A Strategic Approach to Sustainable Shrimp Production in Thailand

THE CASE FOR IMPROVED ECONOMICS AND SUSTAINABILITY

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A STRATEGIC APPROACH TO SUSTAINABLE SHRIMP PRODUCTION IN THAILAND

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EXECUTIVE SUMMARY

The farmed-shrimp industry in Thailand has a business opportunity. It can revitalize and reposition itself as a global leader in sustainability, but achieving this will require bold action.

- Thailand was once the second-largest shrimp producer worldwide. But recently, the industry has lost more than half of its market share due to disease, export bans, and unfavorable trade policies.

- Since 2012, shrimp production in Thailand has been cut in half, and its global share has decreased from about 18% in 2012 to about 8% in 2017, leading to quarterly losses as high as $60 million for individual businesses and between $5 billion and $10 billion of lost value for the entire industry. Meanwhile, competitors have displaced Thailand in the global market, producing large amounts of cheaper shrimp and, in some cases, higher-quality shrimp.

- The country's farmers, processors, and feed manufacturers have struggled to recover. The Thai shrimp market is expected to grow only 3% per year over the next five years. In comparison, the global market is expected to grow more than 5% annually.

- Global retailers, importers, consumers, and governing bodies are growing increasingly concerned about environmental and social issues associated with the shrimp industry, including water pollution, destruction of coastal habitats, and the abuse of human and labor rights. Producers that are able to farm shrimp in a more efficient and sustainable manner have an opportunity to rebrand Thai shrimp in the mass market, access a small but fast-growing niche market, and set a new bar for shrimp aquaculture.

- In 2014, the Seafood Task Force, an international industry coalition, was formed to lead Thailand's seafood supply chain toward a more sustainable pathway. This has sparked significant improvements, but much work still needs to be done—and competitors are moving fast.

Thai shrimp producers can benefit from implementing more advanced farming techniques in the near term, but there is a much bigger opportunity at hand.

- Innovative farming methods—including functional feeds that promote shrimp growth and health, as well as effective water treatment systems—can increase farm productivity, reduce the risk of disease, and promote higher output volumes while reducing the use of resources. These methods can boost revenues and EBIT margins in the near term. However, they cannot, on their own, address the larger trends currently reshaping the industry.

- To reduce reputational risk, retailers are pressuring shrimp suppliers for greater accountability and transparency related to product traceability, residue testing, environmental impact, and labor rights. Additionally, import authorities in major markets, such as the US and the EU, are instituting and enforcing tougher regulations to increase seafood safety and ensure that no labor or human rights abuses are part of farmed-shrimp supply chains.

- By offering full product traceability across the supply chain, Thai shrimp producers can gain access to lost markets, enter new markets, avoid import bans and product recalls, charge premium prices to a niche segment of consumers, and gain a competitive edge.

- If Thailand were to regain its peak export levels to the EU, for example, it would be able to yield additional export revenues of up to $300 million per year.[1] Immediate, short-term changes would reap only about 4% of this value, or as much as $12 million.

Indoor farming can be a game changer.

- Indoor farming offers many transformative benefits for the Thai shrimp industry: high and stable volumes, less risk of disease, improved and more consistent shrimp quality, product traceability (if the supply chain is fully integrated), and significantly improved environmental performance.

- Given its up-front costs, complexity, and scale, indoor farming is applicable mostly to large-scale, integrated players, but it provides the most viable route across the industry for strong future performance.

Thailand has always been among the pioneers in shrimp farming. The industry can recover, but competitors are ramping up quickly, flooding the market with inexpensive products. The time for the Thai farmed-shrimp industry to act is now.

This report highlights the current and near-term challenges facing the Thai farmed-shrimp industry and offers multiple recommendations about what Thai shrimp producers and traders can do to succeed financially, boost productivity and efficiency, and become leaders in sustainability. Given that Thailand already has multiple initiatives underway to improve sustainability, it is in an excellent position to regain lost ground in the farmed-shrimp industry.

MARKET FORCES ARE RESHAPING THE GLOBAL SHRIMP INDUSTRY

FARMED SHRIMP IS AMONG the fastest-growing food products in the world. In less than two decades, global production has more than tripled from about 1.2 million metric tons in 2000 to some 4.2 million metric tons in 2017. As the global population and consumer affluence grow, farm-raised shrimp represents an increasingly important source of protein around the world. In the US alone, the average annual consumption of shrimp has risen to four pounds per capita.

In 2017, the global market for shrimp, including farmed and wild-caught shrimp, was valued at about $40 billion. Farmed whiteleg shrimp (the dominant species of farmed shrimp) accounts for about $14 billion. Shrimp production worldwide is expected to grow by more than 5% annually, the greatest demand coming from China and the US.

The overall industry is growing at a record pace, but not all shrimp producers are thriving.

In the early years of this century, Thailand and Vietnam were leaders in the shrimp-farming sector, but the competitive landscape has shifted. Disease outbreaks and rising labor costs have threatened this once-thriving industry in both countries, and competitors such as India and Indonesia have seized the opportunity to dramatically increase their share in the global shrimp market by producing large volumes at low prices. India has become the second-largest shrimp producer worldwide, accounting for 14% of global shrimp production with 600,000 metric tons produced annually—almost double Thailand's current production output.

In 2018, the global shrimp market experienced a price drop that was the result of high inventory levels in import nations such as the US, further squeezing profit margins and giving low-cost players an advantage. This poses an additional challenge because shrimp in most markets is priced on the basis of supply and demand.

Thai producers must find new ways to stay ahead of fast-moving, low-price competitors while coping with demand dynamics. Retailers and regulators are demanding accountability and sustainability in products, and a niche market segment is willing to pay a premium.

The global trend toward environmentally sustainable and socially responsible food production has raised questions about food safety and sustainability within the shrimp industry. Retailers, regulators, and consumers have become much more attuned to the negative environmental and social impact of unregulated shrimp production, including the use of banned chemicals, environmental degradation, and human and labor rights violations.

In a world with 24-hour access to social media, ongoing consumer awareness campaigns, new regulations in importing countries, and accelerated dissemination of information worldwide, retailers face intense pressure to protect their brands from the damage that results from product recalls, scandals, and supply chains that are disrupted by new import controls.

As more attention is focused on these issues, retailers, regulators, and, in some cases, consumers are demanding sustainable, traceable products in nearly all food categories. From 2012 through 2017, the sustainable-seafood segment in major European markets grew by about 12%, while market demand for other seafood segments declined. Similar trends have been observed in the US, though on a smaller scale, and the growth of sustainable products in China has been driven mainly by food safety scandals and government targets. Overall, there is growing demand for responsibly produced shrimp, and a niche consumer segment is willing to pay a premium for it.

A 2015 survey of approximately 3,000 consumers worldwide found that 68% wanted to know where their food was coming from and how it was produced. While statistics show that this consumer-driven pressure is currently less urgent in the US and China, these countries have introduced stricter import regulations and government targets.

Nearly all major retail chains, supermarkets, and convenience stores around the world have pledged to increase their share of sustainably produced food, including shrimp and other seafood categories, and an increasing number of major retailers are requiring suppliers to sign contracts and carry out in-depth due diligence to ensure traceability and adherence to eco-friendly production methods as a form of legal risk insurance. Regulators, too, are increasing their monitoring of shrimp imports for drug and chemical residuals and are threatening to ban imports. Any company charged with regulatory violations would risk suffering serious economic losses and reputational damage.

As the demand for sustainability grows, there is increasing urgency for a paradigm shift toward truly responsible production and sourcing. Retailers' pledges of sustainability and niche consumers' increasing willingness to purchase sustainable products represent forward movement. However, the definition of "sustainability" is not consistently precise. There are many different ways to define sustainability, and retailers and consumers may unknowingly purchase products that fall short in fundamental areas, such as environmental stewardship and social responsibility.

To foster real change, it is important to establish a clear definition of what it means for food to be labeled sustainable. To put it simply, sustainable products should be produced today in ways that do not compromise the ability to produce those same products tomorrow. The products should minimize environmental degradation and the use of natural resources and should be traceable across the supply chain to provide greater transparency and accountability. For sustainability to have maximum impact, it is important for all stakeholders to understand and adhere to these fundamental principles.

Thailand has much to gain from embracing sustainability, and there is a clear incentive for the industry to lead this paradigm shift. As changes are implemented across the supply chain, it will be imperative to align on the definition of sustainability and establish mechanisms that will hold all actors accountable.

THE THAI SHRIMP INDUSTRY IS AT AN INFLECTION POINT

FOUR DEVELOPMENTS HAVE HAD negative impact on Thailand's farmed-shrimp industry in recent years, and they continue to challenge its prospects for recovery: disease outbreaks, market restrictions, export challenges, and environmental and social concerns.

