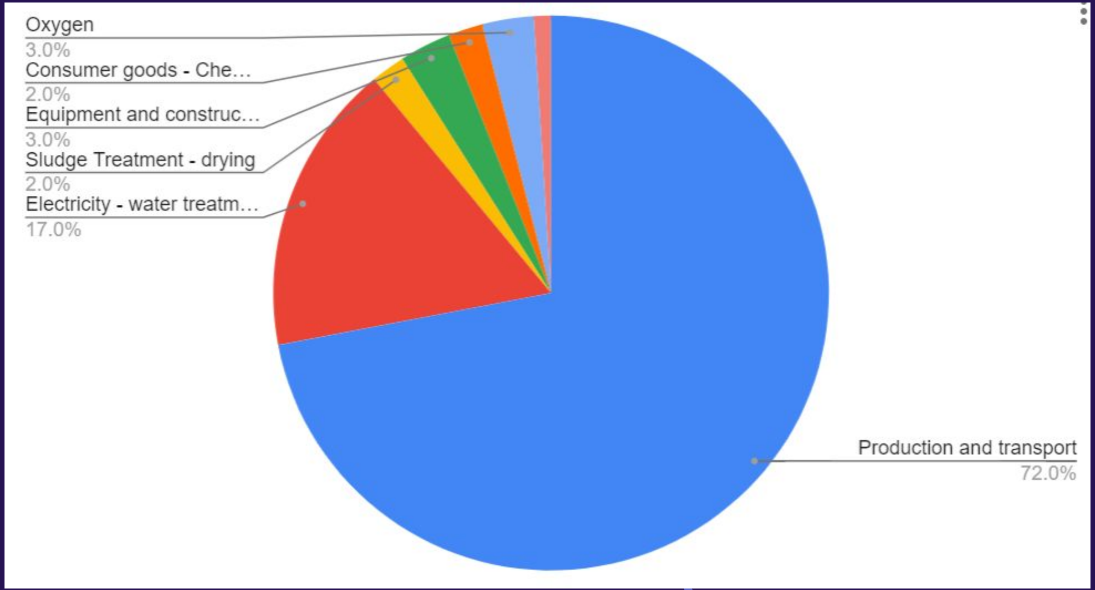
Group 9

Challenge 3: Improving energy efficiency and exploring opportunities for renewable energy

What are the sources of energy use in closed containment aquaculture systems?

SINTEF Ocean's life cycle analysis of Landbased Atlantic recirculating aquaculture systems produced the following results:

Atlantic RAS systems produce a ratio of 5,1 kg CO2e/kg of farmed fish fit for consumption.



Size and shapes of CULTURE TANKS

Culture tanks

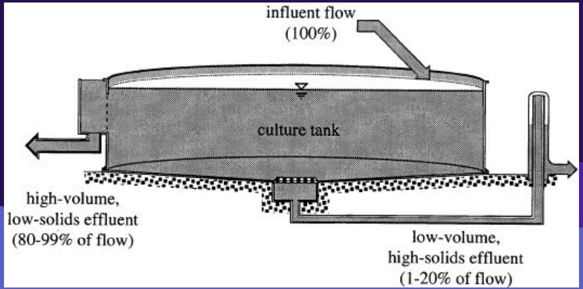
Tanks used to concentrate solids (ex. Fecal matter, uneaten feed, etc.) to make it easier to drain

Circular

- Circular circulation optimizes tank space
- Less energy used compared to rectangular tanks

Small > large

- Volume 1 - 100m^3
- Triangular current → better water circulation
- Promotes self-cleaning tanks (more efficient water use)
- Large tanks → more turbulence → dead zones → more energy needed to keep up water flow



USING WASTE

WASTE HEAT

Work is never 100% efficient, and oftentimes a lot of energy is lost in the form of heat. This means that a lot of energy is being lost to the atmosphere, requiring more to be used.

WHAT ABOUT WASTE?

