S2G INVESTMENTS

Aquaculture Feed Innovation: A Critical Unlock to Global Food Security

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By 2050, the global population is expected to approach 10 billion.[1]

Meeting the nutritional requirements of this population will demand roughly 70% more food than is produced today,[2] with much of that increase needing to come from high-quality protein. Expanding farmland, extracting more freshwater, or intensifying chemical inputs is not a sustainable path forward. Soils are already degraded across large regions, freshwater reserves are nearing ecological thresholds, and climate change is undermining the stability upon which food systems depend.

The ocean plays a central role in maintaining this stability. It absorbs more than 90% of excess anthropogenic heat and around one-quarter of global carbon dioxide emissions,[3] shaping climate patterns that directly affect agriculture. Yet its resilience is weakening. The 2025 Planetary Health Check from the Potsdam Institute for Climate Impact Research reports that the Ocean Acidification boundary has now been assessed as breached for the first time.[4] Since the industrial era, surface ocean pH has dropped by 0.1 units—a 30–40% increase in acidity[5]—reducing the ocean's ability to buffer climate change and pushing marine ecosystems beyond healthy limits.

Within this context, aquaculture emerges as a critical pathway for future food security. It already supplies more than half of seafood consumed globally and is projected to provide nearly two-thirds by 2030.[6] Aquaculture is among the most efficient converters of feed into animal protein, often outperforming terrestrial livestock by wide margins. Yet its future hinges on reimagining aquafeed, which accounts for up to 70% of production costs and much of the sector's environmental footprint.[7] How feed is produced will determine whether aquaculture can scale sustainably to meet rising nutritional demand.

Why Seafood Matters for Global Food Security

Seafood occupies a central position in global nutrition, providing both a major source of protein and essential nutrients that are difficult to replace.

- **More than 3.3 billion people** rely on seafood as their primary source of animal protein,[8] with reliance exceeding 50% in parts of Southeast Asia, West Africa, and small island states.[9]
- **For one in 10 people worldwide,** fish provides over 20% of their total animal protein intake.[10] In regions where access to other protein sources is limited, seafood is often the most affordable and culturally significant option.

The importance of seafood extends beyond its role in supplying calories. Fish provide long-chain omega-3 fatty acids, which are critical for brain development, cardiovascular health, and maternal and child outcomes, as well as highly bioavailable micronutrients such as iodine, selenium, vitamin D, and zinc. These nutrients are often lacking in terrestrial foods and play essential roles in reducing malnutrition and disease burden.

Aquaculture has become the engine of this supply. Global aquaculture now accounts for more than 56% of seafood consumed, a share that is projected to rise to nearly two-thirds by 2030.[11] This expansion represents an additional 50 million tons of seafood production in less than a decade. Yet growth at this scale depends on the availability of feed. Meeting demand will require more than 60 million additional tons of feed ingredients annually,[12] a challenge that places aquafeed at the center of global protein security.

The efficiency of aquaculture compared to terrestrial livestock makes this challenge worth addressing. Farmed fish convert feed into edible protein far more effectively than cattle, pigs, or poultry, with three to seven times greater efficiency than beef.[13] This advantage positions seafood as one of the most sustainable options for expanding protein supply within planetary boundaries. However, without innovation in feed systems, aquaculture risks replicating the ecological limitations of terrestrial livestock: resource depletion, emissions, and ecosystem impacts. Whether seafood can fulfill its role as a cornerstone of global food security will depend on transforming how farmed fish are fed.

The Constraints of Today's Feed System

Aquaculture's expansion has been enabled by a handful of core feed ingredients that provide the protein and energy needed for fish growth. Chief among these are fishmeal, derived from wild-caught forage fish, alongside terrestrial crops like soy and canola, and rendered animal byproducts. The industry's dependence on these ingredients exposes aquaculture to risks familiar from terrestrial livestock: resource depletion, volatile commodity markets, and environmental impacts.

Fishmeal ties aquaculture to the health of wild fisheries, while soy connects it to global land-use and deforestation debates. Alternative plant proteins help diversify supply, but their nutritional limitations and competition with human food markets constrain adoption. Animal byproducts offer cost-effective protein, yet concerns over quality, traceability, and consumer acceptance curb broader use.

