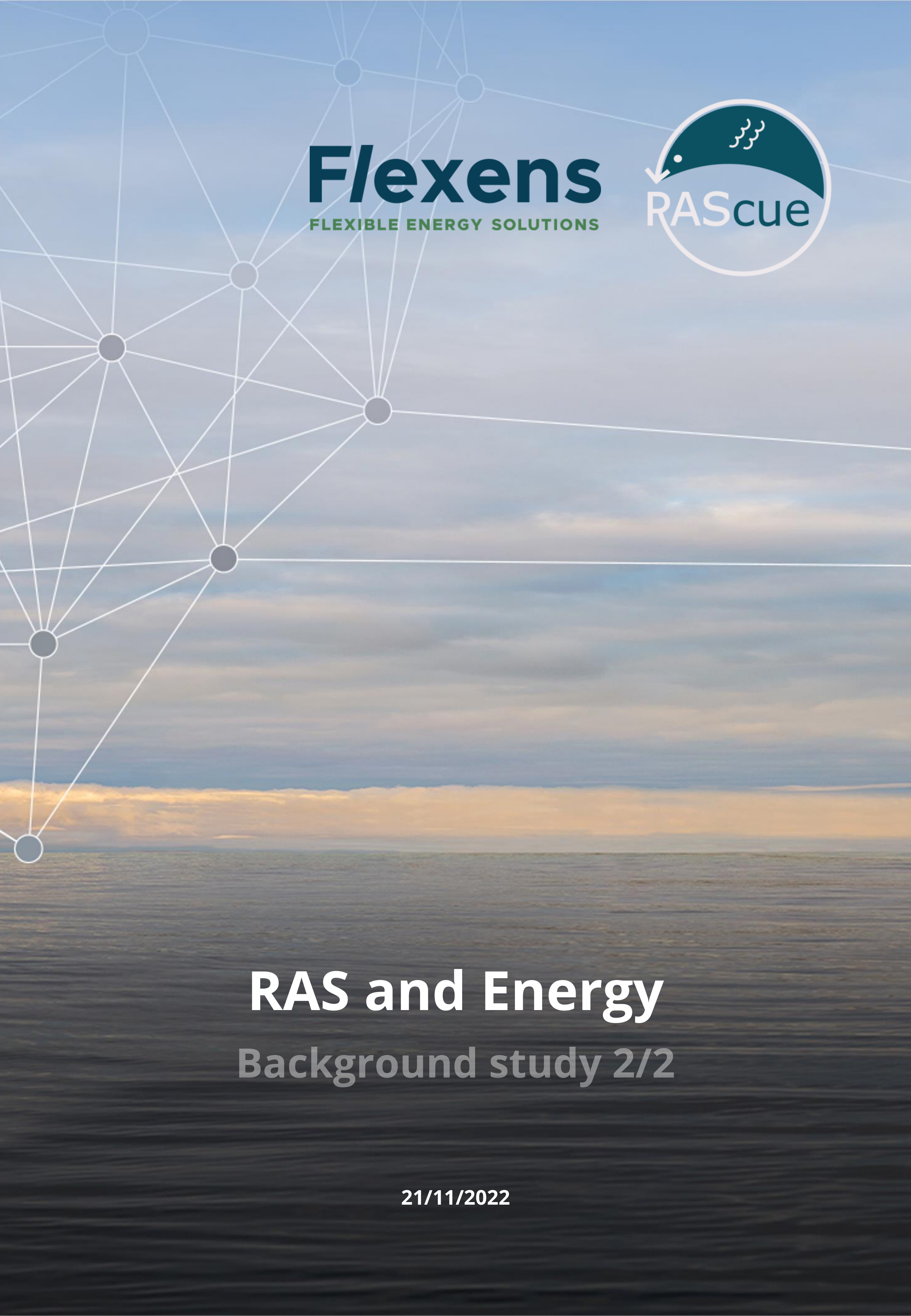

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RAScue

RAS and Energy

Background study 2/2

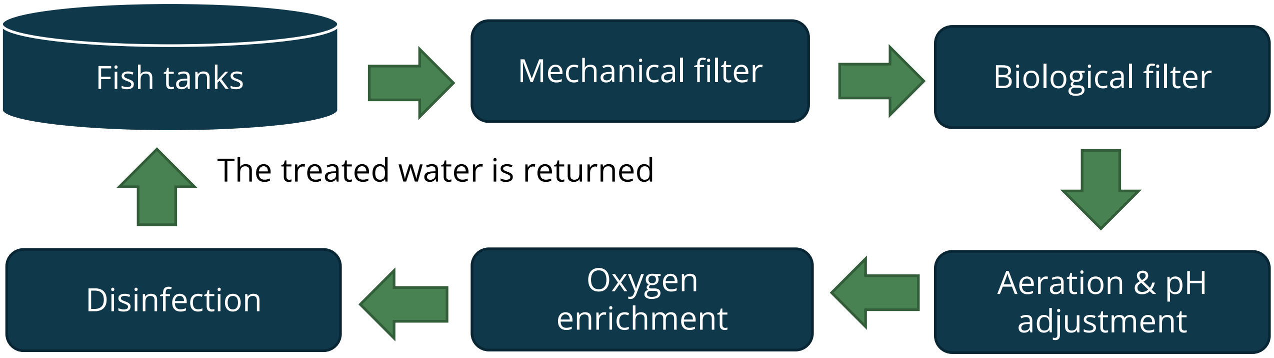
21/11/2022

Recirculating Aquaculture Systems

Recirculating Aquaculture Systems (RAS) are land-based fish farms in which water is recirculated, thereby reducing both water and land usage. While the degree of recirculation can vary, in super intensive RAS as little as 0.3 m^3/kg fish/year is consumed as opposed to 30 m^3 in non-recirculating flow-through systems. The fish are grown in tanks in a highly controlled environment. RAS yields benefits such as nutrient capture, and elimination of the need for pesticides and antibiotics. On the other hand, maintaining the water quality and recirculation requires high energy demand, making RAS economically challenging.

TYPICAL WATER TREAMENT STAGES IN RAS

To maintain the water quality and the optimal conditions for fish growth and well-being, various water treatment steps are incorporated in RAS. While the steps vary case-by-case, the following steps are generally incorporated:



PARAMETERS IMPACTING FISH GROWTH AND WELL-BEING

In land-based RAS, the natural environment of the fish must be emulated. To do so, the fish farmer must regulate the various parameters that impact the growth and well-being of the fish. The parameter requirements vary depending on the fish species and growth stage. Some of the parameters are listed below.

- Temperature
- O_2 & CO_2
- Salinity & pH
- Water flow
- Feeding rate
- Stocking density

Energy consumption of RAS farms

The main sources of energy consumption at land-based RAS farms are pumping of water, heating/cooling, oxygen/aeration and filtration and/or removal of solids . These energy demands are primarily met using electricity, rather than fuel.

Therefore, in our studies, we focus solely on electricity consumption. The electricity consumption of existing RAS farms was determined by comparing eight studies from around the globe. The electricity consumption was evaluated based on kWh/kg live weight fish produced. The findings are depicted in Table 1.

Table 1. Comparison of electricity consumption of RAS farms from literature.