Waste is products that are eliminated or discarded after the completion of another process. In aquaculture systems, energy use is one of the greatest drawbacks, but utilizing waste, both heat and physical waste, can help to reduce energy consumption.

WASTE-TO-ENERGY

Generating heat or electrical energy through the primary treatment of waste, particularly sludge

WASTE TO ENERGY USING SLUDGE

- Sludge → fish farming waste consisting of feces and excess feed
- Methanization → anaerobic digestion of sludge in large tanks
    - It is organic material→ methanogenic bacteria are able to digest it and produce methane as a byproduct in anaerobic conditions after around 20 days
    - Methane gas (combustible biogas) can partially replace the gas used for heating→ alternative for heating water for fish
    - Would reduce carbon dioxide emissions from combustion of other fuels (fossil fuels)
    - The residue can also be used to mix into organic fertilizer

- 500,000 kWh can be produced per 9 million smolt
- Recycling waste (reducing waste and reducing other energy use like the combustion of fossil fuels)

In Norway

- Forsan biogas plant, Settefiskanglegg
- More feasible in a country like Norway that has enough money to pursue these solutions
- Need to find out if there are any bio gas plants nearby as transportation can also be a logistical issue

Drawbacks

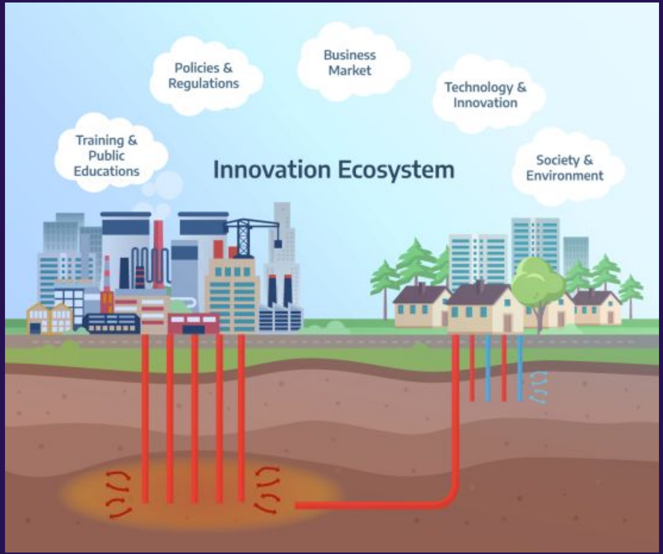
- Higher cost for infrastructure such as digestion tanks
- More labour intensive
- Needs careful protocol because sludge can contain pathogens and hazardous micro-organisms

USING HEAT ENERGY

- No systems are 100% efficient, meaning that some energy is always lost when work is being done (Law of Thermodynamics)

- Heat is lost to the atmosphere which can contribute to global warming, but mostly it means that energy use is very inefficient
  - Leads to more fuel being consumed to meet required energy output
  - Can help reduce carbon dioxide emissions

- Aquaculture systems can use heat waste from other industries (data centres produce lots of heat waste)
- Waste heat (hot air) can be used to heat water that is redirected to the facilities that need it→ can be used to heat aquaculture system



In Norway

- More heat mapping needs to be done to identify areas or centres with lots of waste heat
- Norway has many data centers that have not been sufficiently identified and map
- Requires planning to see how industries emitting lots of heat waste can be connected to aquaculture systems

Drawbacks

- Requires a lot of planning, mapping, and infrastructure
- Can cost more money to implement systems to conserve heat waste
- Waste heat is low quality energy, and it can take a lot to achieve the necessary energy needed

Renewable energy production though PV-panels and wind turbines

It is estimated that by using wind turbines and PV panels in addition to a diesel generator for handling the energy peaks, farms can reduce their CO_2 emissions by almost 50 per cent, and a typical fish farm will at the same time be able to cut costs by 16 per cent. *(Syse)*

Section will be exploring:

- Wind turbines in offshore aquaculture
- Photovoltaic panels in offshore aquaculture
- Potential methods of energy storage

Wind turbines

How to incorporate wind turbines in aquaculture?