Understanding these legacy inputs is essential to charting a new course. They represent the foundations upon which aquaculture has scaled so far, but also the bottlenecks that threaten its future.

Fishmeal & Fish Oil

Usage

Most farmed fish today are fed diets rich in fishmeal and fish oil derived from wild-caught forage fish. Each year, around 16 million tons of wild fish are caught and processed into feed, which represents nearly one-fifth of the global wild-caught seafood supply.[14] Fishmeal and fish oil have been central to aquaculture growth due to their digestibility, amino acid balance, and omega-3 content.

Limitations

- Represents one of the least efficient protein transfers on Earth, with 35–50% lost as byproducts, mortality, or spoilage.
- Depletes ecosystems by removing prey for seabirds, whales, and predatory fish.
- Reduces availability of omega-3 for direct human consumption, diverting nutrients that are scarce in global diets.
- Undermines the livelihoods of small-scale fishers in regions like Peru and Senegal.
- Leaves producers exposed to volatile commodity markets, with fishmeal often above $2,000 per ton and fish oil exceeding $3,000 per ton.[15]

Outlook

While fishmeal and fish oil will likely remain in aquafeeds at reduced levels, reliance on wild fisheries caps supply and exposes producers to ecological and economic risks. Aquaculture's ability to scale will largely depend on supplementing or replacing these inputs with alternative proteins and oils to ensure aquaculture can scale sustainably.

Soy

Usage

For the last two decades, soy protein has been the backbone alternative to fishmeal. It is abundant, relatively inexpensive, and nutritionally valuable, accounting for up to 20–30% of some salmon diets.[16] Without soy, the rapid growth of aquaculture would not have been possible.

Limitations

- Requires supplementation since it lacks key amino acids and contains anti-nutritional factors that strain digestion.
- Production is tied to deforestation, fertilizer and pesticide use, and high GHG emissions.[17]
- Prices are volatile, and supply is under pressure from its role as the foundation of swine and poultry feed and a significant part of human diets.
- Heavy reliance on soy raises systemic risks of competition for land, water, and food security.

Outlook

Over time, soy is expected to shift from being the dominant substitute for fishmeal to serving as one ingredient within a more diverse, resilient protein portfolio. Innovation is emerging through higher-protein soybean varieties, deforestation-free sourcing commitments, and integration with alternative proteins.

Secondary Plant Proteins

Usage

Plant proteins such as canola, corn gluten, pea, and sunflower meal are increasingly used to diversify diets and lower dependence on fishmeal. They offer relatively consistent supply chains and can partially substitute protein requirements across freshwater and marine species.

Limitations

- Poorer amino acid balance compared to fishmeal.
- Anti-nutritional factors and digestibility issues can impair growth and increase waste output in ponds and cages.
- Compete with human food and livestock feed, creating price and supply challenges.

Outlook

Advances in processing, selective breeding, and fermentation are improving digestibility and protein quality, but most of these ingredients will remain partial replacements rather than full substitutes for fishmeal.

Animal Byproducts

Usage

Rendered animal proteins from poultry, blood, and feathers are cost-effective feed inputs, often used to replace part of the fishmeal fraction. They recycle nutrients from terrestrial livestock systems and can perform well in carnivorous species when processed correctly.

Limitations

- Variable quality depending on raw material and rendering process.
- Consumer and regional resistance to animal byproducts in aquafeeds.
- Biosecurity concerns if processing standards are not met.
- Competition with poultry and swine feed markets can limit stable supply.

Outlook

With standardized processing and traceability, animal byproducts can remain an efficient, circular feed source. However, long-term reliance is constrained by consumer perception and limited scalability compared to emerging protein innovations.

The Feed Innovation Landscape

Aquaculture's ability to scale largely depends on building a more diverse and resilient feed system. To secure the sector's role in global food security, innovation is essential.

What makes this transition particularly compelling is that many of these solutions are already proving their value in adjacent markets. Insects, algae, and functional additives are gaining early traction in petcare, where demand for sustainable, high-quality nutrition is strong and margins allow new technologies to scale. This dynamic provides innovators with proof-of-concept, revenue, and operational experience before moving into aquafeed at industrial scale. The cross-sector momentum highlights the role of pet nutrition as an accelerator for aquafeed innovation.