<table>
<tr><th rowspan="2">Species</th><th rowspan="2">Area</th><th rowspan="2">Annual production [tonnes live-w.]</th><th rowspan="2">Avg. T (H_2O) [°C]</th><th rowspan="2">Prod. losses (Rel. mortality) [%]</th><th rowspan="2">Liquid oxygen [kg/kg]</th><th colspan="3">Electricity use (kWh/kg live-weight)</th><th rowspan="2">Feed conversion ratio</th></tr>
<tr><th>Feed production</th><th>Hatchery / Smolt</th><th>Grow-out</th></tr>
<tr><td>Atlantic Salmon[1]</td><td><i>Northern China</i></td><td>145</td><td>15</td><td>17</td><td>0.953</td><td>0.4</td><td>0.5</td><td>7.5</td><td>1.45</td></tr>
<tr><td>Atlantic Salmon Smolt[2]</td><td><i>Pacific NW., USA</i></td><td>192</td><td>16</td><td>14</td><td>0.828</td><td>22.3</td><td>47.4</td><td>ND</td><td>1.1</td></tr>
<tr><td>Arctic Char[3]</td><td><i>Nova Scotia, Canada</i></td><td>46.2</td><td>ND</td><td>30.1</td><td>0[b]</td><td colspan="3">22.6</td><td>1.45</td></tr>
<tr><td>Clarias[4]</td><td><i>Sweden</i></td><td>20</td><td>30</td><td>ND</td><td>0</td><td>0.5</td><td>0.0</td><td>0.2</td><td>1.1</td></tr>
<tr><td>Florida Pompano[5]</td><td><i>Fort Pierce, FL, USA</i></td><td>0.34</td><td>26.2</td><td>42.3 – 18.3</td><td>ND</td><td>ND</td><td>ND</td><td>40.3</td><td>3.4 – 4.2</td></tr>
<tr><td>Rainbow Trout[6]</td><td><i>Iran</i></td><td>1</td><td>ND</td><td>ND</td><td>ND</td><td colspan="3">8.1</td><td>1.47</td></tr>
<tr><td>Tilapia[7]</td><td><i>Sweden</i></td><td>20</td><td>30</td><td>ND</td><td>0</td><td>1.0</td><td>0.0</td><td>2.0</td><td>1.1</td></tr>
<tr><td>Turbot[8]</td><td><i>Brittany, France</i></td><td>70.4</td><td>17</td><td>ND</td><td>ND</td><td>8.6[c]</td><td>ND</td><td>69.4[c]</td><td>1.23</td></tr>
<tr><td>Turbot[9]</td><td><i>Galicia, Spain</i></td><td>3500</td><td>ND</td><td>ND</td><td>3.478</td><td>ND</td><td>14.8[d]</td><td>5.2[d]</td><td>ND</td></tr>
</table>

a. Based off of slaughtered weight, rather than live weight
b. Oxygen generated on-site
c. Includes fuel consumption as well
d. Based off of 1 kg of turbot consumed at households, rather than live weight

(1) Song et al., 2019
(2) Colt et al., 2008
(3) Ayer and Tyedmers, 2009
(4,7) Bergman et al., 2020
(5) Pfeiffer and Riche, 2011
(6) Dekamin 2015
(8) Aubin et al 2006
(9) Iribarren et al 2012

Analysis: A few pointers

From Table 1, it can be concluded that there are large variations in electricity consumption among the different farms. This can be attributed to the following:

- Some studies were based off commercial-scale farms while other studies were based off fixed-term experimental farms. As a result, the production scale of the farms varied from 0.34 to 3500 tonnes per year.
- There were large variations in the study scopes. Some studies aggregated the electricity usage of the feed production with the on-site electricity usage of the farm, while others provided the electricity usage for each category or only on-site electricity usage. Some farms included hatchery/smolt production while others focused only on the grow-out stage of the fish. In the study conducted by Aubin et al. 2006, the fuel and electricity consumption were aggregated.
- The control of parameters varied based on the needs of the fish. Both warm and cold-water fish species were studied. Average water temperatures ranged from 15-30 degrees Celsius. Feed conversion ratio (FCR) ranged from 1.1-4.2 and liquid oxygen added ranged from 0-3.478 kg/kg.
- The sourcing of the oxygen yielded differences in electricity consumption. For example, the farm in Nova Scotia used on-site oxygen generators, which therefore increased on-site electricity demand.
- The highest value of electricity consumption alone was for the grow-out stage of the Florida pompano (40.3 kWh/kg) in the study conducted by Pfeiffer and Riche 2011. This high value may be attributed to the fact that the study was based on an experimental farm that ran for a 306-day trial period and produced only 0.43 tonnes of fish. Furthermore, the study had the highest mortality rate, reaching up to 42.3% in one of the fish tanks. Therefore, if more of the fish had survived, the relative electricity consumption would have decreased since more harvest-ready fish would have been produced.
- The farms with the lowest relative electricity consumption were the Tilapia and Clarias farms in Sweden. No oxygenation was required, which can lower the electricity demand. By using heat exchangers and well-insulated buildings, the electricity required for heat production was minimised.