- The cheapest solutions would probably be to install the wind turbines directly on the infrastructure already in place on a salmon farm e.g. the feed barge. (With the current size of the barges, only relatively small wind turbines could be installed without increasing the size and thereby the cost of the barge.)
- Another option is bottom fixed turbines in shallow waters, or floating wind turbines in deeper waters.

Vertical Axis Wind Turbines (VAWT)

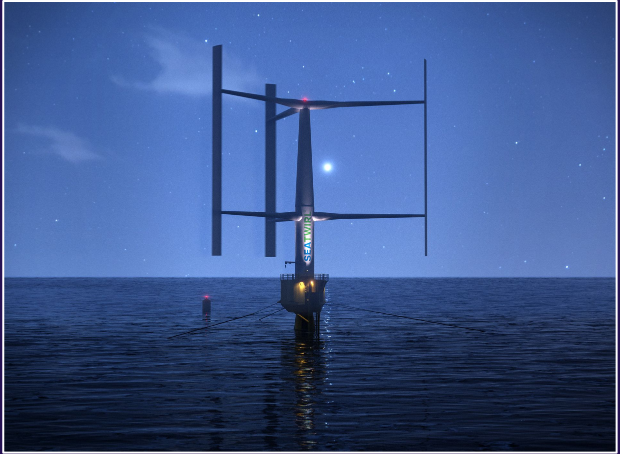
Investing in VAWT could be a potential way to increase the energy efficiency and renewable energy in aquaculture. Benefits include:

VAWT works better in turbulent and gusty winds and can therefore be grouped closed together or closer to the ground.

Lower centre of mass - beneficial for floating turbines (and barge turbines) - VAWT has easier maintenance as well.

Omni-directional - do not need to turn up against wind.

(Ashwill et al.)



Photovoltaic panels

How can photovoltaic panels be incorporated into aquaculture?

- The simplest option is to place the PV panels directly on the feed barge.
- Nearby island or as floating modules at sea are also possibilities.

However, to get a substantial power production, a relatively large area is needed,
particularly in Norway where the average solar insolation is low, especially in winter.

PV on feeding barge:
A typical feeding barge measures 22x12 metres, making the total area 264 m2, however, due to pathways between panels and silo hatches, an estimated 70% of this can be utilized for PV panels, making 185 m2. A typical 250W PV-panel measures around 1.7 m2 (Solar World, 2016). With a total surface area of 185 m2 a total of 108 of these panels could be fitted on the feed barge, making the total installed capacity 27.2 kW

PV panels on Floating Modules:
PV panels may be employed on floating modules. This would allow for a larger surface area. However the risks that accompany saltwater damages and waves should be evaluated.

Energy Storage Solutions

Both wind and solar are non-dispatchable resources, meaning that they cannot be switched on or off to meet a fluctuating electricity demand. Because of this, storage is needed for load matching, and to take advantage of the energy produced when there is no demand. *(Harack)*

Lead-Acid Batteries:
Lead-Acid batteries have low costs, and have been the main type of batteries used for energy storage

However, they have a lower energy density and a lower efficiency than Lithium-Ion batteries. *(Breen)*

Lead-Acid batteries can generate hydrogen gas, which is highly flammable, hence could have safety issues.

Li-Ion Batteries
Lithium-Ion have a longer lifetime and a higher efficiency because they can accept a lower minimum state of charge.

Due to its popularity in the electric car market, the price has decreased significantly in recent years, and is expected to do so in the future as well.
(Ayre)

Compressed Air Storage:
The largest portion of the energy consumption on a salmon farm is normally the feeding system.