Taken together, these developments signal that the building blocks of a new feed system exist today, are scaling, and are beginning to reshape how nutrients are sourced, processed, and delivered. The challenge now is to expand these innovations from niche and high-value applications into bulk aquafeed markets, where the greatest impact on food security, climate, and ecosystems can be realized.

Diversification of inputs is at the core of this transition, with alternative proteins alone representing up to an estimated $15 billion opportunity in the coming decade.[18]

Case studies are provided for illustrative purposes only as examples of the S2G team's investment experience and do not purport to be a complete list of investments. There should be no assumption that future investments will be similar in quality or performance. A full list of S2G portfolio companies is available upon request.

Alternative Proteins & Oils: Insects, Algae, and Microbial Proteins

The search for sustainable aquafeed ingredients has accelerated innovation beyond traditional fishmeal and fish oil.

New protein and oil sources are emerging that bypass the land, water, and ecological pressures of conventional agriculture and wild fisheries. These solutions deliver essential nutrients while reducing dependency on volatile commodity markets. Insects are recycling organic waste into protein-rich meal, algae is generating omega-3 oils without depleting marine stocks, and microbial proteins are harnessing fermentation to turn carbon into high-value inputs with companies such as Calysta and Unibio pioneering this pathway.

Market Size

$10-15B

The global alternative protein market for aquafeed is projected to reach between $10-$15 billion by the early 2030s.[19] The fastest growth is expected to come from insects and algae. Already, dozens of pilot plants are scaling up production, with Europe and Asia taking the lead in both regulatory approvals and commercial deployment.

$4.6B

The global market for fish oil alternatives (non-fish sources of omega-3s) was estimated at ~$2.8 billion in 2025, with projections to reach $4.6 billion by 2035.[20] Rising demand for plant-based and algae-derived omega-3s in aquaculture, dietary supplements, and functional foods is driving this growth. Industry analysts note that algae oil in particular is expanding rapidly, supported by new investments in large-scale fermentation facilities and growing corporate commitments to sustainable feed ingredients.

Case Studies

Mara Renewables

Scaling Algae-Based Omega-3

Mara produces algae-based omega-3 ingredients that remove dependence on wild caught fish. Omega-3 is a critical component of aquaculture feed, yet most supply today still comes from forage fisheries under increasing pressure. Mara has developed a fermentation system that grows microalgae, the original source of these fatty acids in marine ecosystems, to create consistent, high-quality omega-3 inputs for aquaculture and animal feed, supplements, functional foods, and infant nutrition. In 2024, its production displaced the equivalent of 6.7 billion anchovies from the supply chain.[21] Its marine-free approach helps ensure reliable supply, removes contaminants, and supports cleaner formulation options. With proven industrial-scale manufacturing, Mara has built commercial momentum across global markets.

Enthos

Feed Solutions Powered By Black Soldier Flies

Enthos Circular Feed Technologies is building scalable insect protein infrastructure to convert food waste into high-quality feed ingredients using Black Soldier Fly (BSF) larvae. BSF systems can yield up to 1,500 times more protein per hectare than soy, and the larvae themselves can grow more than 200 times their original size in about 15 days.[22] Enthos' flagship facility in Colombia aims to be one of Latin America's largest insect protein production hubs. By upcycling organic waste, Enthos reduces reliance on volatile fishmeal and soy markets while lowering feed costs and environmental impact. Life cycle studies show BSF proteins emit just 0.017kg CO_2e per kg protein, compared to 57-500 kg for conventional protein sources.[23]

What the Industry Needs to Grow

For alternative proteins and oils to succeed, producers must achieve both scale and cost competitiveness with conventional inputs. Production must expand into the hundreds of thousands of tons annually to rival soy and fishmeal, while also ensuring steady omega-3 oil supply to replace fish oil. In many cases, producers cannot rely on premium pricing and must compete at parity or discount levels. Challenges include consistent feedstock access, cost of controlled environments, shipping logistics, and limited ability to deliver complete feed solutions. Stable regulatory frameworks and long-term offtake agreements with feed majors such as Skretting, Cargill, and BioMar remain critical.

Hurdles

Scaling production of alternative proteins and oils requires significant upfront capital, whether for bioreactors, fermentation tanks, or insect farms. Uncertainty across regions continues to slow regulatory approvals, especially for novel oils. Consumer perception is another risk, as buyers may view non-traditional ingredients as "unnatural" without clear education and sustainability credentials. Overcoming these barriers will require capital, policy support, and evidence of both nutritional performance and cost competitiveness.


