State of Salmon Aquaculture Technologies

2019

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Purpose

There is strong interest from government, industry, non-government organizations and Indigenous peoples to accelerate the adoption of salmon aquaculture technology that minimizes environmental impacts in British Columbia, while supporting rural economic development, employment, and the security of Canada's food supply.

Background

Globally, there are two primary drivers of new salmon production technologies, namely: 1) pressures from governments and stakeholders to adopt more environmentally friendly technologies, and 2) challenges such as sea lice and algal blooms that affect salmon production. The industry has largely focused on improvements to conventional marine netpen systems to improve environmental performance while maintaining operational and financial feasibility, but new alternative production system technologies are advancing to meet these needs.

Indigenous communities

Indigenous communities have a key role to play as they already contribute at least 10% of Canada's aquaculture economic activity and are engaged in every aspect of the salmon farming value chain. They have played a central role in new technology developments including the Kuterra land-based RAS project. Furthermore, the Government of British Columbia adopted a policy in 2018 whereby, starting in 2022, the Province will grant tenures only to fish farm operators who have negotiated agreements with the First Nation(s) in whose territory they propose to operate.

Approach and scope

This report highlights Canadian developments along with a global scan of major technological advancements in four production systems that offer new opportunities for producing market-sized salmon:

- **land-based** recirculating aquaculture systems (RAS),
- **hybrids** involving land and marine based systems,
- **floating** closed-containment systems (CCS), and
- **offshore** open production systems.

Other technologies that support the main production systems are discussed including: sensors and control systems, data analysis for "intelligent farming", feed innovation, transport and logistics, nets and mooring, robotics, and broodstock development.

State of development

The current global status of the four production technologies is described briefly to illustrate key features, current production capabilities, indications of planned and actual commercial scale operations, key requirements for successful deployment of each system, and on-going areas of research that aim to address remaining challenges.

B.C. meeting requirements
There are valuable assets in B.C. that serve as a foundation for developing these technologies including: the well-developed aquaculture industry with transferable expertise, research and training capabilities, fish health and diagnostic capacity, supply chain inputs such as feed sources and distribution of products to markets, as well as the biophysical advantages of coastal B.C. More specific site requirements such as saltwater and freshwater resources, access to low carbon grid-connected power, road and communication networks, waste discharge and processing options are also discussed. Overall, B.C. is well-positioned for existing salmon farmers and new industry entrants to successfully develop these technologies.

Assessment of strengths, weaknesses, and uncertainties
The four production systems are evaluated across seven (7) environmental criteria, three (3) social criteria, and seven (7) economic criteria. These represent key requirements that must be met for salmon production volumes in B.C. to resume historic growth trends. The assessment reflects the broad state of technologies rather than specific designs, and uncertainties are noted as some technologies are yet to be proven commercially and applied in B.C. All four systems offer multiple improvements over today's conventional netpen production systems, however each system offers different advantages and disadvantages in terms of environmental, social, and economic performance. Land-based RAS and hybrid systems are the two technologies ready for commercial development in B.C., while floating closed containment requires 2-5 years of further review, and offshore technologies may require 5 to 10 years of review.

Development path in B.C.
Several things need to be aligned in order to promote innovation in Canada and to position B.C.'s salmon aquaculture sector for growing global seafood export opportunities. In general, national legislation and policy needs to clarify the requirements for aquaculture in terms of environmental and social performance and this will send the appropriate signals for investors to develop the technologies that meet the challenge. There are other requirements specific to each of the four production systems and these are discussed in order to attract and stimulate industry investment.

Incentives to build innovation in Canada
A number of measures are suggested for nurturing innovation based on what has taken place in other countries that are leading technology advancements. Some examples are development licences with reduced fees, marine sites with biomass allocations for innovative technologies, guaranteed loans, accelerated capital depreciation, along with research and development funding models that combine industry, government, and academia contributions.

1. Introduction

1.1 Background

There is strong interest from government, industry, non-government organizations and Indigenous peoples to accelerate the adoption of salmon aquaculture technology that minimizes environmental impacts in British Columbia, while supporting rural economic development, employment, and the security of Canada's food supply.

This interest extends beyond the province and is shared internationally across salmon producing countries. There are two primary drivers of new salmon production technologies, namely: 1) pressures from governments and stakeholders to adopt more environmentally friendly technologies, and 2) challenges such as sea lice and algal blooms that affect salmon production. The industry has largely focused on improvements to conventional marine netpen systems to improve environmental performance while maintaining operational and financial feasibility, but new alternative production system technologies are now advancing rapidly.

As concerns with conventional netpen systems were not fully addressed, expansion of salmon aquaculture slowed in recent years. Since 2000, the average annual growth in production volumes nearly stalled both in B.C. and globally (Figure 1) as limited opportunities for conventional aquaculture expansion were available. Space for marine netpens in some jurisdictions are fully utilized and governments have not increased the number of sites or biomass stocking limits at existing sites (e.g. New Brunswick). In other jurisdictions there have been moratoriums on allocation of new sites even though space is available, while comprehensive reviews were undertaken to establish new approaches for salmon aquaculture development (e.g. Nova Scotia).

While the pace of growth slowed, demand continued to grow. This bears out in rising prices reflecting the tension between demand and supply of farmed salmon products. Since 2000, prices for major markets including Europe, Chile, and North America have all climbed (Figure below).

Two factors continue to apply upward pressure on demand: 1) the stagnation in global fisheries catch, and 2) the rising global population including a growing middle class in many countries. World capture fisheries landings have been flat since the mid-1990s as numerous fisheries reached unsustainable levels (Figure 3). There are no near-term prospects for increasing fisheries catches, however aquaculture production (all products) climbed since the 1990s and farmed fish volume surpassed captured fish volume for the first time in 2014 (FAO, 2018). Additionally, the global population is expected to reach nearly 10 billion by 2050 (2 billion more than today; FAO, 2018) and there will be strong demand for aquaculture products as a valuable source of protein.

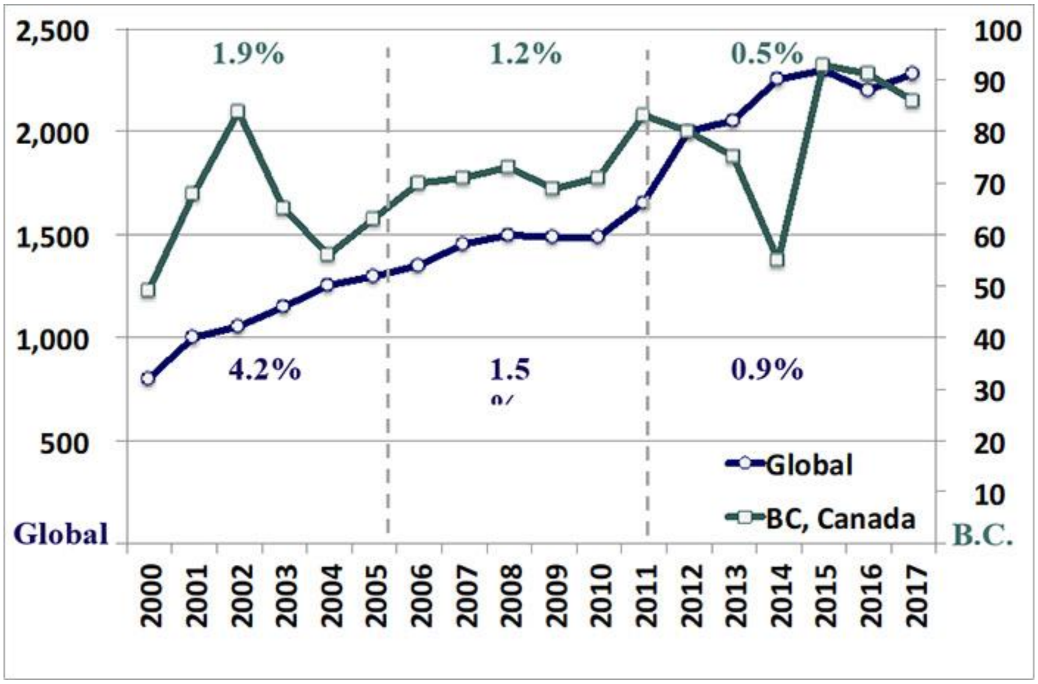

Figure 1: British Columbia and global salmon aquaculture production and growth rates from 2000 - 2017 (000s mt)

Canada's farmed salmon products compete in global commodity markets where prices fluctuate as much as 30% in a year according to supply and demand. Canadian producers must remain competitive and resilient under these market pressures.

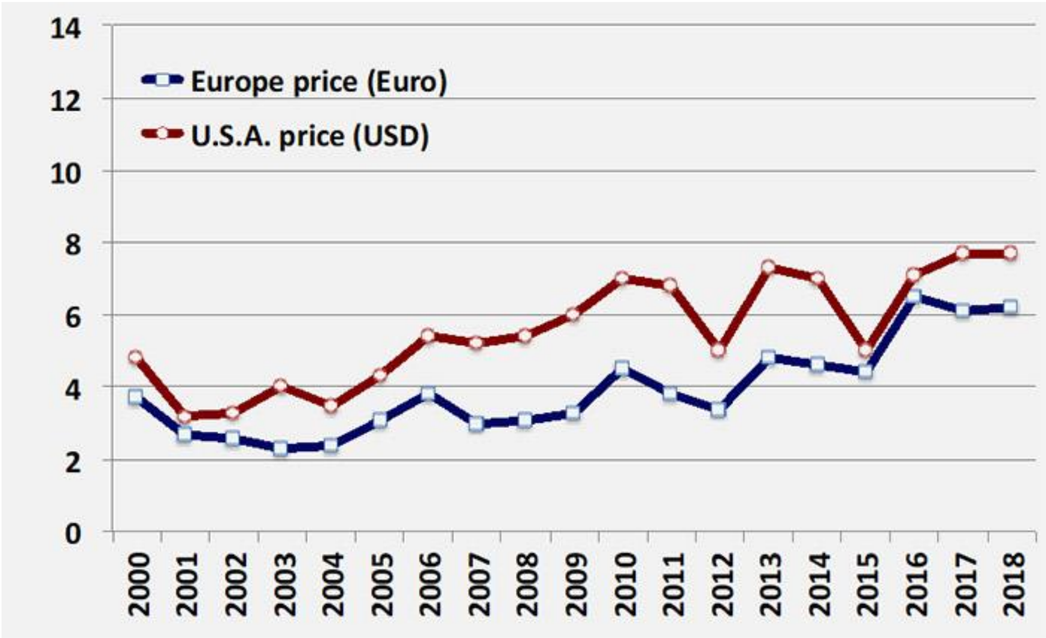

Figure 2: NASDAQ price indices per kg of farmed salmon in Europe and U.S.A., 2000 - 2018

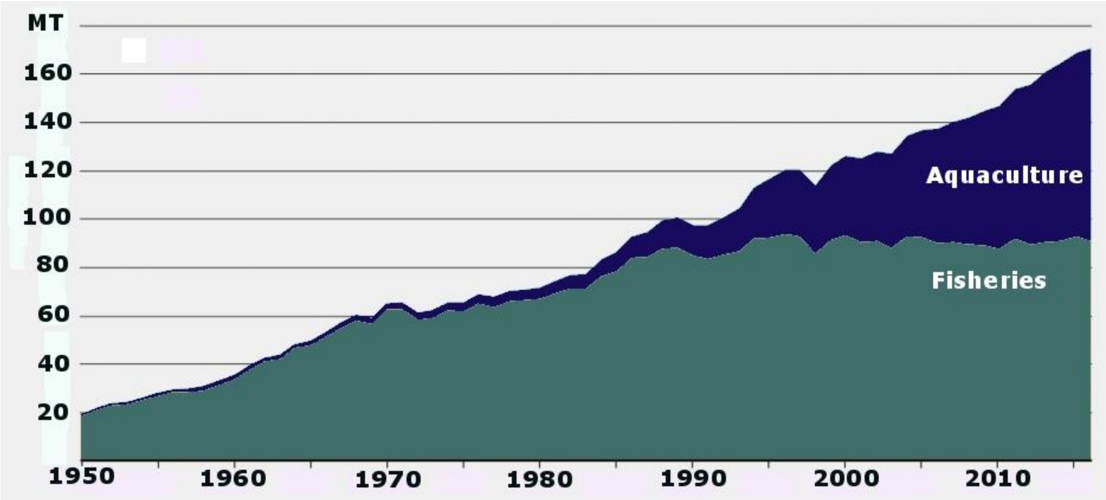

Figure 3: Global commercial fisheries and aquaculture production since 1950. Source: FAO, 2019.

This combination of pressures on salmon producers has spurred efforts to develop new technologies for salmon production that address the key issues noted above. The last ten years have seen major steps towards aquaculture production technologies that significantly reduce interactions between aquaculture and the natural environment. Closed-containment systems are of particular interest where, for example in land based systems, most water is continuously treated and re-used. Ocean-based closed containment (i.e., solid walled cages), and open-ocean (offshore) aquaculture systems are also being extensively researched. The use of these production technologies along with innovations such as sensor technologies and data analytics offer reduced environmental impacts for marine environments.

At this critical point in global salmon aquaculture development an assessment of alternative technologies for salmon aquaculture is necessary to advance sustainable economic growth in Canada. Fisheries and Oceans Canada (DFO) in partnership with the Province of British Columbia and Sustainable Development Technology Canada (SDTC) commissioned this study on the global state of salmon production technology with a focus on British Columbia's (B.C.) operating environment. This will support the aquaculture industry to consider alternative production systems that facilitates expansion of the industry to meet the strong growth and demand for sustainable seafood.

1.2 Indigenous communities

Indigenous communities have a key role to play as new aquaculture technologies develop in British Columbia. Indigenous communities are in an excellent position to participate in aquaculture growth due to their aquatic resources, rights, and access to suitable aquaculture sites. They are already engaged in every aspect of the salmon farming value chain from hatchery, grow-out, processing, and support services to distribution and marketing. They have also played a central role in new technology developments including the Kuterra land-based RAS project. National aquaculture socio-economic impact estimates indicate that about 10% of all economic activity in Canada is the result of Indigenous participation (GP, 2016). This percentage is higher in B.C. than other parts of Canada, and recent developments support further indigenous participation.