The Perfect Storm Has Hit Thai Shrimp Production in Recent Years

Disease has significantly reduced shrimp farm yields, necessitating production reforms. On account of alleged labor and human rights violations, markets have restricted Thai shrimp imports. Trade policies have had a negative impact on Thai shrimp exports. And shrimp farms have contributed to the degradation of natural resources and ecosystems.

Disease Outbreaks. Two diseases—early-mortality syndrome (EMS) from 2012 to 2013 and Enterocytozoon hepatopenaei (EHP) in 2017—reduced production output of Thai shrimp farms. While other countries have also experienced frequent disease outbreaks, Thailand has arguably been hit the hardest. The EMS outbreak alone cost Thailand an estimated $5 billion to $10 billion in lost export sales.

Although local regulations governing production methods have tightened to mitigate the risk of further large-scale disease outbreaks, the risk of disease in Thailand's shrimp-farming industry remains high. This is because the most common production systems used today—mainly intensive outdoor ponds that exchange water with the natural environment—provide inadequate disease control and can easily become contaminated. Importers and retailers are very aware of this risk.

Market Restrictions. A 2014 investigation by *The Guardian* uncovered alleged human rights violations aboard fishing boats that supply ingredients for feed to the Thai shrimp industry. In light of these allegations, the EU issued a yellow card, warning that Thailand was not sufficiently tackling illegal, unreported, and unregulated fishing.

Products of Thai marine fisheries were not completely banned in the EU, but the regulatory attention and media coverage heightened retailer and consumer awareness, sharply reducing demand for Thai shrimp products when the industry was still recovering from the outbreaks of disease. From 2015 to 2019, crustacean imports from Thailand declined significantly across many member states, including Belgium (down 82%), France (down 85%), Germany (down 76%), Spain (down 100%), and the UK (down 60%). The annual value of imported seafood from Thailand to the EU plummeted from €689 million in 2011 to €368 million in 2016.

In response, European and US retailers, their suppliers, Thailand's major shrimp processors and feed companies, and NGOs established the Seafood Task Force to address these issues. As a result of their work, and that of Thailand's government, the EU lifted the yellow card in January 2019. The decision to lift the yellow card was met with heavy criticism by some international civil organizations that said Thailand has not yet done enough to reform the industry. The Thai fishing and shrimp-farming industry will, therefore, continue to face serious scrutiny from the media and international NGOs for several years to come, necessitating continued and publicly reported improvements from Thai commercial interests and government agencies.

Export Challenges. Market restrictions, such as the EU's yellow card, have had negative impact on Thailand's shrimp industry, but other factors, such as shifting trade policies, have played a role in its decline as well.

In 2015, Thailand lost access to the EU's generalized scheme of preferences (GSP), which allows vulnerable developing countries to pay fewer and lower duties on exports to the EU. As a result, a 7% tariff on Thailand's exports of cooked and processed shrimp rose to 20%. Similarly, the tariff on raw-shrimp exports jumped from 4% to 7%.

The loss of GSP status was exacerbated by the fact that, in 2014, Thailand was in the process of negotiating a free-trade deal with the EU. Unfortunately, a military coup in May of that year cut negotiations short. The EU said it would resume talks only after Thailand held a democratic election. After repeated postponements, the democratic election took place on March 24, 2019.

Another challenge arose in 2018 when the US, one of Thailand's largest export markets, tightened its import rules for shrimp in 2018. Farmed-shrimp exports are now covered by the Seafood Import Monitoring Program (SIMP), which requires full transparency on shrimp origins and trade routes from the point of harvest to the US point of entry. China also imposed stricter regulations on imports in the wake of the food safety scandals. In 2015, for example, the Chinese government revised the 2009 Food Safety Law, imposing stricter controls and supervision on food production and management.

Negative Environmental and Social Concerns. In recent years, the environmental and social impact of Thai shrimp production has become a concern to supply chain actors and regulators alike. It has been suggested that Thai shrimp farmers have pushed the limits of responsible production, contributing to pollution, high-stress conditions, and disease epidemics. Although water treatment has significantly improved since the 1990s, the nutrient and sediment pollution of local water bodies has contributed to eutrophication in the coastal environment. Additionally, because 50% to 65% of mangrove habitats had already been converted and replaced by shrimp farms, the assimilative capacity of processing these nutrients and waste was reduced. Furthermore, human and labor rights abuses in shrimp processing shacks and aboard Thai boats that are fishing for shrimp feed have been publicly documented and widely reported.

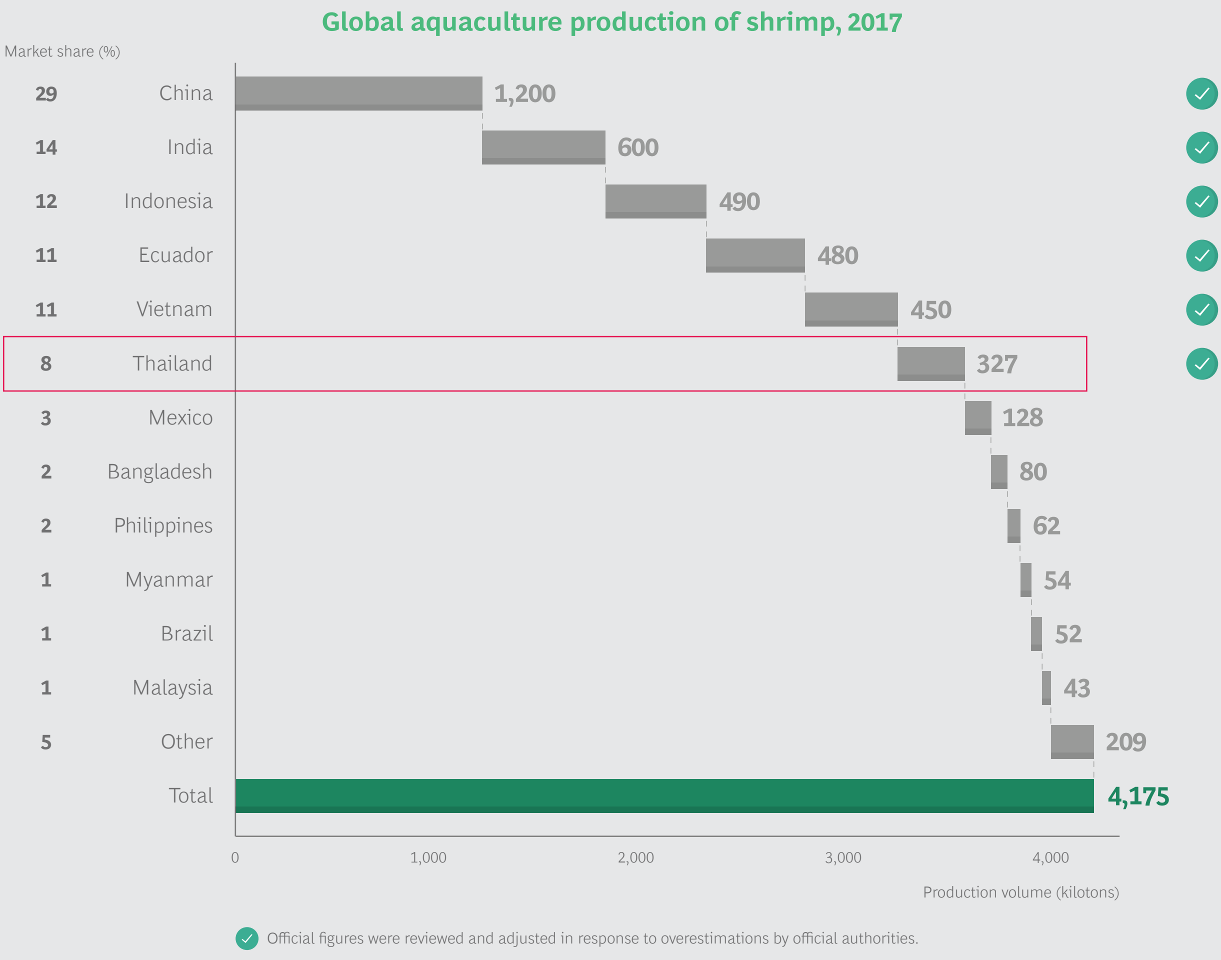
Thailand Is Weathering the Storm but Is Still Losing Ground to Competitors

Since 2012, farmed-shrimp production in Thailand has been cut in half, and its global share has decreased from 18% in 2012 to 8% in 2017. Thailand is currently the world's sixth-largest producer of shrimp; it was the second-largest producer in 2012.[2] (See Exhibit 1.)

Thailand's farmed-shrimp market is recovering very slowly. (See Exhibit 2.) At its current growth rate, the market will need more than 20 years to return to the previous peak-production levels of 2012. In the meantime, Thailand's competitors are increasing their own production and market share. India's estimated production growth rate, for example, stands at 11% per annum.