Mara Renewables


Enthos

Circular Economy Feeds: Turning Waste into Value

A defining feature of the global food system is inefficiency, with more than 1.3 billion tons of food wasted annually.[24]

Circular economy feed solutions address this imbalance by capturing nutrient streams that would otherwise be discarded and converting them into inputs for aquaculture. This reduces pressure on land and ocean ecosystems while improving waste management. Byproducts from food processing, invasive species removal, and insect bioconversion are emerging as promising sources of feed-grade protein and oils. These pathways displace conventional inputs and create closed-loop systems where waste becomes a resource, advancing both ecological and economic resilience.

10%

The market potential for circular feeds is vast. If just 10% of global food waste were redirected, it could replace millions of tons of soy and fishmeal.[25] This shift would equate to several billion dollars in feed value. A growing number of projects are already demonstrating this potential, particularly those that convert food industry byproducts, fish trimmings, and invasive species into feed-grade protein.

Case Study

Aquatic Protein

Harnessing Invasive Species for Feed

Aquatic Protein is converting invasive Asian Carp and other low-value fish species into high-quality fishmeal and fish oil for use in aquaculture and animal nutrition markets. Its Midwest facility focuses on remediating invasive carp from the Mississippi River Basin, purchasing catches from commercial and bow fishers who otherwise struggle to sell in small quantities. Invasive carp have proliferated for over 50 years and are now a top multi-state management priority, threatening native fish and Great Lakes access. Commercial harvest programs in Illinois and other states have demonstrated that targeted removals can reduce carp densities and reproductive potential. By creating an offtake market for invasive species, Aquatic Protein supports local livelihoods and alleviates pressure on forage fisheries, while producing cost-efficient alternatives to conventional feed inputs.

What the Industry Needs to Grow

For circular feeds to expand meaningfully, several conditions must be met. Access to a consistent feedstock supply is critical, and a key question remains of who bears the cost of sourcing and processing waste. Infrastructure for collection, sorting, and safe processing must be developed at scale, along with the ability to handle food-grade products within cold chain systems. Just as important is establishing proof of biosecurity, ensuring that no pathogens or contaminants are introduced into feed supplies.

Hurdles

Despite the promise of circular feeds, scaling beyond niche or localized supply chains remains difficult, as does managing the logistics and variability of feedstock. Regulatory scrutiny over food safety and animal health adds further complexity, creating barriers to broad adoption. Overcoming these challenges will be necessary for circular feeds to reach their full potential as a sustainable and economically viable feed solution.

Precision Nutrition: Smarter Feeding with AI and Data

Feed typically accounts for the largest share of aquaculture operating costs, yet a substantial portion is wasted.[26]

This inefficiency raises expenses and contributes to water pollution and other environmental impacts. Precision nutrition tools address this challenge by aligning feed delivery with fish appetite and growth needs in real time. Companies are deploying AI-driven cameras and sensors that monitor fish behavior, enabling farmers to adjust feeding accordingly. By preventing overfeeding and tailoring diets more effectively, these tools reduce costs, minimize ecological impacts, and support better animal health.

Market Size

$1-2B

The market for digital aquaculture solutions is projected to exceed $1-2 billion by 2030 as farms scale up adoption of AI platforms.[27] The opportunity is significant given that feed represents the majority of farm costs, meaning even modest efficiency gains deliver substantial upside. The sector has already drawn strategic interest, illustrated by sales such as Google's Tidal platform to Kverva and Optoscale's transaction with Insight Partners. These moves highlight strong demand from investors and corporates seeking to capitalize on the shift toward data-driven aquaculture.