Minimising electricity consumption

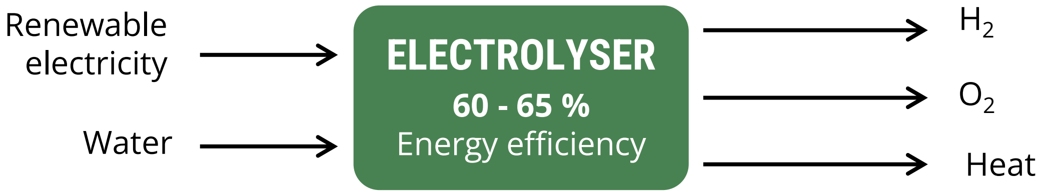
From the studies, it is concluded that the relative electricity consumption value can be decreased by lowering the mortality rate of the fish, thereby minimising "wasted" energy. While certain aspects of electricity consumption (i.e., electricity for pumping water and operating mechanical and biological filters) are difficult to reduce at existing RAS farms, other aspects such as heating, and cooling can be optimised by having more efficient heat exchange and well-insulated buildings.

The production of oxygen on-site also increases electricity consumption. The total operational costs are impacted by the amount of oxygen required, which is determined by the fish species and stages of growth included at the farm.

SECTOR COUPLING AND INTEGRATION WITH RENEWABLES

In addition to optimizing on-site equipment and decreasing fish mortality, in certain cases fish farms can reduce their on-site electricity consumption by meeting the demands of the site through external sources. For example, rather than using on-site electricity to produce heat, the heat can be sourced from nearby industries. Some industries with waste heat are summarised in **Appendix D**.

To make the RAS not only more energy-efficient, but also more sustainable, the integration of on-site renewable energy technologies is also evaluated. The technologies evaluated are solar panels, wind turbines, lithium-ion batteries, cold thermal energy storage (CTES) and electrolysers. The use of these technologies not only ensures that the electricity is sourced from renewables, but also yields flexibility in electricity prices, energy security and possibilities for an additional revenue stream from selling excess electricity to the grid.



Cold Thermal Energy Storage (CTES) refers to storing cooling capacity in an appropriate medium at temperatures below the nominal temperature of the space or processing system. Useful in fish farms where the water needs to be cool. The main purpose of CTES is to shift electricity use from on-peak to off-peak hours, thus decreasing costs (Abdul Galil, 2013; Dorgan & Elleson, 1993).

Case examples: Sector coupling

In this section, examples of fish farms employing sector coupling and integration of renewable energy technologies are presented in the form of short case studies.

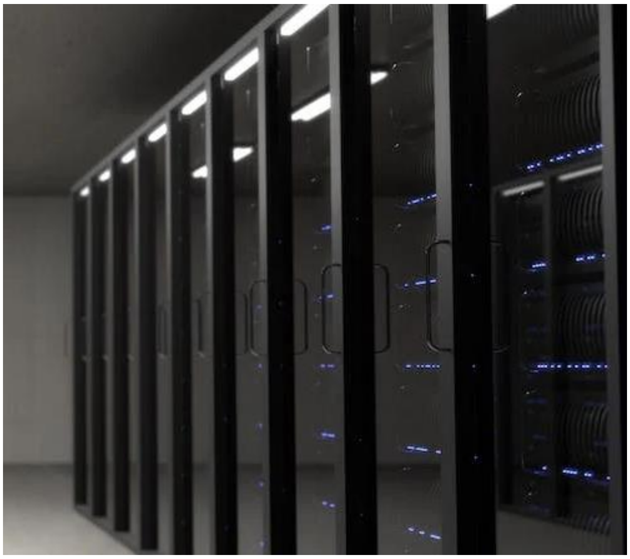
HEATING WITH GEOTHERMAL ENERGY IN ICELAND

In Iceland, 15-20 fish farms currently use geothermal water for heating the water at the farm, either in heat exchangers or by direct mixing. The geothermal energy is mainly used for juvenile production of arctic char and salmon, but also for post-smolt rearing to market-size.

One particular farm, **Stolt Sea Farm**, is mixing outlet water from the Reykjanes geothermal power plant with cold sea water to produce the optimal temperature recirculating water for growing warm-water Senagese sole at their land-based farm in Reykjanes.