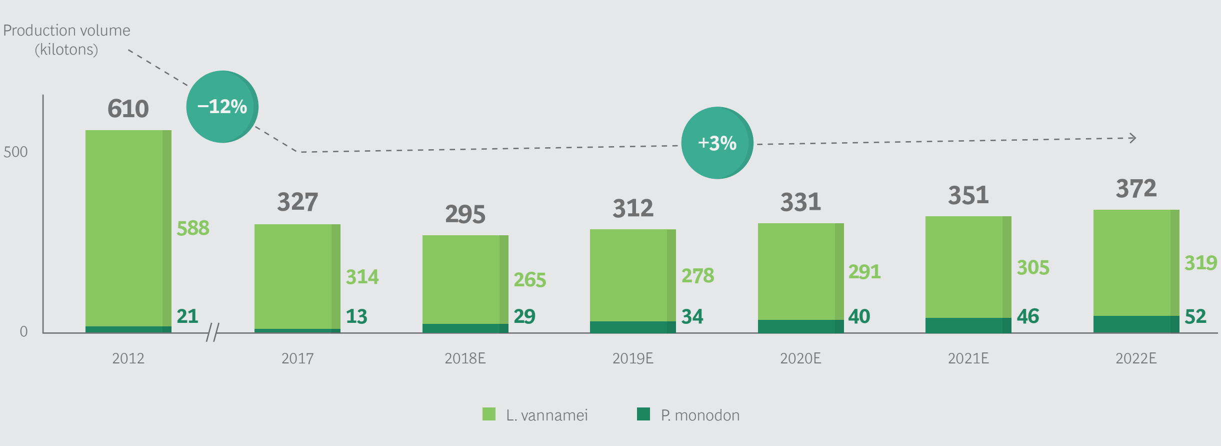
The declines in volumes and industry strength have hit Thai farmers hard. Wild-capture fisheries and aquaculture contribute about 1% to Thailand's GDP (about $413 billion in 2016) and employ approximately 2 million people (some 5% of the Thai workforce). Approximately 40% of these are fishermen and fish farmers, while the remain-

Exhibit 1 | With 8% Market Share, Thailand Is the World's Sixth-Largest Shrimp Producer



Sources: Cámara Nacional de Acuacultura; Food and Agriculture Organization of the United Nations, FishStat Plus (2016); Thailand Department of Fisheries; Imarc Research; BCG analysis.
Note: The figure for India is for fiscal year 2017–2018.

Exhibit 2 | Thailand's Shrimp Production Market, 2012–2022E



Sources: Thailand Department of Fisheries; expert interviews; BCG analysis.
Note: L. vannamei = Litopenaeus vannamei; P. monodon = Penaeus monodon. Because of rounding, not all numbers add up to the totals shown.

ing 60% are employed in related or supporting industries. In 2016, shrimp products made up 6% of Thailand's agricultural exports.

Although wholesale prices for Thai farmed shrimp have somewhat stabilized since the EMS outbreak, they are still lower than when they peaked in 2013 and 2014 (as are global wholesale prices, though the downward effect is less pronounced). Low prices and uncertainty about the future of the shrimp industry have made it hard for Thai farmers and others along the value chain to invest in their businesses. According to Thailand's government, about 20,000 farms were situated along the coast of Thailand in 2016. (See Exhibit 3.) Some shrimp associations claim that by 2018 only 7,000 farms were still active, and they project this number to dwindle to 6,000 as a result of declining production and decreasing business viability.

New Thai Regulations Guide More Sustainable Production

In an effort to revitalize its local shrimp-farming industry, Thailand's government has instituted several regulations that support shrimp producers, improve sustainable practices, and reposition Thai farmed shrimp in the global market. Some of these regulations support environmental stewardship. For example, it is no longer acceptable to locate a shrimp farm in mangrove forest areas. In addition, water on farms must be tested regularly and treated before discharge.

The Thai government's regulations aimed at preventing disease transmission and controlling the spread of diseases among farms include the following:

- Disease- and pathogen-free breeding stock must be used.
- The source of breeding stock must be identified.
- Farmers raising shrimp at the first larval stage must follow a handbook of best practices.
- All processing equipment must be sterilized correctly.
- The disease or death of unusually large numbers of shrimp on farms must be reported by producers immediately.

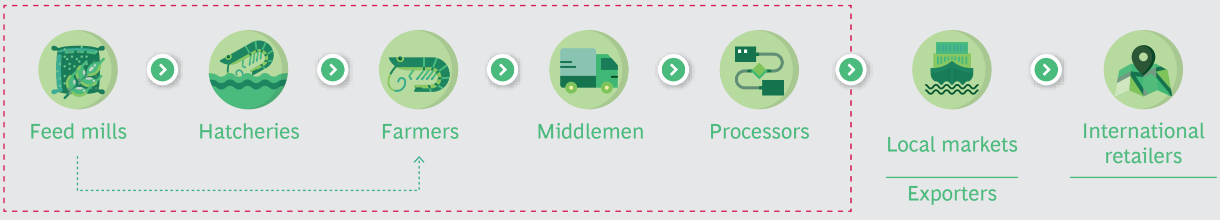
EXHIBIT 3 | Some 21,550 Farms Produce More Than 320 kilotons of L. Vannamei

Total	
Number of farms	21,550
Farming area (rai)	307,120
L. vannamei Shrimp production (metric tons)	321,542

	Number of farms	Farming area (rai)	Shrimp production (metric tons)
Coastal Zone 1	2,705 (13%)	47,748 (16%)	69,053 (21%)
Coastal Zone 2	9,358 (43%)	136,480 (44%)	50,803 (16%)
Coastal Zone 3	1,590 (7%)	30,136 (10%)	68,304(21%)
Coastal Zone 4	2,940 (14%)	23,742 (8%)	34,955 (11%)
Coastal Zone 5	1,568 (7%)	25,319 (8%)	56,044 (17%)
Others	3,389 (16%)	43,695 (14%)	42,383 (13%)

Sources: National Statistical Office of Thailand; BCG analysis.
Note: L. vannamei = Litopenaeus vannamei; 1 rai = 0.396 acres.

EXHIBIT 4 | Thailand's Farmed-Shrimp Supply Chain



Source: BCG analysis.
Note: This report focuses on feed mills, hatcheries, farmers, middlemen. and processors.

Furthermore, farms that use prohibited chemicals may be subject to penalties of up to 300,000 THB (about $9,500), and the Thailand Department of Fisheries is expected to instruct other processors and traders in the value chain not to buy shrimp from those farms. Poor environmental performance, therefore, now directly threatens Thai farmers' license to operate. The enforcement of regulations differs across regions.

The Thai Value Chain Is Complex

The value chain of Thailand's farmed-shrimp industry comprises several interrelated steps: feed mills, hatcheries, farmers, middlemen, processors, exporters, and retailers. (See Exhibit 4.)

This report focuses on the first five value chain steps:

- **Feed Mills.** Thailand's feed mill market is highly concentrated: four major players own feed mills across the country and account for around 80% of overall feed sales.

- **Hatcheries.** The hatchery business is highly consolidated; the Charoen Pokphand Group (CP) controls some 65% of the overall market.

- **Farmers.** Farming, which is largely fragmented, comprises a mix of large-scale producers and small and midsize enterprises.

- **Middlemen.** Thai middlemen, fragmented and operating regionally, facilitate approximately 90% of shrimp sales from farmers to processors.

- **Processors.** About 70% of the shrimp produced in Thailand is processed for export. In most cases, processing and export are handled by a single company, and five players dominate the market with a combined share of 80%.

These five components of the value chain include, essentially, three categories of actors: fully integrated companies that own both upstream suppliers and downstream buyers; downstream integrated companies that own the processing, export, and distribution; and individual players—primarily small family businesses focused on feed and farming. (See Exhibit 5.)

The Thai farmed-shrimp industry is led by CP and Thai Union. Both are integrated across the entire value chain. CP is especially strong upstream, while Thai Union is especially strong downstream. Together they control 60% of the overall market. However, even these integrated players often rely upon middlemen to source and help aggregate shrimp from the highly fragmented farming business. Companies with downstream integration work closely with end users and, therefore, they have more control over processing, export, and distribution. Most of the individual players are small family businesses focused on feed and farming rather than processing or exporting.

Exhibit 5 | The Thai Shrimp Value Chain Comprises Three Business Models

	Value chain presence	Example players	Market share (%)	Commentary
Fully integrated companies	Feed mills, Farmers, Processors, Distributors	Charoen Pokphand Foods	60	• Is the most integrated player, especially upstream • Dominates the feed and PL market • Is engaged in ducks, poultry, and swine production
		Thai Union		• Is less integrated upstream, but leads downstream • Owns many leading canned seafood brands, including Chicken of the Sea and John West
Integrated companies	Feed mills, Farmers, Processors, Distributors	Siam Canadian Foods	14	• Was the second-largest exporter of farmed shrimp in 2015: 28,000 metric tons
		Seafresh	10	• Has a strategic alliance with Marubeni to distribute its shrimp products globally • Generates most of its sales in the EU
		Asian Seafoods Coldstorage	17	• Generates most of its revenues in Thailand (23%), North America (23%), and the EU (17%) • Does not operate farms
Individual players	Feed mills: Grobest, Cargill, INTEQC Group Farmers: SyAqua, Blue Aqua Group Processors: Marine Gold Products Distributors: Lenk Frozen Foods, Pacific Fish Processing Company			• Smaller farmers dominate the farming step • Overall fragmented industry with many (smaller) players focused in the upstream segment

Source: BCG analysis.
Note: The market share for integrated companies represents the processing component of the value chain. PL = post-larvae shrimp.