Case Study

ReelData

Precision Feeding Powered by AI

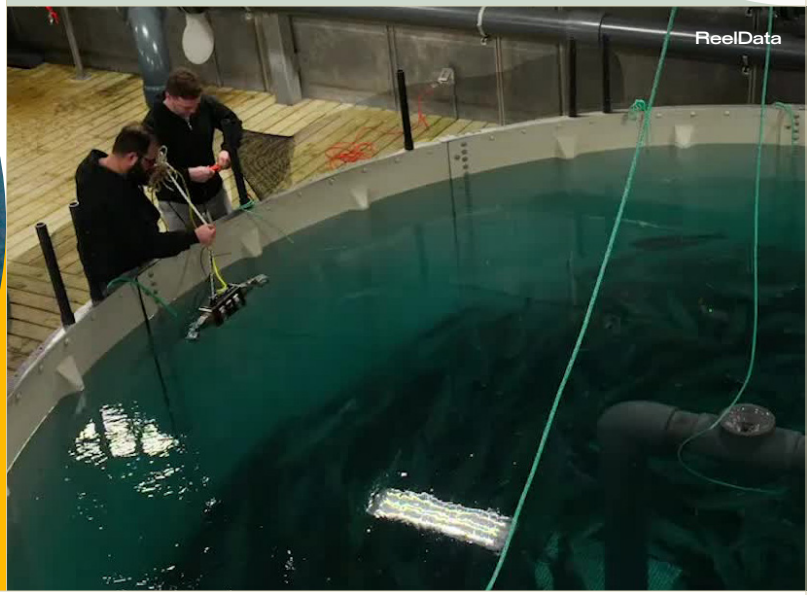
ReelData is an AI-driven technology company optimizing land-based aquaculture through advanced monitoring and predictive analytics that automate smarter feed management. Its platform uses machine learning, imaging, and continuous behavioral analysis to measure biomass, interpret appetite signals, and adjust feeding in real time. By aligning feed delivery to fish behavior, ReelData helps reduce feed waste by up to 25% and accelerate growth rates by 10–15%.[28] This closed-loop approach limits overfeeding, stabilizes conditions, and flags irregular patterns early so farmers can intervene before stress or disease slows performance. The result is lower input costs, more uniform growth, and more predictable harvest cycles.

What the Industry Needs to Grow

Broader digital infrastructure on farms is critical, including reliable connectivity, cameras, and sensors. The integration of diverse environmental data sets will improve the accuracy of AI tools and allow platforms to inform feed optimization and diet formulation. Demonstrating clear and consistent returns on investment across multiple species and geographies is essential to building farmer confidence. Ultimately, establishing data-sharing ecosystems among farms, feed suppliers, and technology providers will facilitate the acceleration of both adoption and innovation.

Hurdles

Many traditional or lower-margin farms remain resistant to adopting new technology, often due to concerns about cost and complexity. The upfront expense of cameras and sensors can be a barrier, although this is increasingly addressed through leasing models or trial programs that demonstrate payback before requiring large capital commitments. Another hurdle is the need for large, high-quality datasets to train algorithms effectively across diverse environmental and operational conditions.



Functional Feeds: Feeding Health, Not Just Growth

Disease remains one of the most significant risks in aquaculture, costing producers billions annually and constraining sector growth.[29]

Traditional reliance on antibiotics is increasingly untenable due to regulatory restrictions, resistance concerns, and consumer preferences. Functional feeds represent a new paradigm: nutrition as a tool to enhance immunity, resilience, and overall animal welfare. By incorporating probiotics, immunostimulants, vitamins, and bioactive compounds, functional feeds are shifting the role of aquafeed from simply supporting growth to actively safeguarding health. These approaches mirror broader trends in human nutrition and medicine, positioning feed innovation as a cornerstone of more resilient aquaculture systems.

Market Size

$3-5B

Functional additives already represent a $3-5 billion segment within the aquaculture feed market, and the sector is expanding rapidly as disease remains one of the industry's most costly challenges.[30] Shrimp and salmon are particularly vulnerable, creating strong demand for new solutions.

Case Studies

Kuehnle AgroSystems

Functional Feeds for Resilient Aquaculture

Kuehnle AgroSystems (KAS) is pioneering functional feed solutions for aquaculture by producing natural, algae derived astaxanthin, a key antioxidant and pigment used in salmon, trout, and shrimp diets. The company uses a patented dark fermentation process that grows non GMO microalgae without light, which drives a 90% cost reduction compared to traditional photobioreactor systems and delivers 75% lower GHG emissions, 85% lower water use, and 98% lower land use than other natural astaxanthin sources used in aquaculture. This model lowers production costs and minimizes resource intensity in a market where most astaxanthin remains synthetic and petrochemical based, increasing demand for cleaner and more sustainable feed ingredients. KAS recently announced a partnership with Corbion to expand commercialization of its fermentation based astaxanthin for global aquafeed and animal nutrition markets.