The Government of British Columbia adopted a policy in 2018 whereby, starting in 2022, the Province will grant tenures only to fish farm operators who have negotiated agreements with the First Nation(s) in whose territory they propose to operate. Indigenous communities are also highly engaged in aquaculture as investors, operating partners, and through a growing share of the aquaculture workforce. Indigenous communities are keenly interested in developing sustainable aquaculture production technologies.

1.3 Approach

Global scan

Canadian companies and researchers have participated in major technological developments including some of the first commercial land-based recirculating aquaculture systems (RAS), floating closed-containment systems (CCS), offshore production systems, and a range of sensors, remote operated vehicles, software and other system advancements. Most of these have been smaller isolated developments in Canada and they are not scaling up across the industry as rapidly as in other countries.

Major investments in leading systems at commercial scales are emerging in Norway, Denmark, Poland, China, and the U.S.A. among others. There are different reasons for advancement in each country that involve combinations of: the size of their aquaculture industry, size of consumer markets, constraints on marine netpen production, or supports for innovation in environmental, social, and economic performance. This assessment relies on a scan of global leaders to identify technologies that are emerging for commercial application and approaches that will move salmon technology forward.

Document review

As technology has advanced and the level of interest has risen dramatically, a great deal has been written about alternative production systems. Industry reports, government studies, academic research papers, conference proceedings, and popular press articles all provide a rich foundation of information for this assessment. As the developments are evolving rapidly it has also been helpful to obtain some of the latest information from the companies that are either developing these technologies or purchasing them.

Interviews

In order to fully appreciate the information and delve into key issues, including advantages and disadvantages of technologies, it is necessary to speak with many key informants. Private sector, public sector, academic, and non-government organization representatives have all helped to inform this assessment. This is particularly helpful with respect to understanding how technologies that are being developed elsewhere should be considered for applicability in B.C.

Evolving technologies
It must be recognized that while this assessment can only reflect a point in time, aquaculture technologies are developing very rapidly. The relevance of similar assessments completed just five years ago is limited. Much of the information about the performance and capabilities of aquaculture systems quickly becomes outdated. The scale of commercial designs increase, capital costs per unit of salmon produced are dropping. The costs associated with new technologies are also dropping as demand increases and designs are standardized to produce modular "off the shelf" products. There are often annual improvements in the efficiency, reliability, and environmental performance of systems. This trend will continue over the next five years and beyond. This means that decision-making criteria such as environmental performance requirements can remain constant, but flexible, will allow for the ongoing evolution of systems and the arrival of other new technologies.

2. Scope of Assessment

2.1 Production systems considered

In January 2018, the B.C. Minister of Agriculture's Advisory Council on Finfish Aquaculture (MAACFA) Final Report made the following recommendation (5.2):

> *"Conduct a study examining the feasibility of utilizing closed containment technology in B.C. (land-based recirculating aquaculture systems, advanced net-pen systems, near-shore floating containment and off-shore farming systems) as (i) an alternative to ocean-based open net-pens and (ii) an option for expanding the current salmon farming production."*

This report builds on that recommendation, specifically by assessing the following four broad production systems:

- **Land-based recirculating aquaculture systems (RAS)** for market salmon;
- **Hybrid systems** combining land RAS production of post-smolts with marine grow-out to market size;
- **Floating closed-containment systems (CCS)** to produce market salmon; and
- **Offshore systems** involving open or closed containment systems.

There is also discussion of supporting technologies such as sensors, artificial intelligence, remote operated vehicles, and other developments that generally support advancements in all of these main production systems.

In order to consider the advantages and disadvantages that the four production technologies offer, the analysis relies on certain assumptions to make systems comparable.

- **Market size salmon** - All four systems are assumed to produce the same average size of market salmon (about 5kg).
- **Commercial scale production** - All systems must offer production capacity that is typically used by companies today (about 3,000 mt) and by arranging modular arrays and multiple sites the technology could be used to meet most or all of British Columbia's current volume outputs.
- **Steady-state analysis** - The analysis primarily focuses on a future steady state of operations for each technology. This is consistent with a number of the recent international studies on new technologies. In places, the construction and installation impacts are discussed to appreciate key differences between technologies.
- **Biomass limits for existing netpens** - The maximum biomass allowed for hybrid systems using marine netpens at current aquaculture sites is assumed to remain the same, although increases for semi-closed and offshore systems may be allowed based on meeting environmental performance requirements.

Before describing the new technologies in more detail, it is helpful to illustrate what environments they are being designed for (Figure below). Most of the environmental concerns relate to inshore sheltered marine ecosystems where wild salmon migration routes exist, are more concentrated and the opportunity for disease transfer are more pronounced. These inshore waters tend to be more shallow with weaker currents and lower rates of water exchange, so waste and effluent from aquaculture is more likely to build up and cause problems. The other technologies consider other location alternatives including land, inshore exposed sites or offshore sites. It has been easiest and cheapest to start developing aquaculture in sheltered inshore locations, but technology advancements now offer capabilities for operation in the other environments.

The most developed new technologies are designed for land and sheltered inshore environments. These new technologies have been operating at commercial scales for several years and "off the shelf" systems are more readily available. Inshore exposed systems and offshore systems are operating at commercial scales, but these have been deployed more recently and are expected to be refined in the next three to five years.

	Land-Based	Inshore - Sheltered	Inshore - Exposed	Offshore
Products:	Smolts Post-smolts Market salmon	Post-smolts Market salmon	Market salmon	Market salmon
Designs:	Recirc. Aqua. System	Semi-Closed Contained	Semi-Closed Contained	Semi-Closed Contained Open system
Readiness:	Developed	Developed	Developing	Developing

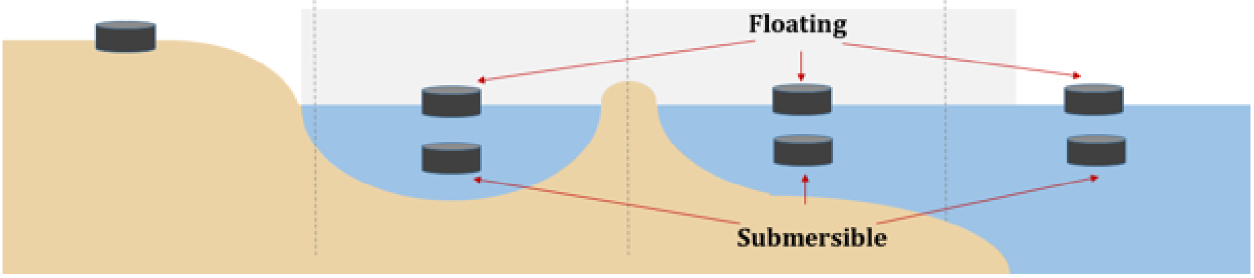

Figure 4: Conceptual diagram of reviewed technologies and their locations.

Currently about 98% of global salmon production comes from open netpen systems in sheltered and exposed in-shore environments (about 94% of B.C. total). The advancements this study focuses on are:

- **Closed containment** – using a barrier added to the containment system to stop transfer of diseases and pathogens, waste effluent, salmon escapes and other wildlife interactions. Water is pumped through the system and may be filtered before supply to the salmon, while waste is removed from outflows for processing on land.
- **Semi-closed containment** – using a barrier that does not remove all waste from system outflows, but reduces diseases such as sea lice.
- **Submersible** – systems may be open or closed with submersible capabilities to help avoid sea lice problems that occur near the surface, and to help access better growing conditions at greater depths (e.g. cooler water in summer). These also avoid storm damage and reduce salmon escapes.
- **Offshore systems** – are mostly open although some re-purposed marine vessels offer full containment that can be moved to offshore locations.

Many of the distinctions between new technologies are related to the grow-out stage of the cycle, and appreciating the implications of this will help to understand the assessment findings later in this report. The following stage sizes and growth periods are based on data from Kuterra research and insights provided by other salmon farming experts:

- **Smolts** are produced in freshwater land-based hatcheries regardless of the technologies that are used to bring salmon to market. Smoltification is when salmon change lifestages from being "parr" in freshwater to "smolts" adapted to saltwater, and this is induced in salmon hatcheries by controlling the amount of light salmon are given each day. This is now commonly done when the salmon reach about 100 to 150g after 8-10 months.
- **Larger smolts and post-smolts** are becoming more common and growers in B.C. are already expanding the use of land-based RAS to grow salmon larger before transferring them to sea. Globally the potential size ranges from 200g to 1kg or more before they are transferred to new technologies for on-growing, or remain in land based RAS to reach market size. Having said this, most of the focus is on larger smolts in the 200g to 500g range, with the aim of keeping the on-growing period to a year or less. The growth from 120g to 1 kg takes about 5-7 months. Since the optimal size for specific technologies and growth plans is still to be determined, there is a wide range of possibilities for this growth stage. This phase is most likely to be carried out in land-based RAS facilities, but may also be carried out by other technologies, especially floating CCS. For this report it is assumed to be carried out in land-based RAS, and grow out to market size is where different technologies are used.
- **Grow-out to market size** will take salmon from between 200g and 1kg to an average size in the range of 5kg to 6kg. The time needed to grow from 1kg to the 5-6kg range is about 9-12 months. The time frame will depend on the target harvest size, and starting at 250g will likely require the full 12 months while starting at 1kg will take closer to 9 months. Being able to keep the grow-out period short will be important for harvest rotations, and flexibility in the timing of transfer to new technologies. Also recognize that the salmon requires greater volumes of high quality water as it grows, and this has implications for the capital and operational costs of different technologies at this stage. For instance, a high proportion of closed containment systems investment is for larger tanks, pumps, and filtration systems needed to meet these grow-out needs, whereas marine systems largely rely on natural water flows and ecosystem services to provide these. In land-based systems the costs are borne by the producer, whereas in open marine systems the "costs" are external to the producer and may be borne by the public or other marine resource users.

2.2 Land-based RAS grow-out

Figure 5: Global Fish location in Poland producing market salmon since 2016

Land-based RAS involves growing salmon in tanks on land in closed buildings to maintain an environment that is highly controlled and secure. The water intake is treated with ultraviolet light or passed through special filters to prevent disease and contamination that could affect fish health. Upwards of 99% of the water is re-circulated on each cycle through the system. Waste material (e.g. faeces and excess feed) is removed from the water (e.g. drum filters), and depending on the contents of the material (e.g. salt) may be suitable for composting, supporting aquaponics (adjacent crop production), or producing energy in connected biodigesters. The water is then passed through bio-filters (bacteria living in sand or plastic media) to convert harmful ammonia generated by the fish into acceptable nitrate form. Aeration is used to drive out carbon dioxide generated by the fish, and oxygen is added to the water before re-circulation. Land-based recirculating aquaculture systems (RAS) have been used for decades in the production of salmon smolts (e.g. 75-100g). RAS designs have been used for an even longer period for producing a wide variety of other fish species. In the last five to ten years these systems have advanced to successfully produce market-size salmon (e.g. 4-6kg).

Some systems have produced up to 1,000 mt of salmon annually, but systems being constructed now tend to be 3,000 mt or more to achieve better financial returns. High capital costs have led to larger facilities being built to gain efficiencies of scale. The larger facilities employ modular designs to reduce risks associated with component failures or contamination events. The list in the table below is only a small selection of land-based RAS developments since there are now over 50 operating, under-construction, or approved, although not designed for market-size Atlantic salmon production.

Table 1: Examples of land-based RAS market salmon system capacities and developments as of 2019

Status	Company	Location	Capacity (mt)
7 years prod	Shandong Oriental	China	2,000
6 years prod	Danish Salmon	Demark	2,000
6 years prod	Atlantic Sapphire	Denmark	700
3 years prod	Global Fish/Pure Salmon	Poland	600+
4 years prod	Kuterra	Canada	370
4 years prod	Sustainable Blue	Canada	500
Construction	Atlantic Sapphire	USA	30,000+
Construction	Whole Oceans	USA	50,000
Construction	Nordic Aquafarms	USA	33,000+

Sources: UnderCurrentNews, 2019; FishFarmingExpert, 2019; company websites.

The initial proposed scale for the Atlantic Sapphire facility in Miami, Florida was 30,000 mt with a phased approach to reach 90,000 mt. The plan for 2030 was just increased to 220,000 mt in an announcement May 8, 2019. This level of production would supply more than half of the current salmon market in the U.S. The projected scale is still highly speculative since the site has not completed a production cycle at this time. Some operators have revised their capacity expectations (e.g. Danish Salmon) as they have not been able to reach initial estimates.

System requirements:

- **Coastal resources** - The versatility of land based RAS systems are facilitating salmon production in other countries with warmer climates including desert conditions (Evans, 2019). Still the need for freshwater and saltwater at temperatures suitable for salmon (e.g. 14 Deg C) means that coastal areas like those found in B.C. are ideal. A couple years may be needed to find the right combination of saltwater, well water, injection wells, transport networks, affordable land, power requirements, and local waste handling requirements. This time frame for siting has been the experience where land-based RAS has been planned and built elsewhere.
- **Low-carbon power** - The high rate of water pumping means that grid connected three-phase power is required, so remote sites where some marine netpen operations currently operate would not work. Electricity should be from a low-carbon source such as B.C. Hydro (about 90% hydroelectricity) given global commitments to reduce greenhouse gas emissions and expected increasing costs of fossil-fuel based power with carbon pricing.
- **Supply-chain** – This involves proximity to feed mills, fish health scientists, fish processors, equipment supply and maintenance companies, and distribution to consumer markets including excellent connections by road and air. When proximity to consumer markets is cited as an advantage of land based RAS in the U.S., it is usually referring to transport costs from Europe, whereas B.C. products reach the U.S. west coast markets and others quickly and economically.