THAILAND: THE CASE FOR CHANGE

Three factors drive the case for change in Thailand's farmed-shrimp industry: low-price competitors in countries such as India are flooding the market with cheap shrimp; the inability to control risk factors leading to disease outbreaks is harming farmers, suppliers, and the industry as a whole; and—partially as a result of NGOs' consumer awareness campaigns—regulators and retailers require more accountability and sustainably produced products. (See Exhibit 6.)

While some pressures are unique to the Thai farmed-shrimp industry, the demand for better traceability and the need to cope with the threat of disease outbreaks concern all major shrimp-farming nations. Thailand is particularly well positioned to drive change and should act quickly, as other countries are already mounting efforts to minimize disease outbreaks and provide supply chain traceability.

Low-Price Competitors

Historically, Thailand has been among the leaders in shrimp culture technologies and volume production. However, in the wake of Thailand's so-called perfect storm, competitors in other countries have been able to surpass Thai shrimp producers by undercutting prices with lower production costs—India, for example, prices its shrimp exports about 20% lower—while Thailand struggles to maintain production levels during disease outbreaks. Dealing with higher labor costs, lack of traceable and sustainably produced products, and migrant worker reforms, Thailand has lost ground, especially in the mass market, which primarily sells high-volume, low-cost, non-traceable shrimp.

Thailand's shrimp industry cannot return to its previous business model. That model has been taken over by competitors. Unless Thai producers can gain market share within the premium segment of high-quality traceable shrimp, they will continue to lose market share to competing producers in other countries. Already, over the past seven years, the Thai shrimp industry has lost to rivals a cumulative $7 billion in exports.

If Thailand's shrimp industry could achieve a growth rate of more than 5%, which is on par with global growth, it could, by 2025, increase its value by as much as $55 million on average annually. Even with sustained annual growth of more than 5%, it will take Thailand's farmed-shrimp industry more than ten years to reach its former annual production levels of 600,000 metric tons of farmed shrimp.

By increasing its productivity, regaining market share, and increasing exports to achieve at-market levels, Thailand could, by 2025, add a total of about $2.3 billion in value to the national economy.

EXHIBIT 6 | The Case for Change Is Driven by Three Factors in Thailand

Source: BCG analysis.

High Risk of Disease

The devastating impact of diseases in recent years has highlighted the fragility of the Thai industry's current farming system.

With the current outdoor open-pond systems, it's hard for farmers to maintain constant control of the culture environment, where disease vectors and polluted intake water stress shrimp and expose them to pathogens. Thailand has endured extreme weather events associated with climate change—such as flooding and rising sea levels—and the occurrence of such events will likely increase in the coming years. With the coastal zone's assimilative capacity being dramatically reduced by the removal of vegetative buffers, the devastating impact of disease outbreaks and extreme weather events can be avoided only with more biosecurity measures and greater control of pond culture dynamics.

The market is changing rapidly, and shrimp producers cannot afford to stay on the current path. Given how much ground they have lost in a relatively short time, Thai producers must act quickly to recover market share. In doing so, they can also set an example for other shrimp-producing nations to follow. A small number of Thailand's high-profile shrimp suppliers—such as Thai Union, CP, Thai Royal Frozen Food, Marine Gold Products, and Asian Seafoods Coldstorage—are advocating for greater accountability as the best path forward, and they are demonstrating the business case that goes along with it. Although the spread of industry efforts to improve sustainability issues on a large scale sets Thailand apart from many other shrimp-farming nations, these pioneers in sustainability are still in the minority.

Market Demand

As market demand for sustainably produced shrimp continues to rise, importers and retailers may increasingly refuse to purchase shrimp from Thailand. On the heels of the allegations of human rights abuses and increased public awareness of environmental and social concerns, retailers and their investors are pushing for higher visibility into the supply chain to protect their reputation and comply with regulations. By implementing traceability, Thailand can direct attention to the lack of traceability in the nations where production has shifted, position itself as a first mover in the mass market, and capture a significant portion of the niche market eager for high-quality, traceable products. In the EU, the market for sustainable seafood now outpaces conventional market growth. This niche market in the US and China is still small, but demand is growing.

Meanwhile, import authorities in major markets are imposing stricter regulations regarding traceability and sustainability of imported goods. Since implementing SIMP, the US Food and Drug Administration has increased its focus on checking imports for chemical and drug contamination. China's 2015 revised Food Safety Law requires strict adherence to food safety and holds exporters and distributors accountable for any contamination or problems arising from their products. In 2017, nine out of ten breaches of food and beverage regulations in Asia-Pacific occurred in China. In 2018, the Chinese government promised a strict crackdown on food safety, urging lifetime bans for offenders of related regulations. These developments clearly demonstrate that shrimp producers must improve their practices to ensure strict adherence to regulations and maintain market access.

To reform the shrimp industry and secure access to the affluent markets, Thai shrimp companies must adjust their production and business practices with the goal of achieving sustainability and product traceability. (See the sidebar "Seafood Task Force: Industry Collaboration.") This approach has many benefits including the following:

- Dramatically reduces the risk of disease outbreaks and associated production losses
- Protects the industry from product recalls and reputational damage, which can have detrimental effects on revenues and profit margins
- Adheres to old and new regulations as well as retail demands as sustainability and traceability become the norm
- Reduces pressure on natural resources, securing the economic health of the industry
- Helps raise the bar for shrimp-farming standards by providing the transparency, as well as the environmental and social safeguards, that buying markets require
- Allows Thai shrimp producers to reposition themselves as leaders in sustainability
- Provides access to more reliable markets with high demand for responsibly farmed shrimp
- Offers opportunities for first movers to set higher prices for a small consumer segment that is willing to pay a premium for sustainable products sold in specialty stores

SEAFOOD TASK FORCE: INDUSTRY COLLABORATION

The Seafood Task Force was formed in the wake of allegations of human and labor rights abuses in the Thai farmed-shrimp supply chain. The task force is a multistakeholder alliance consisting of European and US retailers, their suppliers, the major Thai shrimp processors and feed companies, and NGOs. These stakeholders are collaborating to combat illegal and environmentally destructive practices and to lead the Thai shrimp supply chain toward a more sustainable pathway.

With the support of this industry association across the entire supply chain, Thailand has laid the foundation for achieving national-scale supply chain oversight.

THAI SHRIMP PRODUCERS CAN CREATE IMMEDIATE ECONOMIC VALUE

Thailand's farmed-shrimp industry has three paths into the future. These include pursuing immediate changes to alter current practices on an individual level, increasing efficiency and productivity while improving profit margins; collaborating to achieve product traceability; and making bold shifts toward indoor shrimp farming by investing in closed-containment indoor facilities designed to reduce contamination, increase production output, lower the environmental footprint, and improve accountability. (See Exhibit 7.)

The shift to traceability and transparency and to indoor farming has the highest potential to revitalize the Thai shrimp industry, but these options require considerable capital investment, extensive expertise, and time.

In the meantime, there are several immediate changes that actors, particularly feed mills and farmers, can implement within their own systems and practices to significantly improve financial performance and resource efficiency and create environmental and social benefits.

In this section, we present a brief review of the ways that each player in the Thai farmed-shrimp value chain can benefit from these short-term improvements. (See Exhibits 8 and 9.)