ViAqua

Oral RNA Solutions for Disease Control

ViAqua has pioneered a new approach to disease control in aquaculture by using RNA interference technology delivered through mass application in feed to target pathogens directly. Its platform provides oral RNA-based solutions that combat viral and parasitic diseases without antibiotics or chemicals. Its first product targets White Spot Syndrome Virus (WSSV) in shrimp, a pathogen responsible for billions in annual losses and one of the most damaging threats to shrimp farming worldwide. By embedding RNA molecules into functional feed additives, ViAqua triggers pathogen specific immune responses that reduce outbreaks at farm scale. Several studies conducted by ViAqua and its collaborators supports the scalability of oral RNAi delivery methods, showing protective effects against WSSV when dsRNA is delivered through feed.[31] ViAqua delivery method is cost-efficient, scalable, and compatible with existing feeding systems.

What the Industry Needs to Grow

To achieve broad adoption, functional feed solutions must be validated through peer-reviewed trials and commercial-scale pilots that demonstrate consistent impact on disease resistance. Ongoing research and development is needed to refine formulations that combine probiotics, prebiotics, vitamins, and immunostimulants, tailored to the needs of different species and production environments. Substituting antibiotics with functional additives will also require support from regulators, who are tightening oversight on drug use but may apply uneven approval standards across regions.

Hurdles

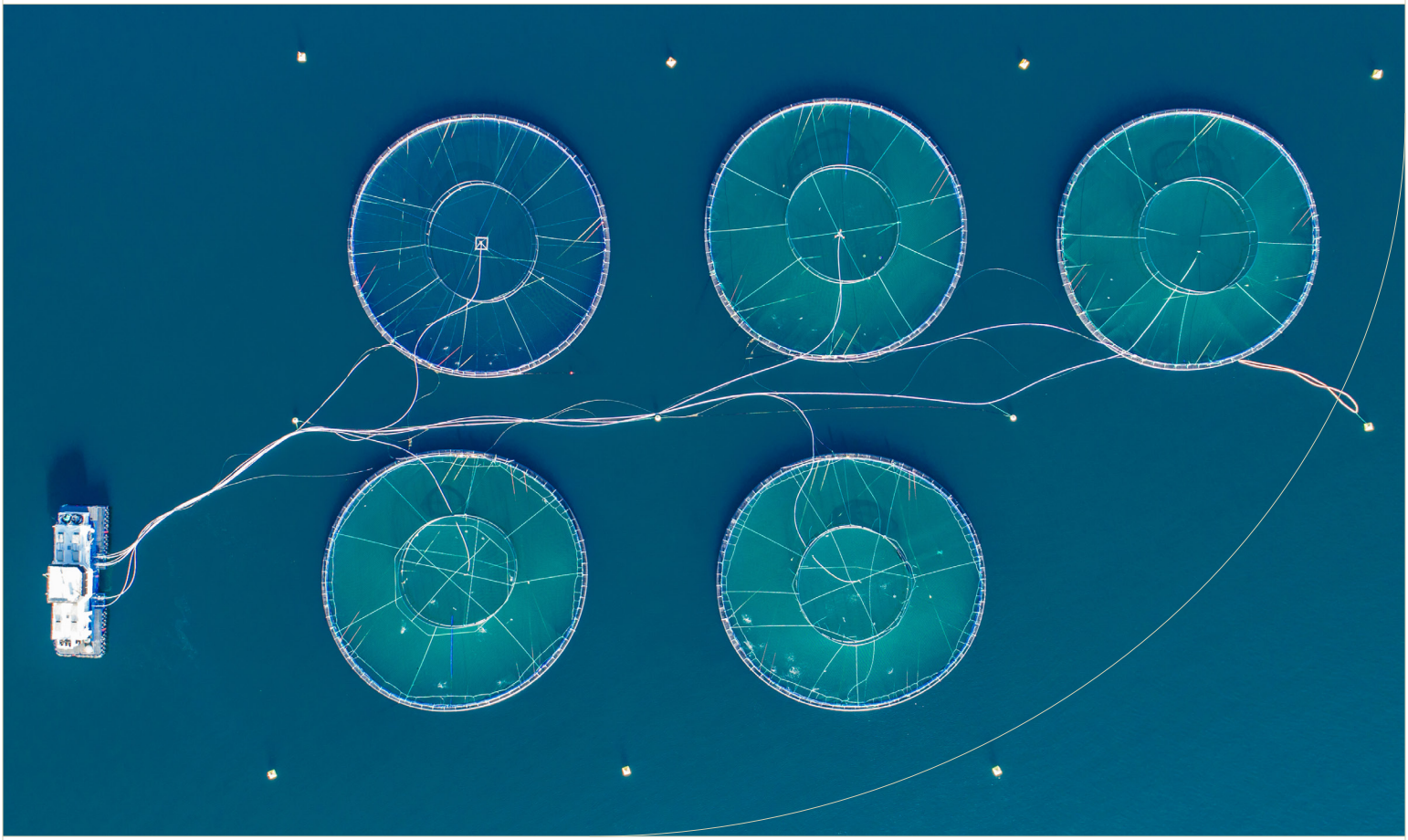
High capital expenditures can limit production capacity, while verification and trust remain key obstacles since farmers demand clear, evidence-based proof of effectiveness before committing to premium-priced products. In commoditized markets, cost premiums can be a significant barrier to entry. Additionally, regulatory frameworks for novel feed additives vary widely across countries, complicating international expansion.