- **Trained workforce** – Producers will need trained workers, and there is currently a shortage globally. Closely tied to this is the need for training programs through universities and colleges in coordination with working land based RAS facilities to provide hands-on experience.
  – (Hobson, 2018; G. Robinson pers. comm., 2019)

Remaining challenges:

- **Fish quality** – Managing the system to avoid off-flavours is an on-going key topic for RAS producers.
- **Fish health** – Microbes and bacteria in particular bacteria are being studied in closed system components, salmon tissues, and under certain growing conditions. Other issues include microparasites and water compounds such as sulfides that can reach toxic levels. Control measures including water intake and recirculation filters, construction materials, anti-fouling agents, ozone treatment, and fish waste management are all important areas of research.
- **Broodstock development** – This will focus on gender advantages, triploidy, late maturation, tolerance to high stocking density and low oxygen.
- **Large tank design** – There is ongoing research to optimize water velocities, placement and design of nozzles, and other measures to achieve proper distribution of oxygenated water and collection of waste in larger tanks of different shapes. This is critical to scaling up facilities.
- **Energy efficiency** – Improvements in water pumping, filtration, lighting, heating and cooling, and other system components and functions will continue to gain efficiencies while maximizing fish welfare and performance.
- **Feed formulations** – New developments aim to meet sustainability criteria with alternatives to fish meal/oil ingredients that are suited to land based RAS needs including efficient waste collection. For these systems this must not hinder biofilter function or off-flavours.
- **Stocking densities** – This affects water flows in tanks, fish health and welfare, revenues, loads on recirculation system components.
- **Design and construction efficiency** – Given the high impact of capital costs on the viability of these systems, there will be continued efforts to find more cost-effective designs and construction techniques.
- **Financial risks** – The projected addition of global salmon production due to land based RAS and other technologies is expected to bring prices down as the tension between supply and demand is alleviated (Gibson, 2019). Depending on the severity of price drops, land based RAS profitability may be affected. This market risk, coupled with production risks, will drive efforts to reduce land based RAS costs and build a stable track record to satisfy investors and insurance companies.
  - (Summerfelt, 2018; Føre et al, 2018; CtrlAqua, 2018; Aspmark, 2018).

2.3 Hybrid systems with land-based and marine sites

Figure 6: Marine Harvest Canada facility, Dalrymple, B.C.

Land-based RAS technologies are being developed for use in combination with marine grow-out sites (i.e. hybrid approach). The hybrid approach involves producing post-smolts weighing from 250g to 1kg. The land-based portion provides better growing conditions and reduces early growth phase risks at sea. The shortened grow-out period reduces some environmental risks at marine sites and avoids the most costly portion of land-based systems in the grow-out phase. The grow-out stage in land-based RAS systems requires substantially more capacity that increases capital and operating costs. Current hybrid technology development is focused on finding the appropriate size of post-smolts for transfer to sea as a number of factors are considered in order to optimize the use of the land and marine production systems. Regardless, the aim is to have salmon in the marine environment for at most one year instead of the typical two years for full marine production. Grow-out could involve floating closed-containment in near-shore environments or offshore production technologies, but the near-term focus is on utilizing netpen technologies at nearshore marine sites. Some examples of netpen technology innovations that help address environmental issues include: automated feeding systems integrated with sensors and machine learning to reduce waste, replacement of antifouling chemicals by high pressure seawater cleaning of netpens, improved materials for nets to avoid escapes and increase water flow through the system, and use of underwater remote operated vehicles (ROV) and robots for a variety of tasks. Sea-lice are a particular focus with developments involving: sea lice vaccines, anti-sea lice skirts, “snorkel” nets that keep salmon below sea-lice in the water column while allowing salmon to reach the surface for air-intake, sea lice detection and monitoring of individual fish, cleaner fish, wellboats coupled with CleanTreat technologies that cleanse the water effluent after treatments, as well as ultrasound and resonator treatments (BCSFA, 2018). The table below is a small selection of global hybrid technology developments.

Table 2: Examples of hybrid land and marine system developments as of 2019

Salmon size	Company	Location	Capacity (mt)
150g+	Grieg	Adamselv, Norway	1,600
250g	Norway Royal Salmon	Hasvik, Norway	2,000
500g	Bakkafrost	Faroe Islands	7,000
650g	Mowi	Faroe Islands	1,000
500g	Leroy Seafood Group	Hordaland, Norway	4,000
700g	Salmones Magallanes	Chile	Expansion
150g	Mowi	B.C., Canada	1,000
300g	Cooke Aquaculture	NB, Canada	Planned

Sources: UnderCurrentNews, 2019; HatcheryInternational, 2019; company websites.

System requirements:

- **Land-based requirements –** This portion of the production cycle in hybrid systems has some requirements equivalent to those already discussed for land-based systems. Keep in mind production of post-smolts generally requires saltwater but not in the Faroe Islands, for example, so water intake and discharge requirements may lead to different facility locations (adjacent to the sea rather than inland) compared to some land-based RAS hatcheries that are using freshwater only. Locating adjacent to the sea and near grow-out sites will also be needed for optimal transfer of salmon.
- **Transfer to marine sites –** This will be similar to conventional transfers today, however stress of fish at larger sizes is being studied to optimize procedures. New larger vessels (not only for transfers) are being designed to service marine sites and coastal infrastructure must be developed to support these.
- **Marine requirements – H**ybrid post-smolt system requirements are similar to existing netpen requirements. Depending on the regulatory limits for biomass by site and/or bay area, availability of sufficient sites to rotate stocking of larger post-smolts will require new production planning, and this can be accommodated in B.C.

Research challenges:

Research challenges identified in the previous land-based RAS are applicable for the hybrid system, although less pronounced since the hybrid approach does not need to bring salmon to market size on land. Land-based RAS hatcheries are already very experienced in producing smolts of about 150g for marine net-pen grow-out today, so hybrid systems need to extend this in the range of 200g to 500g or more and successfully transfer these to sea. Grieg Seafood in Norway put 400g smolts to sea in 2018 and harvested 6kg average salmon after 11 months (F. Mathisen pers. comm., 2019). Some of the specific hybrid system challenges are as follows:

- **Transfers –** The transfer of fish from land to marine sites can cause stress to fish and research is focused on determining the best conditions (e.g. temperature, salinity, feeding, fish size, and genetics) as well as new handling systems for low-stress transfers.

- **Sea lice –** The use of marine netpens for grow-out will continue to require methods for addressing sea lice, although the sealice presence and outbreak risks are greatly reduced with larger post-smolts spending less time in the marine environment. Addressing sea lice is not only a requirement for operation of marine sites, but it helps avoid reduced harvest sizes and revenues. The cost of sea lice management may continue to climb as resistance, fish welfare, and treatment effects on the environment drive investigation of more expensive alternatives. The use of skirts (additional barriers outside netpens) and other measures will continue to evolve for better protection against sea lice and wildlife interactions.
- **Algal blooms –** (Heterosigma algae) may persist as a problem for open netpens. Although insurance can cover some loses, this ultimately comes at a cost to operators. Oxygenation and aeration diffusers for structured upwelling (also to prevent sea lice) are promising to be effective for algal blooms.
- **Other environmental impacts –** Wildlife interactions, escapes, waste effluent, and other environmental issues associated with marine netpen sites will continue to be a focus of research efforts.
  - (Aspmark, 2018; Bjorndal and Tusvik, 2017)

2.4 Floating closed-containment systems (CCS)


Figure 7: Aquafarm Equipment Neptune 3 system.

Floating closed-containment systems (CCS) offer some advantages of closed systems while retaining some benefits of growing in a marine environment. There are design variations with solid or flexible wall construction, and mechanisms for collection of waste materials. The main advantages of this system include collection of most feed and faeces waste, cost-effective use of surrounding waters, and barriers to: diseases, parasites, wildlife interactions, and escapes. The growth and survival of salmon using floating CCS has been superior to open netpen systems, and there have been no sea lice issues. These are more suitable to sheltered sites in lower energy environments, but some are capable of operating in more exposed locations. Most systems are fixed, but mobile versions using new or retrofitted marine vessels also meet floating containment criteria. All systems involve pumping water from sufficient depths (e.g. 12m or deeper) to address sea lice, algae, temperature regulation and other requirements. In most operational systems, the smolts from land-based systems are transferred to the floating CCS system for post-smolt production (1-2kg), then grow-out to market-size occurs in open systems. However, some are now being used to grow salmon to full market size (e.g. Neptune system). Cermaq plans to bring a system into B.C. operations this year to produce 2kg post-smolts in a flexible wall system. The Hauge Aqua designed "egg" technology, purchased by Marine Harvest and granted development licences in Norway, may be stocked this year. It offers a surface cover for complete enclosure, water filtration system, water intake from depth to avoid sea lice, waste collection system, and a unique feeding system that improves food conversion.

The capacity of most systems ranges from about 225 to 1,000 mt per tank and these can be combined in arrays to produce larger volumes. The concepts involving rebuilt ships currently produce about 300 mt, but are poised to become much larger and may eventually exceed 4,500 mt. The assessment (later in this report) will focus on using these for market grow-out, but these are likely to be integrated with existing open netpen arrays as an intermediate step (i.e. post-smolt growth).

Table 3: Examples of floating CCS system capacities and developments as of 2019

Status	Company	Location	Capacity (mt)
5 years prod (PS)	Aquafarm Equipment	Norway	1,000+ per tank
7 years prod (MS)	AkvaFuture	Norway	1,000+ per tank
7 years prod (MS)	AgriMarine*	Canada	1,000+ per tank
4 years prod (PS)	Preline	Norway	300 per vessel
Testing (MS)	Hauge Aqua	Norway	1,000 per egg
Testing (MS)	Botngaard System	Norway	400
Testing (MS)	Seafarm Systems	Norway	1,000

*Sources: UnderCurrentNews, 2019; FishFarmingExpert, 2019; company websites. PS=Post-smolt production, MS=Market-size production * Steelhead salmon grown in a low energy freshwater site.*

System requirements:

- **Coastal resources -** These must be located in sheltered coastal areas with access to suitable saltwater environments (e.g. temperature, currents, water quality). There is somewhat greater flexibility in sites compared to open netpens since warmer locations can be accommodated by pumping cool water from below the tank and sites prone to algal blooms may still be acceptable. Some land may be needed for processing waste materials.
- **Power source – G**rid-connected three-phase power is needed, so remote sites where marine netpen operations currently run on diesel would not meet requirements. Electricity should be from a low-carbon source given global commitments to reduce greenhouse gas emissions.
- **Supply-chain and access -** Connection to feed (inputs) and consumer market (outputs) requires excellent connection by road and/or air.

Remaining challenges:

- **Waste disposal** – Technologies for separating waste from water outflows will continue to improve. Research will seek to increase the amount of solids captured, minimize the amount of dissolved nutrients (e.g. nitrogen and phosphorus), and develop ways of processing and utilizing the waste materials on land.
- **Water flow and tank size** – There is ongoing research to optimize pumping of water through tanks of different shapes and larger sizes. Current floating CCS tank designs tend to be smaller than industry would like for commercial operation so this challenge must be addressed.
- **Structural design** – Materials used to build floating CCS tanks will be explored for rigid and flexible options. The shape and size of tanks as well as walkways, platforms, and other functional components will develop.
- **Market-sized salmon** – There is more floating CCS experience with post-smolt production and market-size for other species, and efforts now focus on refining approaches for market-sized Atlantic salmon production. - (Føre et al, 2018).

2.5 Offshore systems

Offshore systems were tested in Canada in the late 1990s with the launch of Ocean Spar cages in New Brunswick and Norwegian designs deployed in B.C. (Ryan, 2004). Early designs did not sustain commercial production and many improvements have been made globally since. Producers in the Faroe Islands have been leaders in contending with harsh marine conditions, and Ireland producers moved further from the coast in response to strong local opposition to near-shore developments. In the last two years most attention has focused on Norway and China where innovation has rapidly accelerated in response to supportive policies.

There are diverse concepts for offshore salmon aquaculture that each have merits for meeting certain offshore applications. The variety of designs include open and semi-closed systems, floating and submersible options, as well as fixed and mobile systems. Although definitions of offshore environments are somewhat fluid, all designs are meant to operate in minimum water depths of 20 metres and minimum wave heights of 1 metre. In the B.C. context much deeper waters (100-200m) and higher waves (at least over 3m and often over 6m) will be common and systems must operate through extreme events. The design of the structure that contains salmon is central, but equally critical is the design and logistics for servicing the more remote sites. Some designs include living arrangements for staff, while others rely on full automation so that workers are not required for day-to-day operations. Transportation to and from the site and land-side infrastructure are important as the challenges are greater for offshore production.

Figure 8: Topleft SalMars Ocean Farm 1, top right MNH Aquatraz, middle Marine Harvest Egg, bottom left Nordlaks Havfarm 1, bottom right NRS/Aker ASA Arctic Farm (Source: Norwegian Fisheries Directorate, 2019).

The SalMars Ocean Farm 1 holds about 6,500 mt and may be doubled in size. Ocean Farm 1, is mid-way through its year-long trial period, and is reporting good growth rates and low mortality (FAO, 2019). The Nordlaks Havfarm 1 is likely to be the world's longest vessel at 430 metres and capacity for 10,000 mt of salmon. Ramsden (2019) reported that MOWI's application for development licences in Norway was approved for its offshore "Blue Revolution Centre" research station and two offshore production technology designs – the "egg" and the "donut" concepts. Today's designs differ greatly and after a few years of operational experience companies will settle on preferred options. Once that occurs many more could be built with the view that salmon aquaculture industry growth will capitalize on the abundance of space available.

Table 4: Examples of offshore system capacities and developments as of 2019

Status	Company	Location	Capacity (mt)
2 years oper	SalMar owned	Norway	6,500
1 year oper	Rizhao Wanzefeng Fisheries	China	1,000
<1 year oper	Midt-Norsk Havbruk owned	Norway	1,000
2019 start	De Maas design	China	3,750
2020 start	Norway Royal Salmon owned	Norway	3,000
2020 start	Nordlaks owned	Norway	10,000

Sources: UnderCurrentNews, 2019; FishFarmingExpert, 2019; company websites.

System requirements:

- **Offshore locations** – These must be free of conflicts with other marine users including marine transport, protected areas, fisheries, oil and gas, and other resource extraction developments. In many countries these can represent constraints, but coastal B.C. offers many options.
- **Water quality** – This requires suitable temperature profile and currents, while remaining free of contaminants and fish health threats.
- **Transport access** – Ideal sites are within 25 nautical miles with reliable year-round navigation between on-shore and off-shore infrastructure. Floating ice and major storms (e.g. hurricanes and typhoons) can be limitations in parts of some countries, but extensive areas off the B.C. coast are suitable.
- **Proximity** – Minimizing transport for supply-chain inputs (i.e. feed mills and aquaculture goods and services suppliers) and outputs (ie. processing and distribution to markets) is important.
  - (CEA, 2018)

Remaining challenges:

- **Autonomous systems** – This system must incorporate technologies to become less dependent on labour for feeding, monitoring, mortality collection, net cleaning and repair among other regular functions. Guidance, navigation, and control of remote operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) are the subjects of intense research for offshore aquaculture.
- **Remote power** – Research is focused on production systems that integrate solar, wind, wave or water current energy to power pumps, sensor, robotics, and submersible functions are needed to run autonomous offshore systems.
- **Monitoring and decision-support** – to maintain structure integrity and fish heath in the face of challenging conditions including storms. These must be robust and capable of assessing whole farm conditions to drive scheduling and performance of key operations.
- **Structure design** – Efforts are focused on flexible and rigid components that provide functionality and security at remote locations. This also involves alternate shapes that are less vulnerable to offshore conditions, and technologies that allow submersible systems to avoid storms and still meet fish health and performance requirements.
- **Vessel design** – Well-boats that carry live fish, feed supply vessels, and service boats for fish treatments and structure maintenance are all being purpose-built. These must meet more rigorous standards for safety and functionality to handle the wider range of environmental conditions while maintaining safety of structures and personnel. Research is examining the size and shape of vessels, connections (e.g. cranes, hoses, platforms) with offshore aquaculture structures, and dynamic positioning capabilities for vessels to hold their position relative to the structures. Some of this technology is adapted from marine transport, oil and gas, and other marine applications.