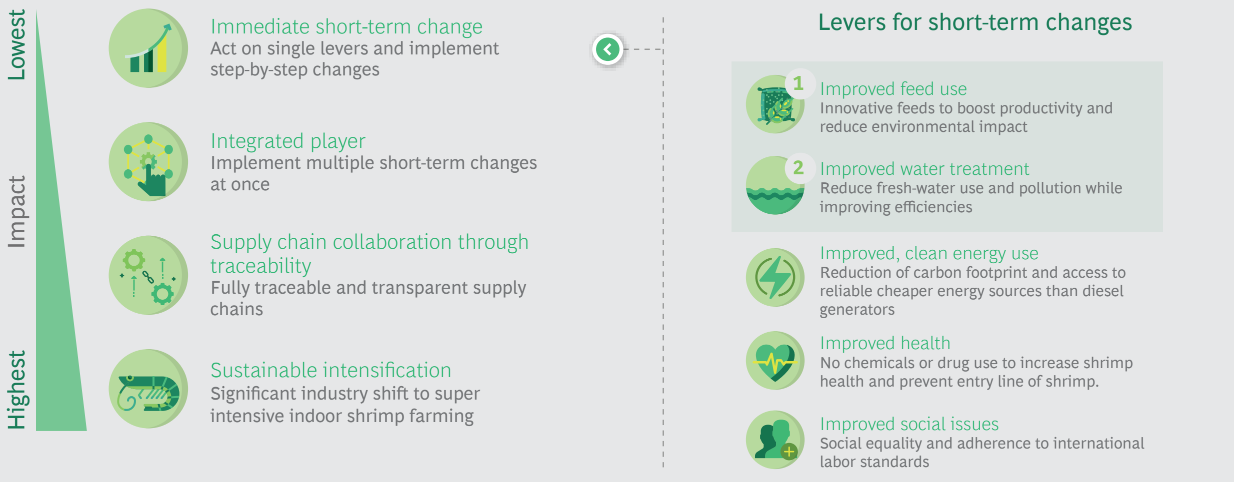
Feed Mills: Highly Profitable Functional Feed Products Offer Opportunities to Diversify Product Offerings

The feed industry has stagnated as a result of declining shrimp production and the reduced demand for shrimp feed. In the wake of Thailand's devastating disease outbreaks, feed mills have an opportunity: they can expand their portfolios by using functional feed—basic feed that has been enhanced with additives, such as proteins, vitamins, or probiotics (but never antibiotics)—to achieve a specific outcome. It is not uncommon for feed mills to improve basic feed with additives, but functional feed is slightly different from improved basic feed: it is used in specific circumstances to achieve a specific outcome, usually includes more additives, and is therefore defined as its own feed category.

Two types of functional feed have high potential.

Growth Enhancement Functional Feed. This is used to increase shrimp growth rates and allow farmers to sell larger shrimp at a potentially higher price or to accelerate growth cycles and, therefore, farm throughput. It offers a positive business case for feed mills. Sales of growth enhancement functional feed could double EBIT margins per kilogram of feed sold. Feed mills incur added

EXHIBIT 7 | Several Levers Can Maximize Business Success While Creating Positive Environmental and Social Impact



Source: BCG analysis.
Note: Our focus is on levers 1 and 2.

costs by selling functional feed, but they can charge a premium of as much as 20%, which farmers are willing to pay because the functional feed can produce larger shrimp.

Health Enhancement Functional Feed. This type of feed can enhance shrimp health and disease resistance, and it also offers several benefits for feed mills, not the least of which is that feed mills can charge premiums of up to 50%, leading to profit margins that could be as much as three times higher than average in an optimal case. Production and feed ingredient costs will likely increase by 10% to 20%, but these costs are typically offset by the revenue boost.

It is fair to assume that demand for functional feed will increase in the years to come, but the demand increase will probably level off at 10% to 15%. Farmers will likely purchase the expensive feed only when there's a direct economic benefit, such as when global shrimp prices rise significantly. The market share for functional feed currently stands at about 5% of a total production of 500,000 metric tons per year. A 1% increase in the total feed market—for example, as a result of higher sales of growth enhancement functional feed—would generate up to $7 million of value per year.[3] Feed mills that can tap into this value will benefit from a diversified feed portfolio, added revenues, and higher average profit margins. To attain these benefits, it is important that feed mills market functional feed and educate farmers on its benefits.

Feed mills that extend their product portfolio by selling functional feed can increase profits, help farmers increase production volumes, and support growth within the shrimp industry as a whole. They have both a clear incentive and a responsibility to act. Switching to functional feed also benefits the environment by decreasing land use by up to 15% per kilogram of shrimp produced (by reducing the feed conversion ratio [FCR], less land is needed for feed production), improving water quality by reducing feed waste, decreasing the use of antibiotics, and requiring less fish meal and fish oil.[4] However, these benefits materialize only if functional feed is widely used, and the positive environmental impact depends on what substitutes are used for fish meal. (See the Appendix for a discussion of growth enhancement and health enhancement functional feed.)

Feed mills are responsible also for careful consideration of the production of the input ingredients for feed. Worldwide, the demand for fish meal in shrimp feed has led to the depletion of some wild-capture fisheries and, in some cases, serious human and labor rights abuses on fishing vessels. Similarly, the culti-

Exhibit 8 | Current Average Economics per Value Chain Step

	Feed mills	Hatcheries	Farmers	Middlemen	Processors	Local markets / Exporters	National retailers / International retailers
Costs	$1.03 per kilogram of feed	$3.54 per thousand PL	$3.83 per kilogram of shrimp	$4.66 per kilogram	$8.27 per kilogram		
Price	$1.15 per kilogram of feed	$3.84 per thousand PL	$4.72 per kilogram 60 pieces per kilogram	$4.87 per kilogram 60 pieces per kilogram	$8.85 per kilogram of shrimp for export		Markups: 20% to 30% for shrimp sold in supermarkets
EBIT margins (%)	~10	5 to 10	~20	3 to 5	5 to 10		

Source: BCG analysis.
Note: PL = post-larvae shrimp. Calculations are for Litopenaeus vannamei only, which represent 95% of the market; prices are average prices for the most common company or farm type; costs are average costs per value chain component; margins include considerations such as survival rate. Rounding errors are possible.

vation of plant ingredients such as soy and corn for shrimp feed creates a high burden on land use. The natural resources used in feed—so-called embodied resources—represent a hidden, but vitally important, depletion of resources and thus need to be considered carefully.

Some feed mills and suppliers of raw materials are experimenting with fish meal and soy bean meal replacements, using, for example, alternative and less resource-intensive ingredients such as marine microbes. Once applied at large scale, these innovations could have far-reaching impact beyond the shrimp supply chain.

The industry is also working to develop feed production methods, such as extrusion (cooking under high temperature and processing under high pressure) and the manufacture of pelleted feeds (no cooking and processing under much less pressure). Both of these approaches have the potential to improve the digestibility of feed ingredients.

Hatcheries: A Clear Economic Incentive to Support the Entire Value Chain

Post-larvae (PL) shrimp produced by hatcheries are critically important for farmers. High-quality PL production can improve grow-out farm survival rates as well as the quality and health of shrimp, ultimately benefiting the entire industry. Hence, hatcheries represent a crucial enabler.

Many hatcheries still rely on imported broodstock, although domestic broodstock and selective breeding techniques ensure better shrimp survival, reduce the risk of disease, and position hatcheries to focus on breeding PL that grow faster and larger. Recent studies have shown that specific pathogen-free lines of selected stocks, maintained under the proper conditions, can even help reestablish farm populations in the event of stock losses caused by the outbreak of disease. In providing high-quality and healthy PL, hatcheries significantly contribute to production cost reductions and output increases at the farm level.

Although our analysis did not reveal many opportunities for hatcheries to implement short-term changes in feeding techniques or water treatment systems, hatcheries that offer high-quality PL can charge premiums for their products. CP, for example, sells PL at prices that are about 5% higher than those of average hatcheries and uses its strong performing PL business to bundle and cross-sell with other products such as feed.

Exhibit 9 | The Economics of Short-Term Improvements

	Status quo	Feed	Water	Combination
Feed mill level	EBIT margin: ~10%	**Growth enhancement** EBIT margin: Up to 21% Increase: +104% **Health enhancement** EBIT margin: Up to 31% Increase: +204%	None In the sale of functional feed, overall feed mill EBIT margins depend on the feed portfolio of individual farms	**Growth enhancement with biofloc** EBIT margin: Up to 21% Increase: +104% Potential revenue loss through improved farm efficiency; with similar increase in farming output
Farm level	EBIT margin: ~20%	**Growth enhancement** EBIT margin: Up to 27% Increase: +41% **Health enhancement** EBIT margin of 21% even during disease outbreaks versus 3% with basic feed	**Biofloc** EBIT margin: Up to 26% Increase: +36% **RAS** EBIT margin: >26% Increase: +40%	**Growth enhancement with biofloc** Positive, but further studies are required **Growth enhancement with RAS** EBIT margin: Up to 33% Increase: +77%

Source: BCG analysis.
Note: RAS = recirculating aquaculture systems.

Individual hatcheries should focus on improving quality by domesticating broodstock and implementing selective breeding practices, since it helps minimize the risk of disease and allows them to compete more effectively against the significant market power of integrated players. Because developing better PL involves genetic testing and investments in R&D, this might be rather difficult for small hatcheries to implement. So institutions and players with the necessary means should support small hatcheries in these efforts. (See the Appendix for a discussion of the business case for hatcheries.)

Farmers: Clear Business Benefits When Using Functional Feed and Improved Water Systems

We have identified multiple business opportunities for implementing immediate change at individual farms by slightly altering existing production systems. These opportunities enable farmers to improve production efficiencies, reduce resource use, and increase profit margins.