SOURCING HEAT FROM DATA CENTERS IN NORWAY

In Norway, colocation company **Green Mountain** and land-based trout farmer **Hima Seafood** have entered into an agreement where the waste heat from Green Mountain's data center will be used at the fish farm. Heated water will be delivered via pipeline from the data center to a heat exchanger at the farm, located 800m away. The circular loop will be closed with the transfer of cooled water from the farm to the data center for cooling purposes.

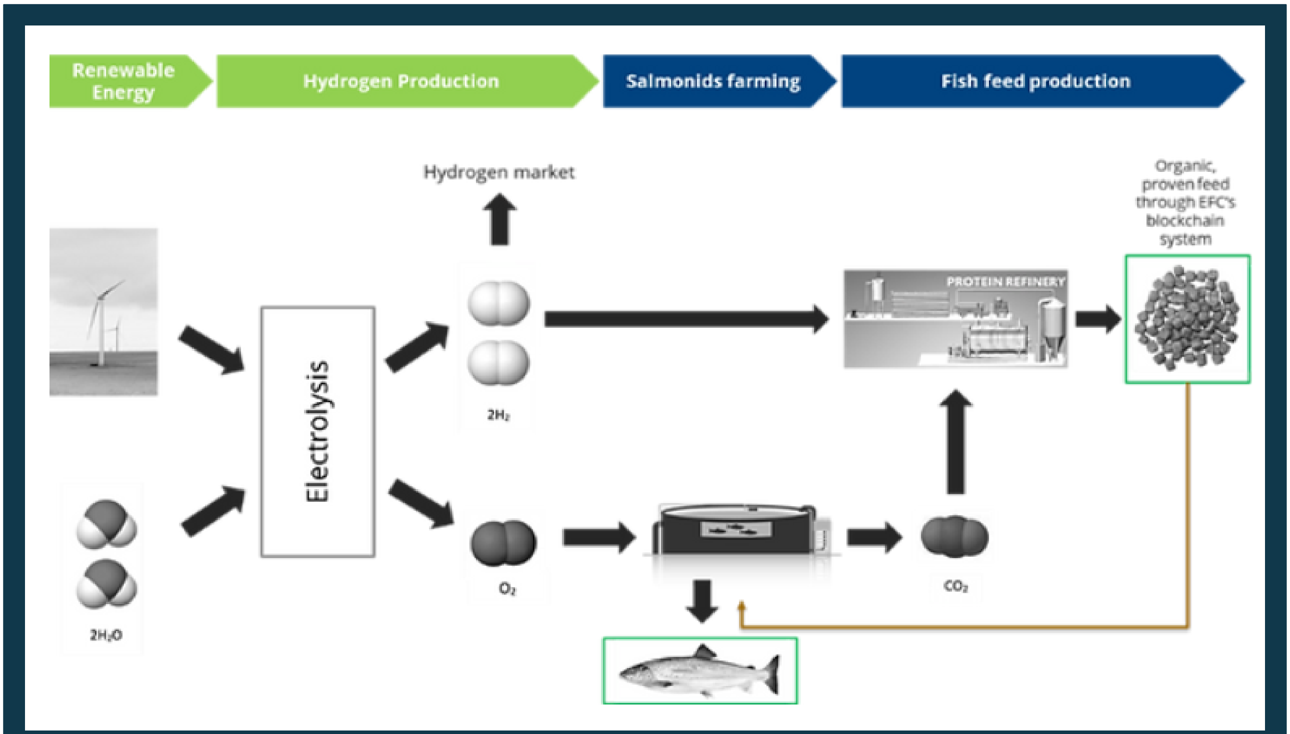


Case examples: Renewable energy

INTEGRATION OF PV PANELS IN CHILE

In Chile, a pilot scale RAS plant is co-growing shrimp and rainbow trout using electricity from PV panels. Solar energy is also used in a water treatment system to reduce the arsenic content of the water. Additionally, the study considered an in-grid plant in which surplus electricity from the PV panels could be sold to the local electricity company.