Building the Future Feed System

Taken together, these four pathways—alternative proteins, circular feeds, precision feeding, and functional feeds—represent complementary building blocks of a new feed system that has the potential to transform the $75 billion industry today into one worth $110 billion by 2030, powered by science, sustainability, and investment.[32]

Each addresses a different dimension of the sector's challenges, from reducing feed costs and volatility to improving availability, sustainability, and animal health. When combined, they create a system that is not only more efficient but also more resilient and environmentally responsible.

For investors and innovators, there are clear opportunities. We believe the companies most likely to succeed are those that scale strategically by entering niche markets before expanding into bulk supply, that build strong partnerships with established players such as feed majors and retailers, and that demonstrate compelling returns on investment through measurable reductions in feed costs, mortality, or emissions. By following these models, stakeholders can capture significant economic value while contributing to a global food system that is better aligned with climate priorities, human health, and long-term resilience.



A Reimagined Future of Aquafeed

By 2030, aquaculture will require over 60 million additional tons of feed.[33] Whether this supports global food security or drives ecological strain depends on feed innovation.

A credible path exists. Alternative proteins can cut pressure on forage fisheries and land use. Circular feeds can turn waste into inputs. Precision nutrition can raise feed conversion and cut loss at the pond or tank level. Functional feeds can lower mortality and antibiotic use. Together, these four levers translate science into lower costs, lower emissions, and healthier animals.

The economics align with impact. Diversified ingredients reduce exposure to volatile commodities. Smarter feeding reduces waste and improves water quality. Healthier fish improve survival and yield. These outcomes support farmers, stabilize rural and coastal economies, and expand supply of nutrient-dense seafood for billions of people.

Real progress requires coordinated action. Ingredient innovators must reach industrial scale. Farmers and feed majors must adopt, validate, and lock in supply through offtake. Regulators must provide clear, risk-based pathways. Investors must back proven platforms and disciplined scale-up.

Priorities for Action

- **Procure at scale:**
  Secure multi-year offtake for insect, algal, and microbial inputs.
- **Adopt precision tools:**
  Tie feed delivery to appetite and biomass data across sites.
- **Invest in health:**
  Prioritize functional feeds that reduce disease and antibiotic use.
- **Standardize and verify:**
  Require traceability, biosecurity, and audited performance.

If we act on these steps, aquaculture can deliver more protein with fewer resources and lower emissions. Feed innovation is the central system upgrade that will determine whether aquaculture becomes a durable solution for climate, nutrition, and livelihoods.

About S2G Investments

S2G Investments is a multi-stage investment firm focused on venture and growth-stage businesses across food & agriculture, oceans, and energy. We provide capital and value-added resources to companies and leadership teams pursuing market-based solutions designed to deliver greater value, improved outcomes, and enhanced performance over traditional alternatives. With a commitment to creating long-term, measurable outcomes, S2G provides tailored capital solutions that span venture, growth equity, debt, and infrastructure financing.

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ReelData
ViAqua

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