That said, the overall effect remains small compared with the more holistic levers of change, such as sophisticated closed-loop and indoor systems. The environmental benefits and control over the supply chain are also relatively limited when compared with more holistic changes in production practices.

Key Opportunity 1: Under the right circumstances, functional feed for farmers offers a highly profitable strategy that requires few technical changes or investments. Thai farmers have much to gain from using growth enhancement and health enhancement functional feed on their shrimp farms—if they use them in a specialized manner to address specific challenges.

Growth enhancement functional feed has the potential to accelerate shrimp growth rates or to produce larger shrimp. Farmers are likely to opt for growth enhancement functional feed when global shrimp prices rise and they want to take advantage of the opportunity. Under these circumstances, it can be beneficial to use growth enhancement feed during the second half of the growth cycle to boost growth rates and reduce FCR. When growth enhancement functional feed is managed properly, FCR can be reduced by a total of 15%, and the larger shrimp can be sold for up to 6% more, significantly improving EBIT margins. This approach, which drastically reduces quantities of feed needed per kilogram of shrimp produced, compensates for the higher feed price—up to 20% per kilogram. Farmers who manage to sell larger shrimp at higher market prices can achieve EBIT margins of up to 27%, representing as much as 41% increases over average EBIT margins. If global shrimp prices stay high, fast-growing shrimp could allow for an additional production cycle, significantly increasing farming output.

Health enhancement functional feed, which can cost up to 50% more than basic feed, appears quite expensive when the consideration is a single use per kilogram of shrimp produced. However, should farmers anticipate disease outbreaks, health enhancement feed can achieve an EBIT margin of up to 21% because the feed drastically increases survival rates during disease outbreaks. This compares quite favorably with the 3% EBIT margin when only basic feed is used during disease outbreaks and farmers are hit by low survival rates.

This scenario assumes that farmers can prevent a disease outbreak that would affect up to 20% of their annual production. A positive business case can be made, but each farmer must evaluate the feasibility and economic viability of purchasing expensive health enhancement feed against the potential losses from outbreaks of disease.

As long as farmers can afford the upfront costs of growth enhancement and health enhancement functional feed, they know when to use it, and they have the management skills to use it diligently, functional feed represents a relatively easy win: no investment or technological upgrades are required. There is also some environmental benefit—resulting mostly from better farm management—which is a prerequisite for the success of using this feed. (See the Appendix for a discussion of growth enhancement and health enhancement functional feed.)

Key Opportunity 2: Better water treatment can improve water use and quality while boosting EBIT margins. Intensive outdoor shrimp production systems require considerable amounts of fresh water and are major sources of pollution. In these “throughput systems,” once a growth cycle is completed, discharged effluents—along with the chemicals, fertilizers, and antibiotics used to treat the water—can leak into the environment.

More farms are using closed-loop treatment systems that improve water quality and reduce water discharge. These applications vary widely in their mode of action, ease of use, and feasibility.

There are farming technologies that use alternatives to chemicals and fertilizers to enhance water quality, as well as filter systems that aim to recycle water and reduce wastewater leakage into the environment.

Two systems that are focused on improving water quality and reducing wastewater discharge through circulation and filtering are biofloc and recirculating aquaculture systems (RAS). (See the Appendix for additional information on water treatment systems.)

Biofloc allows shrimp farmers to improve water quality and provide an additional feed source at the same time. Carbohydrates are added to pond water to compound waste products that can then be eaten by shrimp.

There can be significant variability in the business benefits for farmers because it can be tricky to implement and scale biofloc. In the best-case scenario, farmers benefit from an EBIT increase of up to 36%; at worst, if biofloc is applied incorrectly, farmers could suffer a marginal decrease in EBIT. The change in EBIT margins is a result of decreased costs for feed and chemicals, combined with the potential to grow shrimp faster or larger during the same period of time, thus increasing revenues. This is due to biofloc’s higher protein content.

With this opportunity, large companies tend to have an advantage over smaller farms because they traditionally have better access to knowledge and expertise—imperatives for the successful use of biofloc. For farmers with the right equipment—such as aerators and monitoring equipment, as well as access to the necessary training and knowledge to maintain biofloc in ponds—this approach is a promising option. When used properly, it can reduce water pollution and prevent eutrophication of natural ecosystems by reusing water. In some cases, however, its incorrect application can have an adverse effect on the heterotrophic pond environment by creating excessive waste compounds in the water, possibly reducing shrimp survival rates. (See the Appendix for additional information on biofloc.)

RAS are sophisticated filtering systems that treat water so it can be reused in the same location.[5] These kinds of closed-loop systems offer two significant benefits: no unfiltered wastewater is discharged into the local environment, and demand for "new" water is reduced. In an ideal case, no water exchange is required. Moreover, these systems can improve farm and resource efficiency and boost productivity, as they reduce the need for such production inputs as chemicals, feed, and fertilizers, and lead to increased EBIT margins for farmers. RAS can be basic biofilters or more sophisticated water recirculating systems and can vary in effectiveness, investment and operating costs, and environmental impact.

Effective RAS implementation usually requires a high financial investment owing to the need to install new facilities and train workers in what is an advanced farming technique. However, because RAS offer the opportunity to intensify production, these systems also promote larger output per hectare.

For producers that can afford the investment, sophisticated RAS—at a cost of $150,000 per hectare—can boost EBIT margins as much as 40% per kilogram of shrimp produced. This increase in EBIT margins assumes that farmers can double stocking densities to counterbalance the capital investment and the higher electricity costs from the use of aerators. RAS can also be used on multiple adjacent farms—within a farm collective, for example. Beyond these benefits, the application of aerators combined with higher stocking densities represents a first step toward sustainable intensification of shrimp farming, which is the direction the industry will likely take in the near future.

The use of RAS likely reduces new intake water use (except to make up for seepage and evaporation), but it also causes a surge in total energy and feed use due to increased stocking densities. Using renewable energy and functional feed with a minimal environmental footprint could potentially mitigate this negative effect. (See the Appendix for additional information on RAS.)

Key Opportunity 3: Combining functional feed and water treatment systems can maximize economic benefit and environmental impact. Producers that seek to maximize the effect of immediate, short-term change can combine growth enhancement functional feed and closed-loop systems such as RAS. In fact, the combination of the two levers is advised because they reinforce each other. If they implement the combination correctly, farmers can obtain EBIT margins of up to 33%—an increase of up to 77% over today's average. It is also an improvement of as much as 25% over both the standalone use of functional feed and the standalone use of RAS.

The combination of functional feed and RAS offers several benefits, including an increase in volume through higher stocking intensities, more efficient production, higher survival rates, better water treatment, and reduced wastewater discharge. Nevertheless, the risk of disease remains high and cannot be fully mitigated in this scenario. In line with the standalone growth enhancement functional feed case, farmers would not continually use functional feed. Farms take advantage of growth enhancement feed when there is a surge in global shrimp prices as a way to maximize shrimp production volumes.

Another option is to combine growth enhancement functional feed with biofloc. The combined impact of these two solutions affect the same production parameters, and its efficacy is difficult to predict. However, it is likely to yield results that are superior to standalone options.

While these combined approaches have promising potential, they also require farming expertise and changes in production and farm management. They are, therefore, not likely to be widely adopted unless farmers receive guidance from key partners across the value chain, including representatives from feed mills and processors, as well as technology providers for sophisticated systems such as RAS. Without knowledge sharing across the industry, these techniques will very rarely be used. (See the Appendix for a detailed discussion of combining functional feed and water treatment systems.)

There is also the option of switching to renewable energy, such as solar power. However, as the great majority of Thai shrimp farms rely solely on grid-sourced electricity and do not have to use expensive diesel generators to compensate for energy outages, there is no feasible business case for adopting renewable energy sources. (See the Appendix for an analysis of the business case for solar-powered farms.)

Finally, because these examples of immediate change in production methods are implemented on an individual basis, they will likely not sufficiently address the structural and environmental challenges the industry is facing. To truly transform the industry and create lasting financial returns and environmental change, a holistic approach is needed: one that cascades along the entire supply chain and fundamentally overhauls traditional production methods.

Middlemen: Imperative to Support the Transformation to a Fully Transparent Supply Chain

Middlemen play a key role in the farmed-shrimp supply chain. They frequently serve as gatekeepers and facilitators between shrimp farmers and shrimp processors, provide labor support to farmers during the harvest, and, in some cases, even provide financing to farmers. This wide network of middlemen currently handles about 90% of all shrimp produced in Thailand. The current business model of middlemen in Thailand is highly profitable, and they are quite wealthy, relative to most small-scale farmers. Because they play an informal role in the value chain, keep minimal records on shrimp purchased and sold, and receive little regulatory or company oversight, a shift in how middlemen conduct their business will be key to the industry's successful transformation to a more traceable and sustainable supply chain. (See Exhibit 10.)