"The feeding system requires energy to run air compressors. The compressed air
is in turn used to blow feed pellets through hoses out to the sea cages, where they are
spread out. Because of this, it could make sense to store the energy as compressed air
that could be used directly to run the feeding system." *(Syse)*

Storage of compressed air could either be in the form of small scale storage in pressure tanks at the feed barge, or larger scale in subsea underground reservoirs.

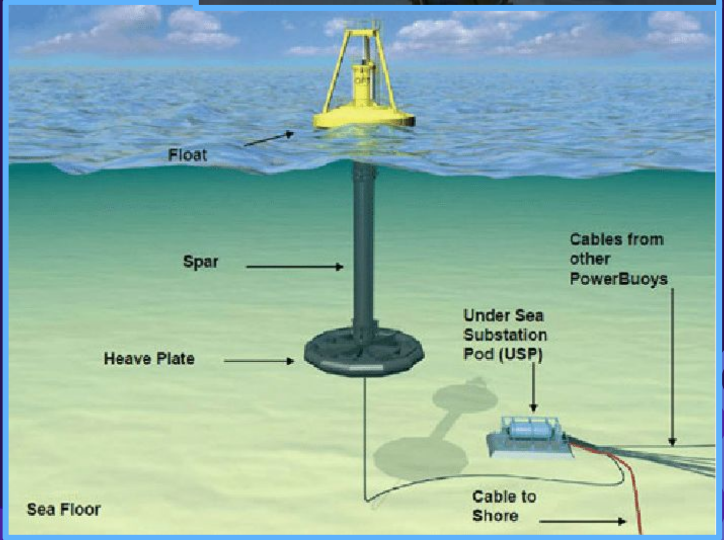
Wave power

- Wave power is the capture of energy of wind made waves to do many things, such as, produce electricity and pump water.
- A machine using wave power is called a wave energy converter (WEC).
- Waves are mainly produced by wind (also by tidal forces, temperature changes among other factors.)
- Norway experiences strong winds and relatively large amounts of waves

  -> Norway has a good environment for wave energy
- Wave energy in aquaculture could be utilised effectively in offshore farming.
- Current technologies include:
  - A point absorber
  - An oscillating wave surge converter
  - An oscillating water column

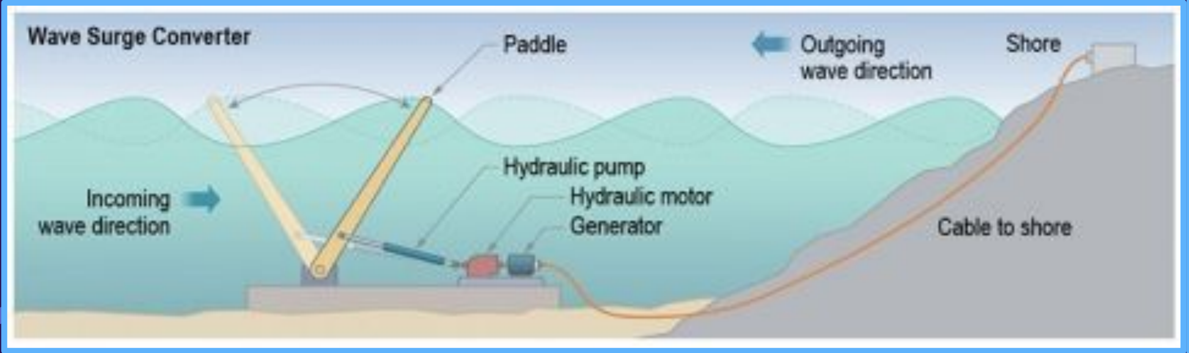
Point absorber

- A point absorber is a floating buoy that absorbs energy through the movement of the waves at the water's surface.
- Can be placed almost anywhere.
- The increasing size of modern aquaculture units is creating opportunities for wave power units to be integrated into offshore structures, especially for an absorber design.
- Example: AWS Waveswing - technology https://www.fishfarmermagazine.com/features/partnership-potential/