- **Safety** – must be met according to occupational health and safety laws, which are not necessarily developed for offshore aquaculture. For instance, the Atlantic Offshore Health and Safety Regulations are developed under the Canada Labour Code with a focus on oil and gas activities. These specify requirements for training and education of personnel, certification of systems and equipment, risk assessment plans, monitoring and controls, record-keeping, passenger transit, fall protection, diving safety, and other requirements must be devised for offshore aquaculture.
- **Fish health** – key factors in offshore environments must be better understood. Stocking, feeding, treatment of diseases and parasites must be designed for this environment involving stronger currents and larger waves.
- **Wildlife interactions** – Unlike near-shore environments where most aquaculture production experience exists today, the offshore environment has different marine mammals and predators and there is a need to understand how they will interact with these systems, especially as they become larger and more numerous.
- **Regulatory uncertainty** – Pilot testing will help regulators to understand and monitor these systems then develop appropriate regulatory frameworks. Key questions involve site ownership, who will grant approvals, the application process and requirements to be met.
  - (Exposed, 2018; Bjelland et al., 2015, Fard and Tedeschi, 2018; NRCan, 2018; Holmen et al., 2017)

2.6 Supportive technologies

There are a wide range of technologies with cross-cutting benefits for all four alternative production systems. These technologies are not formally assessed according to environmental, social, and economic criteria, but they are expected to improve performance across the board. Some of the most promising recent developments are described briefly in turn below and a few Canadian opportunities are highlighted.

Sensors and control systems – Traditional data collection from monitoring and diagnostics is all being digitalized and analyzed in real-time for timely management decisions. Temperature measures, carbon dioxide and dissolved oxygen readings, video recordings, signs of disease, stress indicators, and many other important data feedbacks from the growing environment are captured from growing sites and monitored at data centres. This allows quick recognition of issues and faster response times. "Big data" can also be used to determine trends, identify drivers of performance, support decision-making, and link biological measures with economic performance. Sensors, feed systems, and computers are being linked by wireless networks building the Internet of Things for aquaculture production. Some data is already available on mobile devices so managers can monitor from anywhere. Software to integrate systems and employ artificial intelligence is leading to automatic decision-making by advanced production systems. Many companies are contributing elements and some are developing packaged integrated solutions.

"Intelligent" farming – Sensors and data analysis are being combined to deliver individualized farming for fish. This can lead to precise feeding and treatments for each fish based on fish health and a suite of measurements. BioSort and Cermaq have combined efforts to develop iFarm that uses recognition of spot patterns and other morphological features to identify individual fish and track their health. For example, instead of treating all fish for sea lice, only the individuals that meet thresholds will be treated. This type of technology avoids over- and under-feeding each fish, and individual fish can be selected for harvest based on size and availability.

Feed innovation – Feed suppliers must continually develop products that meet the changing needs of new production systems. Feed formulations are designed for certain health benefits to address diseases, diets for extreme environmental conditions, and to include novel ingredients such as immunostimulants, antioxidants, or metabolic stimulants. Feeds are developed for increased efficiency (i.e. feed conversion), better quality control, and more sustainable supply chains. Canada's largest feed suppliers including Skretting (offices in Saint Andrew's, NB and Vancouver, B.C.), and Corey Aquafeeds (Fredericton, NB), remain at the forefront of feed research and they supply feed to clients all over the world.

Transport and logistics – Marine vessels and containers are increasingly specialized for new production systems. Advanced positioning systems and cranes are being developed in parallel with the needs of new vessels. Work-boats and well-boats are equipped with fish handling and treatment capabilities, and harvest ships are being developed with on-board processing so salmon are ready for market by the time they return to shore. Other vessels are being specially designed for exposed and offshore locations including the Arctic. The international firm AKVA group (satellite office in St. George, New Brunswick) is delivering a barge to Arctic Offshore Farming (Norway Royal Salmon) to use above the Polar Circle. It can operate in 7.5 metre waves and has 800 tonnes of feed capacity for supplying submersible production systems. Canada has a number of ship and boat building companies that have extensive experience customizing designs for specialized applications.

Nets and mooring – As production systems move to exposed and offshore environments there is a need for innovation in containment materials (e.g. steel, HPDE, Dynema, AquaGrid and other nets). These offer strength, rigidity, reduced risk of escapes, reduced antifouling and maintenance, and suitability for integrating monitoring systems. Mooring equipment may come in flexible and rigid forms and it is critical to reduce risks associated with metal fatigue and corrosion, as well as component failure that could lead to potential system failure. Companies are developing products made of lighter-weight materials, with increased lifespans, faster installation, and certification to international standards. Based in Campbell River, B.C., Poseidon OceanSystems is a supplier of these products and spends close to half of staff time on research and development, resulting in over a dozen product innovations and four (4) patents in recent years.

Robotics – Semi – to fully automatic robots as well as remote operated vehicles (ROVs) now perform a number of previously difficult and costly tasks. Inspection of nets and moorings for damage has traditionally been done by divers, but dive time and safety precautions make this a challenge. Cleaning and repair of nets and other components can be done by robots, along with sample collection and analysis from sediments below nets or inside containment structures.

Specialized broodstock – It is becoming more important to develop salmon with certain high performance characteristics for new systems. Key characteristics include gender, late maturation, tolerance to less oxygen, survival in high energy environments (e.g. offshore), among others. Canadian salmon producers, universities, Genome Canada (B.C. and Atlantic centres), and private research firms are engaged in these developments.

3. Sustainable Aquaculture Technology Criteria

3.1 Technology assessment

Innovation in aquaculture aims to improve upon the performance of current production systems and ultimately the success of farm operators. Innovations may improve private and public outcomes of salmon farming operations. Improvements in private outcomes include better designs that lead to lower capital or operating costs, and improvements that gain more revenue through higher quantity and quality of products. Improvements in public outcomes may result from system designs that reduce waste released to the environment, avoid impacts to other wild organisms, minimize energy usage and greenhouse gas emissions, and provide more social and economic benefits to society.

Each of the four production systems that are profiled in this report are assessed according to a suite of criteria grouped into environmental, social, and economic themes. The criteria are considered important to assess since these relate to the primary issues associated with salmon aquaculture production to date. There is no order of importance to the criteria, none is assigned more weight than another, and these are all considered priorities for new technologies to address. After the criteria are briefly described below, the strengths and weakness of the four production systems will be assessed in terms of these criteria.

The assessment is forward looking since these are relatively new production systems that have yet to be widely adopted. As for all outlooks on new technologies there is some uncertainty regarding their performance at large scales and over the long-term. Aspects of the four production technologies that are subject to greater uncertainty and risk will be noted. It must be recognized that there are numerous designs and aquaculture sites for each of the four production systems and these will all have somewhat different performance capabilities, so the assessment is broadly indicative of the expected performance of each production system. Finally, innovation is moving quickly on all four production technologies and this assessment only represents a point in time and this should be reviewed as substantial advancements occur.

3.2 Environmental criteria

There are several key environmental criteria that new technologies aim to meet. The following briefly explains the essence of each criterion so that the benefits of different system capabilities are clear. The first five environmental criteria relate to outputs of salmon production and the last three relate to inputs.

- **Marine escapes** – New technologies must avoid salmon escapes from production systems, including escapes during salmon transfer and transport activities. Escaped salmon potentially affect wild salmon populations by competing for food and habitat, and by impacting wild populations through interbreeding.
- **Salmon diseases** – Transfer of diseases and pathogens between farmed salmon and wild populations must be avoided. Sea lice is currently the main issue although others are a concern (e.g. piscine reovirus, amoebic gill disease), while potentially resistant and new diseases in the future are also important to avoid.
- **Waste effluent** – Ecosystem effects of salmon faeces and feed falling to the seafloor must be avoided. These waste deposits cause oxygen depletion in the water as it breaks down and this can both suppress desirable marine organisms and promote undesirable ones (e.g algal blooms). Some commercial fisheries are concerned that effluents can affect the habitat, survival, and productivity of fishery stocks. In land-based RAS systems any saltwater discharge must be be done carefully to protect freshwater and marine resources.
- **Chemical release** – Release of harmful chemicals and substances into the marine environment must be avoided. The concerns include anti-fouling agents used to keep cages clean, chemicals used in the treatment of diseases, and feed ingredients. As these disperse in the environment, they can negatively affect other organisms.
- **Wildlife interactions** – Interactions with marine predators (e.g. seals and sea lions seeking salmon for food) as well as seabirds must be avoided. Wildlife can affect the farm structures and even the farmed salmon, or they may be killed by operators following protocols to protect their farm structures and stocks.
- **Water usage** – Unsustainable use of water must be avoided. The withdrawal or return of wastewater to sensitive sources, especially involving limited freshwater supplies such as aquifers, can deplete valuable water resources over time.
- **Energy usage** – High energy intensity must be avoided, especially from carbon-based and non-renewable sources. Renewable energy sources and grid connected electricity from B.C. Hydro (90% hydroelectricity) are best. Atlantic salmon aquaculture requires energy for system construction, operation, and transport of products to and from the site. As efforts to combat climate change accelerate, the energy types and quantities used will be increasingly important considerations. Life-cycle analysis results capturing all aspects of construction, operation, and delivery to market (i.e. egg to plate) are the best basis for comparing production technologies.

3.3 Social criteria

Long-standing tensions between salmon aquaculture producers and other interested groups are essential to resolve. Meeting environmental and economic criteria is part of resolving conflicts, but social criteria extend beyond this. Focusing on local, global, and consumer perspectives, the assessment highlights how the use of new technologies can help build support and trust in salmon aquaculture production.

- **Local support** – Local people in B.C. concerned about salmon aquaculture include: Indigenous people, other residents near production sites (permanent or seasonal), commercial fishers, recreational fishers, tourism operators, aquaculture employees, and local businesses that benefit from economic development. Local support will generally grow for new technologies that are *trusted* to deliver the benefits of aquaculture while minimizing the negative impacts. Understanding, engagement, partnership, and transparency in use of new technologies will enhance trust.
- **Global support** – Environmental non-government organisations (ENGOs) may have a local presence, but are often working more broadly to improve aquaculture operations nationally and internationally. Closely tied to this are third-party sustainable certifications for aquaculture products such as the: Aquaculture Stewardship Council farmed salmon certification, Global Aquaculture Alliance best aquaculture practices program, Monterey Bay Aquarium Seafood Watch program, and the Canadian General Standards Board organic aquaculture standard. These certifications help the other social objectives (i.e. local support and consumer support), as the support of ENGOs can also.
- **Consumer support** – B.C. producers ship to over 70 countries, however principal markets are in the U.S. and Canada. Many consumers are price sensitive and not necessarily aware of conventional salmon production issues. Eco-labelling can alert retailers and consumers to choices available, but these have had mixed results (Roheim et al., 2011; Rudd et al., 2011; Hallstein and Villas-Boas, 2013). As production grows using alternative technologies it may be important for access to certain markets including retailers, food service chains, or countries. Consumer perspectives will also evolve as more production from alternative technologies comes online and these products are no longer limited.

3.4 Economic criteria

New aquaculture technologies will change the economics of salmon production and this has implications for both aquaculture participants and the general public. Aquaculture participants including private companies, indigenous communities, lending institutions, insurance companies, and government will be concerned with financial performance. Local and regional communities, all three levels of government, and the general public will be more concerned with broader economic impacts beyond the interests of aquaculture participants.

- **Profitability –** New technologies must be profitable or they will not be (widely) adopted. Profitability is signaled by investor support of new technologies, and ultimately by successful operations that produce profits over several years.
- **Capital cost** – Capital costs will shape how quickly new facilities can be built and expanded. Capital costs are also a factor in financial risk (more below).
- **Operational cost –** Operational costs will affect long-run financial performance and ability to compete with other technologies and producers in the market.

- **Financial risk** – Financial risk will shape the speed and scale of technology adoption. The amount of experience and demonstrated operation of each technology at commercial scale will affect its speed of adoption as well as the profitability expected by investors (i.e. risk adjusted rate of return). Some risks can be mitigated with increased capital costs (e.g. back-up systems, sensors and alarms), or with operational costs (e.g. insurance), while other risks relate to market fluctuations and other factors that can't be controlled easily.
- **Supply chain** – The availability of the necessary supply-chain to support new technologies must be considered in the B.C. context. This includes technology suppliers, construction expertise, operational expertise, system inputs such as feed, energy, fish health testing, processing, marketing and distribution capacity.
- **Economy** – There is a public interest to maximize economic benefits in terms of jobs, incomes, community economic development, and tax revenues to governments. New technologies change the quantity and nature of economic benefits depending on system requirements, location, and potential to grow in a competitive global marketplace for salmon products. This report refers to full-time equivalent jobs unless otherwise indicated.
- **Expansion** – Each technology offers different opportunities for expansion of production in B.C. and for export of goods and services to other countries.

4. New Technology Assessment

4.1 Introduction

The strengths, weaknesses, and uncertainties for the four production technologies are assessed according to the environmental, social, and economic criteria in the tables below. More detail regarding the assessments for each criterion follows the tables.