EXHIBIT 10 | Middlemen Play a Critical Role from Farm to Processing Markets

Sources: Expert interviews; BCG analysis.

Middlemen are uniquely positioned to support farmers as they improve their production systems and technologies across the value chain. For example, middlemen can provide detailed records to help track shrimp along the value chain and can inform farmers about ways to produce shrimp more sustainably and thus differentiate their product in the market. By becoming more involved in the shift toward sustainability, middlemen can stay relevant in an industry that might otherwise, over time, cut them out. Until they see this threat materialize—most likely from processors—middlemen are unlikely to see the need to make the required effort. (See the Appendix for a discussion of the business case for middlemen.)

Processors: Obligation to Increase Ethical Conduct and Drive Change in the Upstream Market

About 70% of Thailand's farmed-shrimp production is handled by processors. Processors typically handle exports as well and are therefore directly affected by allegations of ethical misconduct in farmed-shrimp supply chains. Processors have, as a result, a clear incentive to help their customers mitigate risks from export penalties, such as the EU's yellow card.

Processors also serve as intermediaries between shrimp producers and retailers. To ensure their consistent access to supply, it is in their interest to help farmers reduce the risk of disease and reliably support the responsible production of high-quality shrimp at sustained volumes to maintain relationships with buyers and meet export regulations. This is especially critical for large standalone processors that face stiff competition from integrated players with more control over their supply chain, as well as players in other shrimp-producing markets that are already at the forefront of traceability. Nevertheless, many integrated players still source large quantities of shrimp from middlemen—an added challenge to achieving traceability. Processors can step up and deliver the much-needed transparency that middlemen typically fail to provide. (See the Appendix for a discussion of the business case for processors.)

Short-Term Change from Individual Players Is a Step in the Right Direction, but Disruptive Industry-wide Transformation Is Needed

The short-term changes outlined above offer several immediate benefits for Thai shrimp producers, but because they are implemented on an individual basis, they do not promote the kind of wide-ranging change that's needed to secure the industry's future. Short-term shifts in production systems and value chain practices could total $60 million in export revenues over the next five years combined, whereas shrimp producers are currently positioned to create just $1.2 million to $3.2 million of additional value (based on exports) within the next year. Over the next five years, the industry could reduce water use by as much as 1% (saving up to 77 million cubic meters), prevent 2.2 million cubic meters of wastewater leakage, and reduce feed use by 7,000 metric tons per year.[6] These changes could reach up to 400 farmers and boost margins by as much as 40% in individual cases.

Although this represents a meaningful step forward, the value created by these immediate, individual changes pales in comparison with the value that can be created if the industry were to set its sights higher. If shrimp producers were to implement traceability and gain back the EU as a long-term export market, for example, it could add up to $300 million annually to the Thai shrimp industry.[7] Short-term changes, on the other hand, would reap only about 4%, or about $12 million, in increased value.

Immediate change on an individual basis enables short-term gains, but true change can be achieved only when the industry works together on a larger scale. What's needed is an innovative business model focused on long-term, inclusive sustainability.

INTEGRATED PLAYERS CAN DRIVE CHANGE TOWARD TRACEABILITY

STANDALONE players can make short-term changes that help their business thrive, but integrated players—because of their value chain control, economic power, and expertise—are uniquely positioned to leverage these changes on a grand scale. (See Exhibits 11 and 12.) They must, however, think carefully about how the changes will play out at each step along the value chain. For example, when integrated players combine growth enhancement functional feed with RAS, their feed mills will likely experience a decline in feed sales, but farmers from whom they source their product can achieve profit margins greater than 30% that represent a 95% increase over today's margins. RAS allow for higher stocking densities, boosting shrimp sales overall. These dramatic improvements in the farming segment can, as a result, more than compensate for the losses in feed mills and support a virtuous cycle: higher farming output encourages additional shrimp farming, which increases the overall demand for feed. (Functional feed is to be used only under specific circumstances.)

In addition to short-term change, integrated players have a much more transformative opportunity within reach. With strong market power, access to financing, and the ability to scale, integrated players can push the entire industry in a new direction, advocating for an industry that delivers superior results at every level: for businesses, the environment, and society as a whole. Once leaders blaze the trail, others will be more inclined to follow.

Traceability is key: no market claims can be made in the absence of transparency and traceability. With traceability, supply chain actions become visible, and actors can be held accountable for their actions. This, in turn, creates an incentive for sustainable and responsible production. Importers and regulators, as well as a niche consumer segment, are pushing for this at the global level. Retailers, too, want to track and trace products from pond to plate so that they can avoid product recalls and minimize the potential for reputational damage. Integrated players in Thailand are positioned to achieve 100% product traceability and become leaders for the rest of the business.

EXHIBIT 11 | Integrated Players' Current Average Economics per Value Chain Step

	Feedmills	Hatcheries	Farmers	Middlemen	Processors	Local market / Export	National retailers / International retailers
Costs	$1.03 per kilogram of feed	$2.66 per thousand PL	$3.97 per kilogram of shrimp	$4.67 per kilogram	$8.27 per kilogram		Markups: 20% to 30% for shrimp sold in supermarkets
Price	$1.21 per kilogram of feed	$5.61 per thousand PL	$4.72 per kilogram 60 pieces per kilogram	$4.87 per kilogram 60 pieces per kilogram	$8.85 per kilogram of shrimp for export		
EBIT margins (%)	~15	>50	~15	3 to 5	5 to 10		

Source: BCG analysis.
Note: PL = post-larvae shrimp. Calculations are for Litopenaeus vannamei only, which represent 95% of the market; prices are average prices for the most common company or farm type; costs are average costs per value chain component; margins include considerations such as survival rate. Rounding errors are possible.

EXHIBIT 12 | Business Cases for Integrated Players

	Status quo	Feed	Water	Combination
Feed mill level	EBIT margin: ~15%	**Growth enhancement** EBIT margin: Up to 25%; Increase: +70% **Health enhancement** EBIT margin: Up to 35%; Increase: +136%	None In the sale of functional feed, overall feed mill EBIT margins depend on the feed portfolio of individual farms	**Growth enhancement with biofloc** EBIT margin: Up to 25%; Increase: +70 % Potential revenue loss through improved farm efficiency; but similar increased farming output
Farm level	EBIT margin: ~15%	**Growth enhancement** EBIT margin: >23%; Increase: +50% **Health enhancement** EBIT margin of 18% even during disease outbreaks versus 2% with basic feed	**Biofloc** EBIT margin: Up to 23%; Increase: +43% **RAS** EBIT margin: Up to 24%; Increase: +50%	**Growth enhancement with biofloc** Positive, but further studies are required **Growth enhancement with RAS** EBIT margin: >30%; Increase: +95%

Source: BCG analysis.
Note: EBIT margin is based on feed per kilogram sold. RAS = recirculating aquaculture systems. Rounding errors are possible.

FULL TRACEABILITY CAN GIVE THAILAND AN EDGE

To create value along the entire supply chain, leaders in the shrimp industry must ensure greater accountability and transparency and ultimately implement full product traceability throughout the supply chain.

As noted, regulators are requiring greater transparency as a precondition for shrimp import approvals, and they have repeatedly refused shrimp imports that fail to provide clean, contamination-free products. From 2002 through 2018, the US Food and Drug Administration refused more than a billion shrimp products, citing reasons that included product contamination and mislabeling on packaging. Farmed-shrimp products originating in Thailand were rejected primarily for being "filthy, putrid, decomposed" or not edible for other reasons. However, no imports were refused on account of drug or chemical contamination. The same cannot be said about some of Thailand's key competitors. Thai shrimp producers have an opportunity to capitalize on this advantage.

Retailers and importers are pushing for full traceability, because it represents a necessity and a business opportunity. As one former executive of a major retailer in North America said, "If you could establish a fully traceable supply chain, so you know where your product is coming from at each step of the chain.... That would have tremendous value. That is what everyone wants and needs." Consumers, too, are increasingly demanding it.

While traceable shrimp is still a niche market, that market is growing quickly, and Thai shrimp suppliers and buyers have much to gain from adhering to new government regulations focused on source of origin and catering to environmentally and socially conscious consumers who are willing to pay more for greater assurances. First movers in this space can expect to achieve price premiums for fully traceable shrimp. Although traceability will eventually become the new norm and prices will come down accordingly, Thailand has the ability to demonstrate a more radical form of transparency at a national level that would differentiate it from other shrimp-producing nations and to shine a light on the risks buyers take when they purchase shrimp with unknown origins from other countries.

With traceability becoming the norm, the shrimp industry in Thailand needs to act now to gain a competitive edge: it is the prerequisite that could transform the Thai shrimp industry.