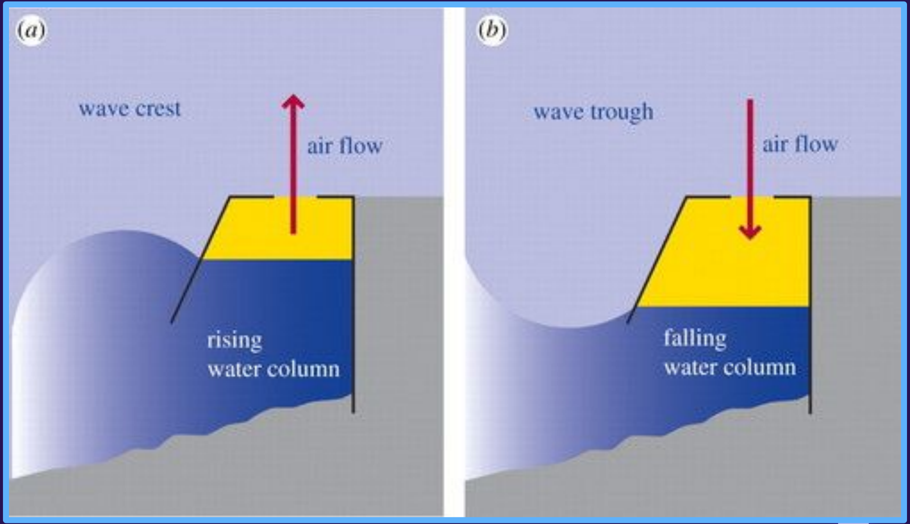
Oscillating wave surge converter

- An oscillating wave surge converter is mounted on the seabed or substructure (other end is free to move) usually in shallower water, and harnesses wave energy with:
  - Floats
  - Flaps
  - Membranes



Oscillating water column

- An oscillating water column (OWC) is a partially submerged, hollow structure which is open to the sea water below the surface and connects to an air turbine above through a chamber. As the waves rise and fall, the air in the chamber is pushed back and forth through the air turbine, generating power.
- Example: Havkraft inks https://www.offshore-energy.biz/havkraft-inks-deal-to-power-fish-farm-using-its-wave-energy-device/



Advantages to using wave power

- Wave power is a form of renewable energy and it replaces the usage of fossil fuels. This also means it is environmentally friendly.
- It does not create any harmful byproducts (such as gas, waste, pollution etc.)
- There are variety of ways to harness wave energy (presented before).
- There is no damage to land created.
- Usually very reliable way of producing energy (depends on the location) so energy production is continuous.
- Waves produce enormous amounts of energy.

https://www.conserve-energy-future.com/advantages_disadvantages_waveenergy.php

Limitations to wave power

- There is an absence of design convergence within the wave energy sector, despite the wide variety of concepts which results in a lower maturity of wave energy converters (WECs) https://www.sciencedirect.com/science/article/pii/S0960148123000095
- The technology can only be placed on top of water so a location without a suitable water body can't utilise wave power.
- Wave energy technology can create hazards for some marine life (distributing the seafloor and creating noise) - these things would have to be worked out before incorporating them into the aquaculture systems.
- Wave energy depends highly on wavelength and some areas have unreliable wave behaviour - the location of the technology would have to be strategic. Also it has weak performance in rough weather conditions.
- Visual pollution may decrease the scenery of the water body. https://www.conserve-energy-future.com/advantages_disadvantages_waveenergy.php

TAILORING FACILITIES

OPTIMIZATION

By tailoring each facility to the site, we can develop the most energy-efficient methods and tools to use

LOCAL

Using locally grown feed, transportation costs can be lowered

MARKET

Close to the market to lower transportation needs

ENVIRONMENT

If environmental conditions are well-monitored, they can be counteracted more efficiently

CENTRAL

Each facility needs to be centrally located

PROCESSING

On-site processing facility to reduce transportation

ARTIFICIAL INTELLIGENCE MONITORING

STAGE 1

Data collection

STAGE 2

Machine learning

STAGE 3

‘Independent’ facilities that run smoothly

AI technologies can be used to collect data on every aspect of each facility, analyze this data and form indicators for future cases.