Table 5: Environmental strengths, weaknesses, and uncertainties for the four new production technologies

Land RAS	Hybrid system	Floating CCS	Offshore system
Marine escapes			
• No risk, the system is contained on land.	• No risk during land-RAS stage • Some risk at sea and during transfers, but reduced time at sea and better transfer timing is helpful	• Low risk due to solid containment, and some risk during fish transfer to/from land	• Some risk due to open containment, but built for harsh conditions • Some risk during fish transfer to/from land • Uncertainties need more research
Wild salmon disease			
• No risk, the system is contained on land.	• No risk during land-RAS stage • Some risk at sea, but time at sea is reduced and salmon are larger and healthier	• Low risk due to solid containment, but still some risk as water filtration will not eliminate all concerns	• Some risks, but submerging capability avoids sea lice, and sites may be located away from salmon migration routes
Waste effluent			
• Waste can be composted, used in aquaponics, or to generate energy • Salt content can be a challenge	• Land-RAS waste can be composted, used in aquaponics, or to generate energy • Most waste is released to sea in grow-out, but some capture possible	• Low waste release with collection system and processing on land, but some dissolved nutrients (e.g. nitrogen, phosphorus) released	• Waste is released to sea • Location offshore in deeper high current waters will be better than inshore sites
Chemical release			
• Very low to no release outside the system • Chemicals are used for bacteria, gill diseases, and pH control	• Very low to no release from land-RAS phase • Marine phase releases chemicals to sea, but reduced use due to larger salmon	• Improved fish health will reduce chemical use, but as for waste effluent some will be released to sea	• Improved health will reduce chemical use, but released to sea • Anti-fouling agents on large metal structures are a concern, but this requires research
Wildlife interactions			

• No risk, the system is contained on land	• No risk for land-RAS phase • Some risk for marine phase, but may be improved with longer fallow periods	• Solid wall containment will eliminate risks • Mooring lines and structures may pose some risk to marine mammals	• Some risks with open containment, but integrity is expected to be very good • Mooring lines and structures may pose some risk to marine mammals • These topics require more research
Water use			
• Very low use in 99.5% recirculation systems • Use of aquifers by very large facilities is a concern	• Very low use for land-RAS phase since not used for grow-out • Marine phase only uses seawater flowing through	• The system only uses seawater flowing through, no limited freshwater resources	• The system only uses seawater flowing through, no limited freshwater resources
Energy use and GHGs			
• High energy use in system construction and operation • Grid electricity in BC has low carbon intensity • Location can minimize transport costs for feed to site and products to market	• Medium energy in grid connected land RAS facility since not used for grow-out • Low energy use in marine phase, but petroleum products may be used for boats and feed systems • Transport to/from marine sites adds to energy use	• Medium energy use in system construction and operation • Grid electricity in BC has low carbon intensity, but some sites may not connect to grid • Transport to/from marine sites adds to energy use	• High energy use in system construction • Medium energy in operation, and petroleum products likely needed for remote operation • Transport to/from marine sites adds to energy use • Research needed on these topics

Overall, all four production technologies offer improvements over conventional aquaculture production. There is no system with the best performance across all environmental criteria. Research is needed to complete more reliable assessments of performance expected for floating closed-containment and offshore systems.

Similarly, for social criteria in the next table, each of the four production technologies will improve local, global, and consumer support. Keep in mind that support is not homogenous or unanimous in each group, for example some consumers may support a particular new technology while others oppose it. The assessment aims to capture the general direction of support and what are the key factors to consider.

Table 6: Social strengths, weaknesses, and uncertainties for the four new production technologies

Land RAS	Hybrid system	Floating CCS	Offshore system
Local support			
• Environmental strengths will earn support, but very large facilities using sensitive water resources will likely raise concerns • Economic aspects may be a concern with fewer jobs, but market access and growth potential will build support	• Environmental performance of land-RAS phase will build support, but marine phase will still be a concern • Economic performance will support local jobs, but marine concerns hampering growth may dampen local support	• Environmental performance will build support, but use of marine sites may still be a concern • Economic performance will support local jobs, while market access and growth potential will attract support	• Avoiding near-shore spatial conflicts will gain local support • Jobs will remain in coastal areas, but there may be fewer with increased automation • Growth potential will build support
Global support			
• Seafood labelling will likely support this system as a "best choice"	• Seafood labelling will likely support this system as a "good alternative" since this already applies to B.C. farmed salmon	• Seafood labelling does not cover this technology for salmon, but it should garner a "good alternative" rating or better	• Seafood labelling does not cover this technology for salmon, but it may earn a "good alternative" rating
Consumer support			
• Premium prices today are an indication of consumer support • Moves to land-RAS in key markets may mean this system is needed for access • Product quality and fish welfare may be a concern • Higher cost may be a challenge to sell into price sensitive markets	• Products will not be distinguished from conventional netpen salmon • Establishment of land-RAS in key markets may limit market access for products of this system • Product quality and cost is very good, but there may be some concerns with marine contaminants	• Products will be distinguished from those produced by open netpen systems • Product quality and fish welfare will be considered good • Higher cost may be a challenge to sell into price sensitive markets	• Products may be distinguished from those produced by near-shore open netpen systems • Product quality and fish welfare will be considered good, but there may be some concerns with marine contaminants • Research is needed to address uncertainties

Table 7: Economic strengths, weaknesses, and uncertainties for the four new production technologies

Land RAS	Hybrid system	Floating CCS	Offshore system
Profitability			
• Large investments mainly by new entrants to farming are expanding this technology at large commercial scale • A couple years of commercial operations are needed to confirm profitability	• Large investments mainly by existing salmon farming companies indicate this is a profitable technology at large commercial scale	• Some investments by existing farming companies indicate this is a technology of interest at large commercial scale • A few years of commercial operations are needed to confirm profitability	• Investments mainly by new entrants to farming indicate this is a technology of interest at large commercial scale • A few years of commercial operations are needed to confirm profitability
Capital cost			
• Cost of 5,000 mt facility is $10 to $14 per kg of capacity • Cost of 10,000 mt facility is $7 to $10 per kg of capacity	• Land-RAS for post-smolt costs much less than for grow-out • Marine phase for grow-out uses very low cost netpen systems in use now	• Cost of $5 to $15 per kg of capacity indicates wide range of designs being evaluated	• Cost of 5,000 mt or more facility is about $20 per kg of capacity • Other designs exist, but costs are uncertain
Operational cost			
• Cost for operations is $5 to $6 per kg of annual salmon produced • New sites are locating near markets to reduce transport costs	• Land-RAS for post-smolt costs much less than for grow-out • Marine phase uses very low cost netpen systems in use now • $3.5 to $4.5 cost per kg needs research	• Cost is lower than land-RAS, but higher than hybrid system • $4.5 to $5.5 cost per kg needs research	• Cost may be one of the lowest amongst new technologies given high degree of automation and use of ecosystem services • Research is needed
Financial risk			
• Biological risks are mortality, high maturation rates, and growth challenges • Market risks are price drops, currency changes, lost price premiums as land-RAS market share increases	• Biological risks are very low since this is an extension of existing technologies • Market risks are those normally associated with salmon aquaculture	• Biological risks are mortality due to system failure • Market risks are price drops, currency changes, lost price premiums as new technology market share increases	• Biological risks are mortality due to high energy environment, system or component failure, growth challenges • Market risks are those normally associated with salmon aquaculture
Supply-chain			

• Feed, fish health, processing, distribution and sales are in BC, but are being developed where new sites are emerging elsewhere • There are limited expertise in BC for construction and operation of land-RAS systems so training and imports are needed	• All elements of the supply chain exist in Canada, although advanced RAS design and expertise draws from other countries • Some additional training are required to expand land-RAS workforce	• All elements of the supply chain exist in Canada including design and operational expertise • Some additional training are required to expand use of this technology	• Most elements of the supply chain exist in Canada, although offshore design and construction expertise draws from other countries • Specialized boats and training for offshore is needed • Research is needed to determine all requirements
Economy			
• Fewer jobs per mt of salmon (26 – 30 direct jobs per 1,000 mt of salmon) and not necessarily in rural areas • High average salaries due to more technical expertise required	• This system keeps most jobs (35 – 40 direct jobs per 1,000 mt of salmon) and largely where they are located now • Some more advanced expertise jobs will command higher salaries	• This system keeps most jobs (35 – 40 direct jobs per 1,000 mt of salmon) and largely where they are located now • Some more advanced expertise jobs will command higher salaries	• There are fewer jobs due to higher amount of system automation • Jobs are still located in rural areas • Some more advanced expertise jobs will command higher salaries
Expansion			
• Several large facilities could double BC salmon production • Site selection takes time to meet requirements, especially discharge permits	• Some expansion can occur at existing marine sites, but grow-out concerns must be addressed for new sites to be allocated	• Some expansion of production can occur by replacing netpens at existing marine sites, and allocation of new sites should be more acceptable due to environmental performance	• BC offers extensive opportunities for expansion once the technology is proven through test sites

The combination of readiness for commercial development, likelihood of being profitable, economic impacts, and opportunity for expansion are what determines the financial and economic benefits expected from new technologies. Overall, land-based RAS and hybrid systems are ready for commercial application in B.C., while the others still need five to ten years. Land-RAS though less financially proven offers greater opportunity for expansion as long as this occurs in B.C. The hybrid system is likely more profitable and anchored in B.C., but expansion may meet challenges.

4.2 Land-based RAS grow-out

The following assessment considers the best available land RAS technology, application in B.C., and facilities being built in different B.C. locations.

Environmental criteria:

- **Marine escapes** – Zero
- **Wild salmon disease impacts** – Zero
- **Waste effluent** – There are no concerns since this is handled on land with acceptable disposal in more advanced designs including: composting, soil amendments for aquaponics (plant production) linked to the facility, or energy generation using biodigesters. Discharge of saltwater must be done carefully to avoid contamination of freshwater or marine resources, and land-based RAS offers the best potential waste management of the new technologies.
- **Wildlife interactions** - Zero
- **Chemical release** – Infection with pathogenic or opportunistic microbes is the main concern in these systems, but standard anti-microbial treatments are avoided since they harm the beneficial bacteria used in the bio-filters (denitrifying bacteria). These systems employ some antibiotics for bacteria, formalin for gill parasites, and alternatives such as low dose ozone.
- **Water usage** – This is minimal in state of the art re-circulation systems, in fact salmon facilities are already operational in desert environments. There is a caution regarding exceptionally large developments and sites with water limitations or sensitive environments (e.g. aquifers). Requirements for a depuration stage to deal with off-flavours before sale to market may also use more water than the rest of the production scale.
- **Energy usage** – This depends on system design and location. In general, these systems use more energy in construction and operation than other systems (Ayer and Tyedmers, 2009). This can be partially offset by generating up to 10% of operational energy requirements using biodigestion of waste material, and locating in proximity to both feed sources and consumer markets to reduce transportation energy. Use of solar panels, wind turbines, and low carbon electricity sources can alleviate climate change concerns.

Social criteria:

- **Local support** – Strong local support will be built on the system's ability to improve environmental performance across nearly all measures. Protection of wild salmon, addressing concerns in recreational and commercial fisheries, and avoiding other marine spatial conflicts will substantially address the opposition to salmon aquaculture. Depending on how land-based RAS is developed, local direct and indirect economic opportunities may be lost so coastal communities will raise concerns. There has been some local opposition to the recent large proposed facilities in the U.S. on the basis of water resource concerns or potential noise issues.

- **Global support –** Land-based RAS systems are expected to meet or exceed sustainability certification requirements. This is a strong indication that global support from environmental organizations will continue. Monterey Bay Aquarium's Seafood Watch™ lists "worldwide indoor recirculating salmon" grown salmon as their "Best Choice" (MBA, 2019).
- **Consumer support** – The acceptability of products from this system is expected to be high since premium prices have been captured in some markets. This does not imply that price premiums will continue, only that it reflects consumer support. The ability to avoid chemicals in feeds and system treatments will appeal to consumers. The assurance of clean water circulating through the system will be an important feature for consumers concerned about pollutants in the marine environment. There have been some historical issues with off-flavours, but these are addressed in modern designs. The issue of fish welfare may yield mixed consumer responses. On the one hand fish welfare is improved with optimal growing conditions and avoidance of potentially stressful treatments for sea lice and other ailments. On the other hand, high biomass density and aggressive fish behavior must be well-managed with transparency to consumers. Some consumers may perceive land-based facilities as an unnatural environment for raising fish and there will be a need for producers to address this.

Economic criteria:

- **Profitability** – Announcements of secured funding for numerous large-scale projects has proven that investors are ready to move this system forward even with relatively high risk. There is a concern that failures of these large projects to deliver on promises to investors could hamper the momentum that exists. Given the need to monitor the success in the next few years for the large systems being built, there is still some caution before declaring these are profitable.
- **Capital costs** – The capital costs have dropped substantially over the last ten years and are now in the range of $10 to $14 per kg of salmon capacity for systems with 5,000 mt capacity (Bjorndal and Tusvik, 2017). The largest proposed projects today (over 10,0000 mt) are in the $7 to $10 per kg range (AquaMaof, 2019). These figures do not account for production not always meeting capacity, so actual capital costs per kg of salmon produced will be important to confirm going forward. These capital costs include: site preparation, buildings, electrical, concrete work, RAS equipment, and other installations (excluding land). The time required for permitting is related to capital costs. Any complexity and delay of permitting and approvals is a deterrent to development of land-based RAS systems since financial capital is tied up longer. The locations where large projects are going forward took many years to meet all regulatory requirements. This ultimately represents a cost to operate, risk to investors, and challenge to achieve returns on projects.
- **Operational cost –** The operational costs are competitive with other systems, especially where optimal growing conditions and system advantages can reduce costs, and reduced transportation exists in ideal locations. The expected production costs per kg of salmon from land based RAS are now about $5 to $6. For B.C. the transport to the U.S. is economical, but shipping to Asian markets may be a competitive challenge with this system, especially as local Atlantic salmon production capacity in Asia is growing

rapidly. Taking into account production challenges such as growing salmon to full size and avoiding any system failures, the actual long-term operational cost will be confirmed going forward.