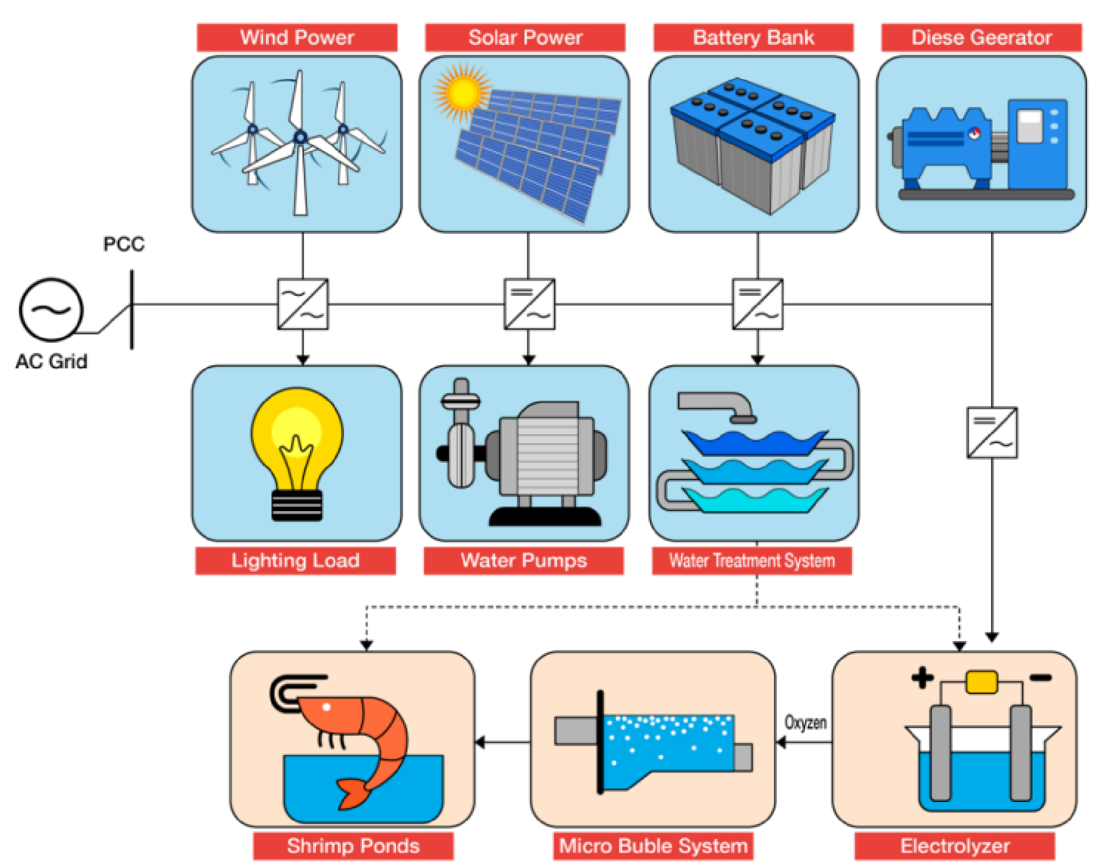
CO_2 CAPTURE AND ELECTROLYSIS



“The new RAS” EcoFishCircle, 2022b

EcoFishCircle (EFC) is a fish farming technology company working towards a new type of land-based salmon farming. EFC is cooperating with **Gas 2 Feed AS** to make nutritional proteins that can be incorporated in the feed from recycled CO_2 from the farm. EFC is also collaborating with HydrogenPro to produce oxygen from electrolysis for the fish and hydrogen for the fermentation.

COMBINATION SYSTEM



Designed system applied to shrimp ponds. Vo et al, 2021

The integration of multiple renewable energy technologies was investigated at a land-based shrimp farm in Vietnam. The farm includes both nursery and grow-out stages of the shrimps.

The optimal design was evaluated based on energy self-sufficiency and lowest environmental impact. The results of the study indicated that for off-grid operation, the optimal design included both PV panels and small-scale wind turbines, with the support of a battery storage and a diesel generator. An electrolyser powered by the onsite renewable energy was recommended for producing on-site oxygen to supply the farm's aeration system. The study concluded that the integrated shrimp farming system could reach both economical and environmental targets..

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