Aspects to be controlled include water temperature, tank flow-dynamics, feeding time, amount of feed given, waste management, water oxygenation (and other biochemical processes in the water), and light conditions.

Eventually, the central AI will be able to run the facility almost independently, providing suggestions to the person in charge and carrying out the approved operations on its own.

https://www.aquamaof.com/ras-blog-post/recirculating-aquaculture-system/?gad=1&gclid=CjwKCAjwkY2qBhBDEiwAoQXK5WOrVc3OBS-bwK93cIj8LK9lCK_4I_7tVwYF90sAQKVQNTlTRv0kXxoC_PMQAvD_BwE

ENERGY EFFICIENT TECHNOLOGIES

MLD **Minimal Liquid Discharge**	**ENV. CONTROL**	**SCALABLE DESIGN**
• Water treatment • Filtering techniques	• Eliminate use of • Antibiotics • Chemicals	• Adaptation to different • Environments • Requirements • Species
Cuts water consumption	Assures high survival rates, therefore less waste of energy	Fits specific needs with no waste of resources

SYSTEM-WIDE EFFICIENCY

PLANT-BASED FEED

If plant-based feeds were to be used, primary producers, there would be no energy loss between trophic levels, the already overfished marine ecosystems would be protected, and all the feed could come from local producers (again lowering transport)

LOW FCR

Aquatic animals (like fish) have a lower FCR (Feed Conversion Ratio), therefore require a lot less feed per kg of edible mass produced than terrestrial ones, meaning less wasted energy within Earth's food production systems

DISADVANTAGES TO METHODS

COST

Energy-efficiency might come at a higher price: the technologies mentioned earlier can be expensive

RESOURCES

Implementing a fully-automated system would require a lot of resources, which of course will be expensive and inefficient from a resource standpoint

COMPLEXITY

With a complex technological infrastructure, the chances are higher for something to malfunction, and depending on the case it may take a lot of time, money or expert labour to fix it

Energy-efficient technologies

Importance of energy-efficiency

- Sustainability: Energy-efficient practices help reduce the environmental impact of aquaculture, making it more sustainable in the long term.
- Cost Reduction: Improved energy efficiency lowers operational costs, enhancing the financial viability of aquaculture operations.
- Mitigation of Climate Change: Lower energy consumption in aquaculture contributes to the broader effort of mitigating climate change.
- Resource Conservation: Efficient energy use minimizes resource consumption, including fossil fuels and electricity, which is critical for responsible resource management.
- Long-Term Viability: Energy efficiency is integral to ensuring the long-term viability of aquaculture as a reliable and sustainable source of seafood.

Energy-efficient lighting (LED)

Benefits of LED lighting

Energy saving

- LED lights are highly energy-efficient, consuming significantly less electricity compared to traditional lighting technologies.

Longer lifespan

- LED bulbs have a much longer lifespan, reducing the frequency of replacements and maintenance

Reduced heat emissions

LEDs produce minimal heat, creating a more stable and comfortable environment for fish, reducing stress and potential health issues.

Application in Aquaculture

- Illuminating fish tanks
  LED lights are used to provide optimal and uniform illumination in fish tanks, promoting fish health, growth, and behavior observation.

- Reducing electricity costs
  LED’s energy efficiency lowers electricity consumption, contributing to significant cost savings in aquaculture operations.

High-efficiency motors

Significance of high-efficiency motors

Lower energy consumption

- High-efficiency motors use less electricity, resulting in reduced energy costs and improved profitability for aquaculture facilities.

Lower maintenance costs

- These motors experience less wear and tear, reducing maintenance and replacement expenses.

Environmental friendliness

- Reduced energy consumption leads to fewer greenhouse gas emissions, contributing to a more sustainable aquaculture industry.