- **Financial risk –** Pathogen control, biosecurity, and system component failures are key concerns for investors as mortality incidents can be severe. High rates of early salmon maturation, poor feeding response to husbandry practices, and stocking density issues can also impact growth, quality, and ultimately revenues. Although recent financing success is a strong indicator that risks are being addressed in new systems, along with a considerable amount of research to advance the above noted concerns, this is ultimately confirmed through successful operations over a number of years. The current environment is favourable, with salmon prices above $9 CAD per kg over the last two years, but in 2011 and 2012 prices fell below $7 CAD per kg (22% lower). These systems must demonstrate financial resilience through price volatility, and also in a global production growth environment. As more land-based capacity develops along with other emerging technologies, a higher proportion of product will be able to meet high consumer expectations and this could erode any premiums that are possible.
- **Supply-chain –** Most of the supply-chain elements required for this system are available, but land-based RAS does not have the best supply-chain advantages amongst the four technologies considered. System-specific managers must be trained and the expertise for construction and maintenance are being primarily developed in Europe. As large-scale land-based systems are being developed particularly in the U.S., the advantages in B.C. are not sufficient to have already attracted large developments, and supply-chains will now be developing elsewhere.
- **Economy –** Advanced skills and expertise are required for most positions in RAS facilities so locations with excellent training and aquaculture industry presence are in a good position. Given the advanced labour requirements, the salaries and wages are attractive for salmon farm workers. However, the location of these systems is very flexible so coastal employment opportunities may be lost as production moves closer to consumer markets and distribution centres. There are also fewer jobs per tonne of salmon produced than most other alternative technologies. Land based RAS systems operating at commercial scale in B.C. are expected to generate about 26-30 direct jobs per 1,000 mt of capacity (CounterPoint, 2019). This is only a small decline compared to hybrid or floating CCS, and a bit more than anticipated for offshore systems. The nature of the jobs will be more technical and average salaries will be higher. The most significant consideration is where these jobs are located in B.C. or elsewhere.
- **Expansion –** Sites already selected for existing, under-construction, and proposed land-based RAS facilities around the world demonstrate the flexibility in siting this technology. Although there are many considerations for meeting system requirements and optimizing performance, British Columbia offers options for suitable sites. Based on the size of land parcels secured for recent large-scale farms in Maine and Florida, about 32,000 mt of salmon can be produced on about 20 hectares of land (50 acres). Subject to water source availability, all of the current farmed salmon production in B.C. could be accommodated in a combined space of about 60-hectares (150 acres). This does not mean it is a simple matter to identify the best location(s), and a couple years may be required for site selection considering the substantial investments involved.

4.3 Hybrid system

Assessing the performance of this system revolves around the salmon growth stage from about 100g to 500g where land-based RAS is used. Any environmental and financial risks associated with the fish at this stage in the marine environment are addressed by moving to land, and there are some additional benefits in the marine grow-out phase. The following assessment assumes the marine portion utilizes open netpens with some improvements and that the allowable biomass in netpens remains the same. Any other improvements to the marine phase involving closed, submersible, or offshore developments would further address a number of the marine risks.

Environmental criteria:

- **Marine escapes** – Escape risks are zero during the land-based phase so over the full life cycle there is a reduction, but not an elimination of risk. During the marine portion low escape risks are expected due to the shorter time at sea, more secure transfers from land to water, and added flexibility regarding when fish are in the marine environment. Transferring larger fish from land will require better vessels and equipment to secure the fish. Shortening the marine phase to one year or less creates flexibility in the timing of stocking and harvest so that adverse weather conditions can be avoided for transfers and growing periods. However, the risk of escape is not zero for the marine portion.
- **Wild salmon disease impacts** – Lower, but not eliminated, disease risk will result from reduced time in the marine environment and increased size of the fish. Sea lice treatments may only be needed once or not at all for the maximum one-year at sea. The shortened time at sea will prevent build-up of sea lice, and the larger fish will be less susceptible to sea lice and other diseases. There is also potential for longer fallow periods that allow disease cycles to be broken.
- **Waste effluent** – Since the land-based portion of the growth cycle is comparable to other systems there are no additional concerns. However, the open netpen system does discharge waste effluent to the marine environment and this will be for the most intensive part of the grow-out at the end of the cycle even though the grow-out period is shorter than for conventional aquaculture. Longer fallow periods will provide some benefits for seafloor recovery, and some waste capture is possible though at higher cost.
- **Chemical release** – Again the marine portion of cycle will be open to the marine environment. The expected reduction in sea lice treatments will reduce therapeutants and other treatment releases in marine waters.
- **Wildlife interactions** – Interactions with wildlife are eliminated for the land-based portion and the marine phase risk is reduced to the extent that the number of sites is reduced and fallow periods are prolonged.
- **Water use** – The length of time salmon will spend in land-based RAS facilities may be half of their life-cycle, but the water usage will be substantially less than half. Salmon growth up to 200g – 1kg needs much less water than salmon growing through the latter part of the cycle to market size (5-6kg). Very high re-use rates that do not depend on sensitive water sources (e.g. aquifers) will perform very well.

- **Energy use** – Similar to water usage, the energy usage for post-smolts in the land-based system is about 10-20% that of the energy required for producing market-sized salmon. The other energy consideration is the location of the land-based system relative to feed sources and consumer markets. In B.C. there will be local supplies of feed, but the primary markets are distant (U.S. and overseas). Land-based RAS for post-smolts in B.C. will offer partial location advantages (feed source) in terms of energy reductions. The energy intensity of the marine component is also low.

Social criteria:

- **Local support** – Although many marine site producers have favourable relations with local communities, this production system is expected to be more contentious than the other four technologies. Local support will improve somewhat based on system gains in environmental performance, but continued use of open netpens will not eliminate issues. Although it may be possible to reduce the overall number of sites so the least appropriate ones today can be abandoned, there will continue to be concerns. On the other hand, this system is most likely to maintain aquaculture employment where it currently exists so there will be corresponding favourable perspectives from coastal communities.
- **Global support –** Although not as environmentally attractive as land-based RAS systems for full on-growing, this system should yield enough improvements to meet most environmental certifications for salmon aquaculture in marine environments. Monterey Bay Aquarium's Seafood Watch™ lists Aquaculture Stewardship Council (ASC) certified Atlantic salmon as a "Good Alternative", and B.C. marine netpen Atlantic salmon are also listed as "Good Alternative" (MBA, 2019). Hybrid systems in B.C. upholding ASC requirements would be viewed favourably.
- **Consumer support** – The salmon products from this system will not likely be distinguished from current netpen products, unless this facilitates third-party certifications the consumer will see on products. As many companies shift to new technologies, high environmental performance will become a consumer expectation rather than a feature. Any potential consumer concerns with salmon spending their full life-cycle in land-based facilities would be largely addressed in this system by spending their last year at sea.

Economic criteria:

- **Profitability** – The financial attractiveness and feasibility is evident as companies are already adopting this system. Grieg Seafood in Norway, for example, started moving toward this system in 2007 and is aiming for 300g average smolt in 2019. The increased costs of sea-lice treatments, faster salmon growth and operational advantages of a hybrid system make it an easier financial decision, but it has taken some time to transition.
- **Capital cost** – This is lower than for full grow-out in land-based RAS or in offshore systems. Permitting and approvals are relatively straight-forward for conversion of existing marine sites to hybrid ones, however there may be challenges getting approval for any new sites in B.C. (more below).

- **Operational cost** – The operational costs are competitive since it aims for the best combination of land-based and marine-based systems. Costs in the range of $3.5 to $4.5 per kg are likely, but research is needed.
- **Financial risk** – This approach is already operating at commercial scales and is being closely considered in Canada. There is no concern whether it can be done reliably, only a question of how far it can go in terms of maximizing the land-based phase and minimizing the marine phase.
- **Supply-chain** – The supply-chain considerations are associated with the land-based facilities including suppliers of the RAS systems and components, and suppliers of feed. Canada would currently seek the most advanced system designs and components from other countries. Recent expansions of RAS for larger smolts (e.g. MOWI) have used European suppliers, but have customized the system in Canada. Feed production is already well established in Canada so there those economic benefits are captured locally.
- **Economy** – Advanced skills and expertise are required for most positions in RAS facilities so locations with excellent training and existing industry presence such as B.C. will be in a good position. Coupling land RAS with a marine stage keeps production locally in the province. More jobs per tonne of salmon will be retained than with full RAS systems. Many jobs will have advanced labour requirements so the salaries and wages will be attractive for salmon farm workers. Hybrid systems operating at commercial scale in B.C. are expected to generate about 35-40 direct jobs per 1,000 mt of capacity (CounterPoint, 2019; MNP, 2015; Bjorndal and Tusvik, 2017). This is similar to floating CS and more than the other two systems. There will be a mix of more technical jobs associated with post-smolt production and current jobs for grow-out operations so average salaries will be slightly higher. These jobs are more likely to remain where they are currently located in B.C. since proximity to grow-out sites will remain important.
- **Expansion** – Some growth of production could occur as a result of using this approach at existing marine sites, however there are anticipated limits to expansion due to on-going concerns with the marine component. Even though some growth is possible, this technology offers the least opportunity for expansion in B.C. amongst the four technologies considered. The improvements in the marine phase with open netpens will not likely be sufficient to lift the constraints on near-shore site availability in B.C. Social licence to expand will require more substantial changes to the marine phase involving other technologies such as near-shore submersible and floating containment systems, or offshore system development.

4.4 Floating closed-containment systems (CCS)

Environmental criteria:

It is important to mention that floating CCS systems are more often considered for post-smolt growth in conjunction with marine netpen grow-out to market size and this technology may have greater opportunity for this type of application. However, the purpose of this assessment is to assess potential for producing market-sized salmon, and there are some preliminary efforts to develop this at commercial scale. It is also important to note that the assessment is focused on solid-wall systems, as opposed to flexible-wall systems that are more limited in where they can be located (sheltered, low energy marine environments).

- **Marine escapes** – Escape risks are low given the full containment structures, but not zero as for land RAS systems. There have been historical escape events from floating CCS systems due to design issues that led to structural failures during storm events. The most recent designs have made many improvements to lower this risk, but the potential for escapes still exists, especially during transfer of salmon to and from the site.
- **Salmon diseases** – These systems will significantly reduce build-up of sea lice, but other disease transfer is possible as untreated water is pumped through the system. Because water is taken from deep under the structure, operators have reported excellent results with no sea lice. Filtering and treatment of outflows may be possible in future, but these are not developed at economical stages yet.
- **Waste effluent** – Considering the most advanced designs that include waste collection and processing on land, the waste effluent is significantly reduced compared to open systems. However, some dissolved nutrients and waste particles are not captured, and there are difficulties processing saltwater waste materials.
- **Chemical release** – Reduction in sea lice and other diseases minimizes or eliminates therapeutants and treatments that are released in marine waters.
- **Wildlife interactions** – Interactions with wildlife are certainly reduced by solid-wall tanks, but not eliminated altogether. Mooring lines and anchoring systems could be a concern for marine mammals, but this requires further research with implementation of these systems.
- **Water use** – Since the water usage is not derived from limited sources (e.g. aquifers), this issue is not associated with these systems.
- **Energy use** – Energy usage is greater than for open netpens, but lower than land-based RAS requirements. Grid connected electricity is best, but not always possible so self-sufficiency with solar and wind energy is being developed to avoid the need for diesel generators. Some energy is used in the service and supply activities to the structure, but this is not substantial over the production cycle or life of the system.

Social criteria:

- **Local support** – Improved local support will rest on the system's ability to improve environmental performance across most measures. The continued use of near-shore sites will not eliminate marine spatial conflicts. These systems have performed well in areas that are prone to algal blooms, so their use maintains flexibility for selection of suitable sites. This system is most likely to maintain aquaculture employment where it currently exists, so local economies will benefit and coastal communities may view this favourably.
- **Global support – T**his system offers a number of environmental performance improvements over open systems and should achieve environmental certifications for salmon aquaculture. However, Monterey Bay Aquarium's Seafood Watch™ list does not

include recommendations specific to floating CCS (MBA, 2019). More experience with these systems over the next few years will confirm the level of support.

- **Consumer support** – Market-sized salmon produced from this system will garner consumer support. There should be a positive consumer association with salmon growing at sea while employing technology with a small footprint to address many of the marine impacts and wild salmon concerns. Certifications and product labels (i.e. global support) will help convey this to consumers.

Economic criteria:

- **Profitability** – Signs of financial attractiveness and feasibility are emerging as companies are investing in this technology. A few years ago this would have been considered a more expensive system, but the increased costs of sea lice treatments coupled with operational advantages of this approach are making it an easier financial decision. There is not yet a surge in development, but proof of commercial viability will grow in the next few years.
- **Capital cost** – Capital costs range from $5 - $15 per kg of salmon capacity and this wide range reflects the variety of designs still being considered. There are fewer opportunities to gain economies of scale and bring unit capital costs down as for large offshore or land based technologies.
- **Operational cost** – The operational costs are lower than for land-based RAS, but higher than for hybrid systems. Costs in the range of $4.5 to $5.5 are likely, but research s needed.
- **Financial risk** – The financial risks associated with system component failures or market fluctuations are much lower than for land-based RAS or offshore systems.
- **Supply-chain** – Canadian companies offer some designs, but use of systems and components from other countries is likely since leading manufacturers are positioned in Europe. Feed production is already well established in Canada so this is one reason for Canada's economy to perform well with this system.
- **Economy** – Some labour requirements will include more advanced technical training and higher salaries, but the existing worforce can adapt easily to this system. The number of jobs required is comparable to current industry operations and the use of B.C. marine sites will keep employment in coastal communities. More jobs per tonne of salmon will be retained than with full RAS systems. Floating CCS operating at commercial scale in B.C. is expected to generate about 30-35 direct jobs per 1,000 mt of capacity (modified from MNP, 2015). This is closely related to netpen labour requirements with more technical management and maintenance offset by reduced treatment and fish health activities. The mix of occupations will command slightly higher average salaries. These jobs are likely to remain where they are currently located in B.C. since marine grow-out sites will be important.
- **Expansion** – Some growth of production could occur as a result of this approach, however there are anticipated limits to marine expansion. The environmental performance advantages, once fully proven, would offer suitability in a wider range of sheltered in-shore environments, but the issue of marine spatial conflicts will place limits on this. As the systems become more robust for submersible and in-shore exposed applications, there will be more expansion potential.

4.5 Offshore

The following focuses on offshore designs that are open with submersible capabilities. These are common characteristics among contending designs that should be examined for performance, recognizing that closed systems will offer even greater environmental advantages as they develop in the medium-term. These systems are all likely to be stocked with post-smolts 200g or larger produced from land-based RAS systems. Larger fish are preferred for stocking to increase survival for offshore systems in stronger currents with higher wave energy.