By employing high-efficiency motors, aquaculture operations can:

- Ensure the efficient circulation and oxygenation of water in fish tanks, creating optimal living conditions for the aquatic species.

- Enhance the performance of feeders and other mechanical systems, resulting in increased productivity and improved overall operation efficiency.

Summary

- Energy-efficient technologies are the cornerstone of a sustainable and economically viable aquaculture industry.

- They reduce operational costs, enhance environmental sustainability, and bolster the long-term health of the sector.
- Energy-efficient technologies offer a multitude of benefits, including substantial cost savings, lower environmental impact, and reduced greenhouse gas emissions.
- They contribute to the economic competitiveness of aquaculture operations while minimizing their ecological footprint.
- To secure a prosperous and sustainable future for aquaculture, it is imperative to embrace and implement these technologies.
  By doing so, the aquaculture industry can thrive, offering high-quality products while simultaneously acting as a responsible steward of our environment.

THANK YOU FOR YOUR ATTENTION!

References

Advantages And Disadvantages Of Waste Heat Recovery Boilers-ZBG Boiler. https://www.zgindustrialboiler.com/news/i/advantages-and-disadvantages-of-waste-hea.html. Accessed 8 Nov. 2023.

Ashwill, Thomas D, et al. A Retrospective of VAWT Technology. 1 Jan. 2012

Badiola, Maddi. “Reusing Heat Energy in RAS.” *RASTECH Magazine*, 16 Aug. 2021, https://www.rastechmagazine.com/reusing-heat-energy-in-ras/. Accessed 8 Nov. 2023.

BIOROCK. “BIOROCK.” *BIOROCK AFRICA (Pty) Ltd*, https://biorock.co.za/blogs/2023/3/how-can-sewage-sludge-be-used-to-produce-energy. Accessed 8 Nov. 2023.

Detail. https://www.sfa.gov.sg/food-for-thought/article/detail/closed-containment-systems-an-answer-to-rising-eco-threats-30-by-30-goa. Accessed 8 Nov. 2023.

Breen, Lewis. Modelling, Optimisation and the Lessons Learned of a Renewable Based Electrical Network -the Isle of Eigg. 23 July 2015, www.esru.strath.ac.uk/Documents/MSc_2015/Breen.pdf. Accessed 2 Nov. 2023.

Harack, Ben. 10 Nov. 2010, www.visionofearth.org/news/how-can-renewables-deliver-dispatchable-power-on-demand/. Accessed 2. Nov. 2023.

Publish Online. https://indd.adobe.com/view/0f9cf744-1480-40f9-8a20-bdb6a46ff0e9. Accessed 8 Nov. 2023.

Syse, Helleik L. Investigating Off-Grid Energy Solutions for the Salmon Farming Industry. 31 Aug. 2016, www.esru.strath.ac.uk/Documents/MSc_2016/Syse.pdf.

“Waste Heat Energy Integration, Storage and Utilization.” *University of Stavanger*, 19 Aug. 2022, https://www.uis.no/en/research/waste-heat-energy-integration-storage-and-utilization. Accessed 8 Nov. 2023.

“Waste Heat: Innovators Turn to an Overlooked Renewable Resource.” *Yale E360*, https://e360.yale.edu/features/waste-heat-innovators-turn-to-an-overlooked-renewable-resource. Accessed 8 Nov. 2023.

Webno. “Biogas from Fish Sludge to Produce 500.000 kWh per Annum.” *Sterner*, 28 Mar. 2019, https://www.sterneras.no/biogas-from-fish-sludge-to-produce-500-000-kwh-per-annum/. Accessed 8 Nov. 2023.

Source: SINTEF Ocean AS: Maroni, Kjell, 39, https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2564532/Konsekvenanalyse%20av%20landbasert%20oppdrett_Postsmolt_Matfisk.pdf?sequence=7, accessed November 2, 2023.