Environmental criteria:

- **Marine escapes** – The risk of escapes is relatively low since these systems are built for very harsh conditions, and the integrity of the containment system for salmon is extremely high. However, there have been issues with earlier systems and it will be important for next generation systems to demonstrate their integrity.
- **Salmon diseases** – These are likely to be open systems so diseases will not be contained, however they offer some advantages for protection of wild salmon from sea lice and potentially other diseases. They will be located away from migratory routes of wild salmon. They will have capabilities such as submergibility to grow salmon below the water depths where sea lice are prevalent. There will be more space offshore to separate growing sites so the transfer of sea lice between sites and resulting build-up will be lowered. Uncertainties about interactions with wild salmon require further research.
- **Waste effluent** – These large systems will produce high amounts of waste given the large number of fish stocked in each structure, however the main waste effluent issues are related to near-shore sites where water depths are much shallower and currents are weaker. Impacts to benthic communities are likely to be minimal offshore given the ability of currents to disperse waste more widely. As long as these materials are biodegradable and do not pose threats to marine life (i.e. better feeds), the amounts accumulating on the seafloor are not expected to trigger problems. Some waste collection is possible, but this raises costs.
- **Chemical release** – Disease pressures including sea lice are expected to be lower therefore use of treatments and therapeutant will be minimized. Where anti-fouling agents (e.g. copper) are used, there is some concern that these will be more common on large metal structures, and once they fall to the seafloor it would be a challenge to recover this in deep waters.
- **Wildlife interactions** – As for open netpens today, wildlife interactions will occur. This is the subject of research to determine what wildlife interactions will be most important at offshore locations, and how these will be handled in terms of preventive measures as well as maintenance of system integrity. Since these systems will be built with stronger materials for security and integrity, this should improve performance. As for floating CCS, offshore system use of mooring lines and anchoring systems could be a concern for

marine mammals, but this requires further research with implementation of these systems.

- **Water use** – This is not considered an issue for offshore systems.
- **Energy use** – There are three main energy requirements to consider namely: the offshore structure construction and operation, the transport of personnel and goods to and from the offshore structure, and proximity to feed sources and consumer markets. These large structures will require substantial energy in construction, although not as much as land-based RAS, and the operational energy requirements will be low since currents will move water through the system. Leading designs are optimizing construction materials to reduce environmental and economic costs, while offering the strength required for offshore environments. Renewable energy such as solar panels and wind turbines can be incorporated into offshore systems, and this will be used to run automatic feed systems, remote operated vehicles, cage movements (rotation or up and down in the water column). Transport of goods and personnel to and from the offshore sites will add to energy requirements, although the frequency of ship movements will be relatively low. Developing these off the coast of B.C. will have the advantage of short distances to existing feed supplies, but still remain distant from major consumer markets.

Social criteria:

- **Local support** – Moving offshore will avoid many marine spatial conflicts and address many environmental concerns, so this should gain strong local support. This system has the ability to maintain aquaculture employment in coastal communities, although the labour requirements are reduced for both the land and offshore phases compared to the hybrid alternative.
- **Global support –** Although not as environmentally attractive as land-based RAS systems for full on-growing, this system should yield enough improvements to meet or exceed the highest environmental certifications. Research over the next few years observing commercial scale systems will confirm the level of support. Monterey Bay Aquarium's Seafood Watch™ list does not include recommendations specific to offshore systems (MBA, 2019).
- **Consumer support** – Through sustainable seafood certifications consumers will recognize that this system addresses many environmental concerns. It will be appealing as a system that produces salmon at sea, as long as appropriate regulatory measures are in place and the offshore areas are perceived as clean environments for food production.

Economic criteria:

- **Profitability** – The financial attractiveness and feasibility is least evident with this system as the largest investments in offshore salmon aquaculture have only begun recently and most are concentrated in China. The drivers for investment in China are different, but some salmon production companies in Europe are deploying offshore systems also. The next 3 to five years will confirm profitability at commercial scales.

- **Capital cost** – This is lower than for full grow-out in land-based RAS, but not as low as hybrid systems. Approvals and permitting processes have not been fully elaborated so this extends the wait for investors. Once this is resolved, the long-run prospect for permits and approvals will be superior to other alternatives owing to the space available and uniformity of offshore locations. The unit capital cost of 5-6,000 mt capacity offshore systems in Norway and China are just over $20 per kg of growing capacity. Annual capital maintenance and depreciation is about 2% of capital costs. The increased costs relate to the large solid structures required to maintain the system in high energy environments. Larger vessels for deployment and servicing are costly, anchoring systems, and advanced automation and controls add to the total. The amount of fish produced in the system is the partially offsetting factor that keeps unit capital costs in a reasonable range (CEA, 2018), but further research is required since multiple designs could emerge successfully.
- **Operational cost** – The operational costs are very competitive since these systems make the best use of automation and natural resources. A 10-15% additional cost compared to conventional netpens is expected in the near-term for offshore systems (CEA, 2018). This is definitely competitive with land-based RAS and floating closed containment system costs, and has the potential to be more economical in the long-run. Feeding and salmon growth is currently not as efficient in offshore environments, insurance costs, and transport to and from shore are key drivers of operational costs.
- **Financial risk** – There is currently a financial risk given this is the newest technology among the alternatives and several years of operation are needed to confirm its reliability. Since there is a relatively high capital investment, it is important to demonstrate that the system is resilient to component failures and market fluctuations (e.g. lower salmon prices).
- **Supply-chain** – Leading offshore system designers and manufacturers are located outside of Canada, however it is possible to bring modules to Canada for domestic assembly and customization. As for other systems, the other primary input is feed supply, which is well-established in Canada.
- **Economy** – Personnel are sometimes needed on the offshore structures, and in transport of goods to and from offshore sites. These positions are fewer than for hybrid systems, but they require advanced skills and expertise and are therefore well-paying. Since this system will utilize B.C. marine waters, this approach will help to retain local jobs. Offshore systems operating at commercial scale in B.C. are challenging to assess, however the high degree of automation and challenging environment point to lower labour demands. There will still be all of the supply-chain, processing and sales activities so direct jobs are estimated in the 20-25 range. This is the lowest among the four systems. The jobs will all be technically demanding so average salaries will be high. The main consideration is that the location of jobs, especially those tied to the offshore site activities will shift in B.C.
- **Expansion** – There are very few limitations to expansion of offshore systems therefore substantial growth could proceed once this technology is fully proven. B.C. offers extensive offshore waters that are suitable for salmon production. It will likely be a decade before significant commercial operation occurs in Canada or the U.S. (CEA, 2018).

5. Development pathway in B.C.

5.1 Introduction

The technologies assessed in this report are operating at large scale, but at different stages of maturity so they are not all ready for commercial application in Canada. Land based RAS and hybrid systems are ready and B.C. is in a position to advance these now, but floating CCS and offshore systems need to be deployed in Canada for a few years before declaring their readiness. The latter two still deserve substantial investment as they offer great potential for grow-out in the marine environment.

The traditional driver for global industry to innovate is for competitive reasons; to reduce costs of production and secure markets. As global demand grows for protein sources and seafood in particular, investment will flow into salmon aquaculture. Production technologies will compete to become the leading modes of supply, and sustainability is increasingly a critical part of attracting investors.

The objective for B.C. is to ensure that investments lead to development of the technologies offering the best combination of environmental, social, and economic performance. Building on existing programs and supports for aquaculture in Canada, this section examines key approaches and measures that target preferred technologies, recognizing that leveraging market forces can help to achieve desired outcomes. Each technology may have different needs so a combination of measures is needed.

5.2 Legislation and policy

Clear and effective legislation and policy has been a pre-cursor in other countries to the development of new technologies. Clarity and stability allows investors to leverage capital, which is essential to profitable businesses and investment in innovation. There have been a number of statements in Canada regarding the need for regulatory clarity and consolidation in the form of an Aquaculture Act (Senate, 2015), and continued work on this initiative will be helpful as long as it maintains a view to the promising technologies reviewed here. In discussions with experts working on each of these technologies there was at least one key area of uncertainty with regard to policy and regulations for each system.

- **Land-based RAS** – The provincial waste discharging permits under the B.C. Environmental Management Act, both for water and solid wastes are topics of uncertainty for land-based system developers. Traditional farms can only use composted aquaculture waste materials as fertilizer for crops if these meet content requirements, in particular low salt levels. This can require costly advanced processing and/or limit potential uses of waste materials. Further, ambiguity exists with the discharge of water effluent with a lack of clear standards where RAS effluent is concerned. Clear and unambiguous permitting criteria are needed to attract developers of this technology. Determining acceptable water intake requirements is another area of uncertainty and it is recognized that this can be site-specific and system-specific, also that it involves testing and assessment processes that take time. One solution is to identify suitable sites that are (pre-) approved based on limits to resource use and waste discharge, then a streamlined approval process for the site will facilitate investment. This could be accessible to multiple companies at a given site providing synergies between producers and cost-efficiencies.

- **Hybrid systems** – These are already being closely considered in B.C. so the regulatory path is more straight-forward, although some questions remain regarding the maximums for biomass stocking and use of marine grow-out sites. The shift to larger fish with shorter grow-out periods allows for different site planning including the number of sites, stocking rotation, and fallow periods. Use of the DEPOMOD aquaculture waste deposition modelling software by DFO and routine sampling under the Aquaculture Activity Regulations must confirm that benthic impacts continue to be within acceptable limits.
- **Floating CCS** – Current legislation and policy is mainly designed for open netpen systems and ensuring that these do not exceed the carrying capacity of the marine environment or interfere with wild salmon populations. Floating CCS largely addresses these issues and should therefore be considered for increased biomass stocking. This would improve financial performance by providing greater returns (i.e. revenue from fish produced each cycle) to support more rapid payback of the capital investment, and improved operational returns, and would ultimately encourage more rapid adoption of this technology. Like land-based RAS, identification of a site for further development of the technology at commercial scale would be helpful by streamlining the approval process.
- **Offshore** – The greatest regulatory and policy uncertainty accompanies offshore aquaculture systems. There is a recognition that the next offshore development projects in Canada may actually help to shape regulatory and policy formation. Implementing a small number of projects will allow for observation and evaluation before opening the offshore to widespread aquaculture development. A developmental licence tailored to the specifics of a prospective technology will be sufficient initially, then more comprehensive requirements can be devised for general development in the future. The Norway Government (2017) has recognized that offshore aquaculture technology is developing so rapidly that flexible rather than prescriptive regulations should be adopted to support ongoing innovation.
- **Hybrid and floating CCS systems –** Marine salmon farms in B.C. are already regulated for sea lice management through their conditions of licence. However, the requirements are not designed to incentivize adoption of new technology. In Norway's "traffic light" system, very low thresholds are set for sea lice and if these are met then marine sites (individually or within a bay) are allowed to increase their biomass stocking, and if not met then biomass stocking is reduced along with other measures. The traffic light system involves maximum average counts specific to sea lice gender, stage of salmon development, time of year, location of salmon

farm, and other factors that are the basis for treatment thresholds, reporting requirements. This motivates producers to adopt the best approaches to minimize or eliminate sea lice, which include technologies in this report.

5.3 Nurturing innovation

Researchers and innovators are needed in B.C. to accompany and guide the development of new technologies. Once new technologies accelerate and the scale of production from these systems increases, researchers and innovators will be more attracted to the sector in B.C. This means there is a positive feedback loop involving innovators and development of new technologies, where growth of one promotes growth of the other. In order to accelerate this, a number of suggestions emerged in the preparation of this report.

- **Intra-industry tech transfer –** In the effort to develop new technologies research and development is often carefully guarded, even if it will eventually be publicly released (e.g. academia), and it can remain entirely confidential in the private sector (e.g. patent development). In some cases this will continue, but the pitfall is that developers working independently without sharing information are likely to duplicate research efforts and repeat mistakes that others have made. The solution is to facilitate and coordinate information sharing. Norway recently tied information sharing and collaboration requirements to the issuing of developmental licences for new technologies. The licences in Norway normally come at a high price and new production capacity is very difficult to obtain, so companies are encouraged to meet the additional requirements. As a result, Norway is the undisputed world leader in fostering an innovation culture that combines government, academia, and the private sector.
- **Inter-industry tech transfer –** There are a number of industries such as aquaculture, fisheries, offshore energy, and marine transport that face common challenges in the marine environment. The need for information sharing and collaboration on technology development between these industries has been recognized in Norway's Ocean Strategy, in particular the opportunity for more established industries (e.g. offshore energy) to share technology for new developments, especially in aquaculture (Norway Government, 2017).
- **Resource mapping and marine spatial planning –** The need to identify marine areas (inshore sheltered, near-shore semi-exposed, and offshore) for appropriate development of aquaculture technologies must be integrated with other industries using marine resources (e.g. offshore energy, transport, tourism, national defence). Again, the Norway Ocean Strategy recognizes a role for the national government to coordinate and deliver integrated digital mapping (i.e. GIS) that contains the key data for businesses and regulators and is distributed so this can be used extensively.
- **Training –** The need to ramp up labour force training and research capacity goes along with efforts to grow new production systems. Several key informants indicated that initiatives will be required to shift the existing aquaculture workforce to more technical positions, and new workers need to be prepared and recruited to avoid a shortage as new technologies surge ahead. The solution is to coordinate

college, university, and private sector training programs with an emphasis on the needs of new production systems. There is a particular gap in proficiency with the "supportive technologies" outlined in this report so companies that develop sensors, software, robotics, and other components may need to be engaged in the development of training programs. Building a critical mass of trained and informed people from different perspectives will stimulate innovation as more human capital can be turned to improving performance.

- **Conferences** – There are a number of forums for leaders in new technologies to share information about recent developments, but these often focus on international projects and topics. B.C. actors will continue to learn from international developments, but the concerted push for new technology development in B.C. requires regular opportunities for discussion of local interests. Meetings provide opportunities unlike information sharing through reports and research results, since it is important for all audiences to participate, ask questions, and contribute to the research and development agenda. The solution is to facilitate an annual meeting in B.C. initially, which could move to other parts of the country as new technologies are deployed.
- **Transparency** – When separate research efforts lead to different perspectives on key issues it can be difficult to resolve competing claims. This leads to confusion and lack of trust on the part of non-technical actors and the general public. The solution is to support public posting of consolidated scientific information in order to help build social support for new aquaculture technologies. Sharing research "dead ends" is just as important as "big discoveries" so that everyone appreciates what has been investigated. As new technologies are deployed, the monitoring and performance data should be readily available for open discussion.

5.4 Financial incentives

The hybrid technology is already being closely considered in B.C., and the other technologies are advancing moreso in other countries. This suggests there is a gap with respect to the other three that requires an incentive or support in order to advance. Financial incentives are used by governments to serve a public interest (e.g. job creation, environmental protection) in two key situations: 1) when jurisdictions compete to attract businesses that are flexible with respect to location, and 2) when businesses want to establish in a particular location, but there is a financial challenge to overcome.

The hybrid system and land-based RAS system are the most capital intensive and likely candidates for financial incentives. The hybrid system and floating CCS technology cannot be located anywhere in the world, since the combined location criteria for each technology must be met and B.C. offers a number of options. Land-based RAS for grow-out and offshore systems are more flexible in location around the world so B.C. competes with others for investment to establish this technology. The following examines financial incentives in the context of developing these systems in B.C.

- **Development licence fee reduction** – In some countries open netpen aquaculture licences are subject to substantial fees, and licences are exchanged between companies at high market prices. Norway instituted fees for licences in 2002 and licences for the standard 780 mt of capacity have recently sold for over $10 million (DNB, 2017). The "development licence"s for projects that meet innovation criteria have been granted for free initially and, after a period, may be convertible to normal licences for about $1 million (90% below value). Over 50 companies have applied for these licences, since they represent the only substantial opportunity for growth. The savings are meant to offset investment costs in alternative technologies. This means access to production is very difficult to obtain even when it is available at all. In order to support new technologies, these licences can be issued for reduced fees (marine) or no fee at all (e.g. land-based RAS in Norway). This requires a high fee to be established in the first place, then preferred technologies can be charged less in order to help advance more sustainable technologies.
- **Local benefits** – Following on the last topic regarding high fees established in Norway, there has been a recognition that benefits should be enhanced for communities that host marine aquaculture production. Norway's Ocean Strategy reported that large portions of the proceeds from new aquaculture licences are now allocated to the local municipalities.
- **Payroll rebates** – These can be helpful, although the labour requirements for new technologies tend to be less than for conventional aquaculture so this is not a strong incentive for investment in new tehnologies.
- **Research and development funding and credits** – Canada has a suite of programs to support research and innovation costs, but there is always a need to target these toward priorities in a coordinated fashion. Identifying technology expansion in aquaculture as a top priority will help to align federal, provincial and regional programs. The various agencies should be aware of projects that are being moved forward so that support can be maximized or duplication avoided as appropriate. The European Union's (EU) Horizon 2020 funding program, for example, provided €1.94 (Euros) for Aquafarm Equipment to develop their Neptune floating CCS technology at commercial scale. This is part of the EU Blue Growth Strategy to sustainably develop more resources from the oceans without compromising benefits for future generations. In Norway there is a small levy on all salmon exports and collected in a fund to be matched 50-50 with industry investments in research and development.
- **Accelerated capital depreciation** – each of the technologies in this report are more capital intensive than conventional netpen aquaculture and could benefit from accelerated depreciation of capital. The attraction of this tool is that the benefit flows when it is most needed up front, and then diminishes over time as the balance sheet improves. The Canada Revenue Agency (CRA, 2019) does offer an Accelerated Investment Incentive program for manufacturing and processing equipment (e.g. fish processing) and for clean energy equipment that may be part of new salmon production systems.
- **Joint ventures** – Government can play a role by working with private companies and other organizations to invest in new technology. This has already been done with Namgis' Kuterra project in order to demonstrate the feasibility of land-based RAS

for grow out at small commercial scale. This model is an option for other technologies going forward.

- **Guaranteed loans** – This is the last form of incentive profiled since it was not raised as a key tool for attracting investment. Unlike five to ten years ago, there is a current belief that investors have sufficient capital to initiate projects. This is clearly occurring with land-based RAS in the U.S., China, and Europe. This form of financial incentive nevertheless helps, but the other incentives and removal of barriers or gaps is likely more important. Furthermore, the companies building land RAS for grow out and offshore systems are now offering to lease their systems. This removes the need to raise capital, and risks associated with the system remain with the supplier. This reduces the need to tap loans from government and builds trust in the system, so salmon producers can just focus on growing their products for market. Guaranteed loans could play a role in pilot projects, smaller independent commercial developments, and Indigenous community involvement in new technology deployment.

5.5 Biomass allocation

The introduction to this report highlighted the slowing pace of salmon aquaculture production globally and in B.C. despite the strong and growing demand for products. This tension creates a strong desire from aquaculture companies to gain access to biomass allocations. As mentioned above, Norway has ensured that access to biomass is tied to use of the best performing technologies.

- **New biomass allocations** – The main principle is that growth should be allowed only when and where the environmental footprint is acceptable. This approach involves new biomass allocations being contingent on investment in new technologies. New allocations can include renewal of existing sites once leases expire, incremental additions of biomass at existing sites, or approval of altogether new sites. Decisions to support additional allocations at existing sites or new sites are rule-based and have more stringent environmental performance requirements (e.g. minimized sea lice levels, no escapes, and reduced benthic impacts). This drives the need to invest in new technologies including land-based RAS for grow-out, floating CCS, or offshore systems. This provides companies with enhanced financial means (revenues and profits from production) and incentives to invest in the new technologies.
- **Trading in open netpen sites** – Norway has issued biomass allocations under new technologies with the requirement for companies to retire an existing open netpen site. This effectively transitions the industry to new technologies over time.
- **Hybrid system as stepping stone** – Although performance of this system is not as high as the other alternatives considered, this one does put in place elements that can support development of the other technologies in the future. Expansion of land-based RAS facilities for post-smolt production can be pushed to larger sizes and full market size in the future. Post-smolts will be needed for floating CCS and offshore systems once they are established. The advancements in marine vessels and other system components also necessary for other systems. The hybrid system may be a

way to get known infrastructure in place, while less developed technologies are finalized for commercial adoption.

5.6 Innovation support in Canada

A number of people interviewed in Canada remarked that "we already know how to support innovation; the approach in other sectors just needs to be applied to aquaculture". The issues and concerns with conventional aquaculture may have prevented a concerted effort to support research, expansion, and export development. With a clear aim to support innovative technologies that address key issues and move beyond current approaches, perhaps a renewed coordination of programs will be possible.

Available elsewhere in Canada:
Growers in B.C. indicate that Atlantic Canada aquaculture companies have access to more support programs that are not available in B.C. or are not designed for the aquaculture sector.

- **The Atlantic Innovation Fund** (AIF) encourages partnerships among private sector firms, co-operatives, universities, colleges and other research institutions to develop and commercialize new or improved products and services.
- **Innovative Communities Fund** (ICF) invests in strategic projects that build the economies of Atlantic Canada's communities, including projects that enhance environmental performance.
- **The Atlantic Trade and Investment Growth Strategy** is a homegrown, historic, and groundbreaking initiative — the first of its kind in Canada — to grow export and boost foreign investment in the region.
- **Atlantic Canada Opportunities Agency (ACOA)** - has supported land-based RAS developments, as well as adoption of new systems or system components for netpen aquaculture.

Focused on other sectors in Canada:
B.C. operators also note that federal programs and those particularly developed for agriculture do not offer similar access for the aquaculture sector, or in some cases aquaculture is ineligible for funding. There are indications from Agriculture Agri-Food Canada that the lack of funding eligibility for aquaculture stems from the view that aquaculture does not fit clearly in the department's mandate. This is a prime example of the need for aquaculture to have it's own clear legislation and policy rather than falling between the lines of different departments.

- **The Innovation, Science and Economic Development Portfolio** - Seventeen federal departments and agencies contribute and are uniquely positioned to further the government's goal of building a knowledge-based economy in all regions of Canada and to advance the government's jobs and growth agenda. This should be re-examined for strengthening the focus and support for advancing the four new production technologies in this report.

- **Agricultural Clean Technology Program** - Funding for projects led by provincial and territorial governments for clean technology research, development, demonstration, commercialization and adoption projects in Canada's agriculture and agri-food sectors ($25 million over three years).
- **AgriInnovate Program** - This program provides repayable contributions for projects that aim to accelerate the demonstration, commercialization and/or adoption of innovative products, technologies, processes or services that increase agri-sector competitiveness and sustainability.
- **AgriScience Program** - The program aims to accelerate the pace of innovation by providing funding and support for pre-commercial science activities and cutting-edge research that benefits the agriculture and agri-food sector and Canadians.
- **Indigenous Agriculture and Food Systems Initiative** - Supports Indigenous communities and entrepreneurs who are ready to launch agriculture and food systems projects and others who want to build their capacity to participate in the Canadian agriculture and agri-food sector.
- **Canadian Agricultural Partnership (formerly Growing Forward)** - For over 15 years, the Canadian government has used agriculture policy frameworks to enhance the competitiveness of agriculture and agri-food companies. The Canadian Agricultural Partnership is a five-year, $3 billion federal-provincial-territorial investment in the agriculture, agri-food and agri-based products sector that began in April 2018, and a five-year $5 million B.C. Agrifood and Seafood Market Development Program is available. This is a small portion of the program and does not support technology development, while land-based parts of the program do.

Need increase support and priority for aquaculture:
Aquaculture is eligible for funding under some federal programs, but these are not targeted solely to the aquaculture sector or are insufficient to support the potential growth of new technologies. These programs need to be prioritized toward aquaculture by allocating more funding and/or creating categories that are focused on new production system technologies in aquaculture.

- **DFO Fisheries and Aquaculture Clean Technology Adoption Program –** This four-year program offers $20 million with a sunset in 2021. Funding up to 75% of eligible project costs is for integration of market-ready clean technologies in day-to-day operations. This has supported integration of RAS technology at a B.C. salmon farm, as well as installation of a biodigester to process fish waste and produce power for a land-based facility;
- **DFO Atlantic Fisheries Fund –** This program, only in Atlantic Canada, offers $295M with a sunset in 2024, and supports research and development of new innovations, bringing them to market, and the creation of partnerships and networks that help innovation in the sector;
- **DFO B.C. Seafood Innovation and Restoration Fund –** Funding is available in B.C. only, for $142.8 million with a sunset in 2024. Current priorities include projects that meet criteria for improved sustainability of the aquaculture industry to ensure the protection and conservation of marine ecosystems and wild fish populations;

- **Sustainable Development Technologies Canada (SDTC):** SDTC funds research and development of new technologies across a range of economic sectors. Funding has already supported the Kuterra land-RAS development ($5 million) and floating closed-containment development in Middle Bay, B.C. ($2 million). SDTC is working with DFO and the B.C. Government to advance new aquaculture production technologies, especially sensor and data technologies that will support sustainable growth of aquaculture in Canada.
- **Aboriginal Aquaculture in Canada Initiative (now under Northern Integrated Commercial Fisheries Initiative) –** This DFO led initiative supports development of Indigenous-owned communal commercial fishing enterprises and aquaculture operations. Aquaculture development funding is available to help Indigenous communities and groups develop sustainable aquaculture operations. This includes costs to expand or upgrade existing aquaculture facilities, for materials required in new and expanded operations, and those associated with entering into an aquaculture business. The intent of this funding is to support capacity-building, revenue and profit generation, employment generation, and self-sustainability of aquaculture operations.
- **Innovation, Science and economic Development (ISED) Canada Super Cluster Initiative –** This is a five-year $950 million funding program with a sunset in 2022, including an Ocean Supercluster. This is the first program of this nature in Canada where funding is delivered to industry-led consortia of businesses, post-secondary institutions, research and government partners. The Ocean Supercluster involves industries such as: marine renewable energy, fisheries, aquaculture, oil and gas, defence, shipbuilding, and transportation. The technology and innovation focus is: digital sensors and monitoring, autonomous marine vehicles, energy generation, automation, marine biotechnology and marine engineering technologies; and
- **NRC Industrial Research Assistance Program –** This program is designed for all stages of innovation in small and medium enterprises (SMEs), and offers financial assistance, advisory services, and connections to experts in Canada.

5.7 Outlook

There is excitement across industry, government, and ENGOs at the prospect of transforming aquaculture production and realizing its full potential. After many years of commercial scale solutions remaining elusive, there is no doubt that technologies now offer the means to improve performance. Environmental, social, and economic objectives can be advanced simultaneously. Popular press articles speak of “inflection points”, “tipping points”, “game changers” when describing commercial projects going forward around the world.

The new technologies discussed in this report, as well as conventional netpen systems, will all play a role in contributing to global production of salmon products. They will compete with one another for investment and expansion opportunities, and they will also compete with other seafoods and protein sources among the choices available to consumers. While certain higher-end product forms (e.g. sushi, smoked salmon), market channels (e.g.

restaurants, specialty food stores), and countries may initially help new technologies succeed, the increasing global supply of salmon will ensure the majority of salmon is sold to price sensitive buyers. New technologies developed in Canada must continually seek efficiencies to match low-cost competitors and remain competitive through periods of price variability.

Setting the course for new production systems in B.C., done properly, will move aquaculture beyond the contentious debate that has afflicted the sector for decades. New technology should be facilitated and encouraged so that improved systems replace existing ones. This will not automatically happen within the aquaculture sector and will require a coordinated and concerted effort to put in place incentives, clear requirements, and the innovation culture that is critical. Building on partnerships between companies, other coastal resource users, Indigenous communities, and governments, a collaborative approach will allow all interests to participate in future success.

Key findings and next steps:

- **Advancing performance -** Each of the production technologies can advance environmental, social, and economic performance of salmon aquaculture in B.C.;
- **Commercial readiness -** Land RAS and hybrid production technologies are ready for commercial development in B.C., while floating containment and offshore production systems need up to 5 years and 10 years respectively to evaluate their potential;
- **Legislation and policy –** A clear national legislative and regulatory framework is needed for aquaculture that supports future development of production technologies;
- **Innovation culture –** Collaboration between industry, government, Indigenous people, academic, and other research centres requires concerted efforts to facilitate information sharing and support for research that addresses challenges;
- **Biomass allocation –** Investment will follow growth opportunities so approvals for more biomass production, especially in the marine environment, must be tied to requirements that are met by the higher performance of new production technologies;
- **Financial incentives –** Existing funding for aquaculture innovation and Indigenous participation need to be prioritized and expanded, and eligibility for funding programs available to other industry sectors pursuing sustainable development needs to be examined;
- **Technology-specific measures –** Identification of suitable sites is needed for land-based RAS production and offshore commercial development. Research support and financial incentives are more appropriate for hybrid systems and floating containment respectively; and
- **Leadership –** Countries currently leading aquaculture innovation developments have taken bold steps to advance environmental, social, and economic objectives together. Canada's aquaculture sector can grow rapidly to a level on par with global leaders with leadership from all key players.

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