The Far-Reaching Business Benefits of Traceability

Exhibit 13 outlines the following advantages and potential of economic benefits of traceability for all players across the value chain:

Exhibit 13 | The Business Benefits of Traceability Are Multifold

More efficient farms
- Traceability allows for leveraging of data analytics
- With traceability, production can be streamlined to increase volumes
- Traceability is an enabler: farms and producers must act to increase efficiency

Sustainable production
- Transparency and accountability along the supply chain induce sustainable behavior
- Traceability allows for rewards and punishment of producers of sustainable and unsustainable products

Improved logistics
- Optimizing transportation routes with analytics
- Traceability allows for the minimization of food waste during transfer
- Traceability enhances the ability to deliver fresh products reliably

Sustainable access to markets
- There is a growing demand for traceable products
- Transparency is likely to become a major purchasing criterion
- Increasing numbers of regulatory bodies require traceability

Brand enhancement
- Traceability can be leveraged as a marketing differentiator
- Branding as a high-quality, high-value traceable supply chain attracts buyers and consumers alike

Opportunity for premium pricing
- Some consumers are willing to pay premiums for traceable food
- Increased wealth will spread along the value chain through token currencies and other rewards

Source: BCG analysis.

- **More Efficient Farms.** With detailed data- and analytics-based records for each step along the supply chain, shrimp farms and production facilities can streamline operations, thereby increasing production volumes. Traceability can increase operational efficiency through record keeping, but that works only if farms take action accordingly.

- **Sustainable Production.** With traceability, retailers can punish producers for their unsustainable practices by refraining from buying, and retailers along with consumers can reward producers for their sustainable practices by paying price premiums. And traceability enables precise tracking of production locations, potentially identifying farms located in, for example, protected or no-go areas such as protected mangrove forests.

- **Improved Logistics.** Transportation routes can be analyzed and optimized, minimizing food waste during transport and maximizing the ability to deliver fresh products.

- **Sustainable Access to Markets.** Buyers, especially those in sophisticated markets, will increasingly demand traceable products and eventually drop suppliers and markets that are not fully transparent and that represent a sustained reputational risk. Import authorities are establishing reporting and record-keeping requirements for imports of certain seafood products to prevent illegal, unreported, and unregulated and misrepresented seafood from entering their markets.

- **Brand Enhancement.** Traceability secures the brand image and can be used as a key marketing differentiator when other claims cannot be validated.

- **Opportunity for Premium Pricing.** Some consumers are willing to pay a premium for traceable food products, making traceability a market differentiator. To spread the wealth along the supply chain, some technology providers, for example, are working to develop ways to share the rewards with upstream players through token currencies and other incentives.

To achieve these benefits, every player in the supply chain must participate and share trusted data with multiple stakeholders. Shielding supply chain data in modern value chains challenges the trust of those purchasing products and calls into question the reliability of companies that are perceived to have something to hide.

Middlemen pose a major challenge: their movements are hard to track, and virtually no records of their operations exist. To avoid losing significance or, worse, posing an obstacle to industry advancement, middlemen will need to formalize their operations to provide greater transparency and accountability. The industry is also quite fragmented at the farm level. There is minimal data collection and little incentive to share data. In a fully traceable supply chain, each player must contribute to the collective industry effort. When traceability is done right, everyone wins.

Traceability Can Be Managed in Many Ways—Each with Different Levels of Effectiveness and Maturity

There are many ways to implement traceability in supply chains, ranging from supply chain integration to software solutions. (See Exhibit 14.)

One way is for integrated players that have full control over their supply chains to provide traceability. This is easier said than done. Some integrated players produce less shrimp than their processing facilities have capacity to process. As a consequence, they turn to middlemen for shrimp to fill their excess capacity, creating a significant traceability challenge, and because they rely on middlemen, it's very hard to trace that shrimp.

Another technique is to verify the country of origin through elemental profiling. This new technique has emerged to provide a check on traceability claims. The procedure involves the analysis of a set of elements that make up a material or a species. Analysts can identify the country of origin of imported shrimp with up to 98% accuracy.[8] This technology represents a significant advance, but it serves only to verify the country of production. It does not represent full supply chain transparency, because it cannot track back to the specific farm where the shrimp was grown, verify the production technologies and methods applied during production, or trace the trading route of the shrimp from production to point of entry.

Consequently, the technique adds another layer of oversight on the path toward traceability, but it is insufficient on its own. To achieve full supply chain traceability, technology- and software-enabled solutions represent the most promising options.

Technology-Enabled Traceability Offers a Promising Path Forward

Traceability along the supply chain allows retailers to demonstrate environmental and social compliance, but it is not enough simply to make the claim. The industry needs tools that can accurately monitor and verify sustainable practices and hold players accountable to uniformly agreed-upon standards. Various technology-enabled traceability solutions, with differing levels of sophistication, are currently being developed.

EXHIBIT 14 | Traceability Is the Future Norm for Supply Chains

Traceability can be addressed in multiple ways

Vertically integrated players	Full control of the supply chain by one vertically integrated company overlooking operations from production to export and sale
Elemental profiling	Analysis of shrimp species, allowing for determination of country of origin with up to 98% accuracy
Software solutions such as blockchain	Technology-enabled traceability ranging from easy-to-deploy mobile applications to sophisticated blockchain and Internet of Things solutions
Certifications	Production standards implemented on the farm and processing levels and labeled accordingly at the point of sale

Certifications provide only perceived traceability

Necessity

- **Regulators** require traceable products to authorize imports
- **Retailers** select suppliers upon provision of traceability and sustainability standards
- **Consumers** are increasingly aware of sustainability issues and are beginning to adapt buying decisions

Opportunity

- **Niche market** allows for premium pricing of up to 40% for traceable and sustainable products
- **New market access** is provided through high-quality traceable products
- **Reduction of bottlenecks and increased efficiency** are results of supply chain tracking

Source: BCG analysis.

Mobile applications can capture farm, production, and transaction data in real time to ensure full transparency. In this scenario, all players across the supply chain share records for each transaction: farmers can easily upload data to accessible online platforms, and all product transactions and movements are registered at each step of the supply chain.

Multiple countries and seafood companies are already experimenting with mobile apps. In 2017, the Seafood Task Force developed a mobile app to track and trace shrimp production along the Thai shrimp supply chain, and the app is currently being tested by members of the task force. The Thailand Department of Fisheries has also indicated that pressure from the private sector has resulted in the need for better technological tools as they explore electronic applications. Mobile apps are easy to use, accessible, and affordable even for the smallest farmers, but they require every player along the supply chain to share truthful, verifiable data. Therefore, traceability must be coupled with transparency.

Pairing the Internet of Things (IoT) with blockchain represents another promising solution for tracing global food chains, in part because these technologies are rapidly becoming more affordable and accessible. Here is a quick look at how IoT and blockchain can be used:

- IoT devices capture production data at the source—for example, from shrimp farms.

- This captured data is stored on ledgers, which can time-stamp, track, and automate transactions so that events can be audited in real time.

- As long as the suppliers enter accurate data, the blockchain establishes proof of quality and provenance across the entire value chain.

Several large supermarkets, including Walmart in the US and Carrefour in the EU, have already deployed blockchain to track the provenance of products in their food supply chains. Although they have determined that they can no longer opt not to know where food originates, they do not yet apply this standard to shrimp. The shrimp supply chain is complicated. Shrimp farmers are highly fragmented, middlemen play an outsize role in the value chain, and very little farming or hatchery data is collected, let alone shared across the supply chain. Consistent data collection is a prerequisite for successful traceability, and its lack consequently poses a significant barrier to implementation.

Many technology companies, including IBM, VeChain, Provenance, ConsenSys, and the newly founded OpenSC food-tracking platform are enabling traceability for various products, but these are more appropriate for products with less complex supply chains than that of the shrimp industry. Will shrimp be next?

The Thai shrimp industry is well positioned to become a pioneer in traceability, helping to address several of its most pressing challenges. Single players and the Seafood Task Force are already undertaking efforts to provide traceability solutions. While traceability is an important step forward for the industry, on its own, it does not boost production volumes. For that, an even bolder approach is needed. (See the sidebar "Certifications: There Are No Shortcuts to Full Traceability.")

CERTIFICATIONS: THERE ARE NO SHORTCUTS TO FULL TRACEABILITY

Retailers and producers, in collaboration with certification bodies, offer many certifications for seafood and shrimp products. Many of these certifications can have positive impact on certain production or supply chain elements, but many do not address environmental and social issues within the farmed-shrimp value chain. Furthermore, because the supply chain is so complex, it is nearly impossible to guarantee with 100% certainty that shrimp producers adhere to certification standards. Ultimately, the lack of traceability of certified supply chains often renders

CERTIFICATIONS: THERE ARE NO SHORTCUTS TO FULL TRACEABILITY
(continued)

labeling untrustworthy and provides "perceived" rather than actual sustainably and responsibly produced shrimp.

Because no reliable alternative to these certifications currently exists, many consumers accept them as proof of sustainability and increasingly demand labeled seafood. In 2016, about 14% of seafood (farmed and caught) was certified, and this number is expected to climb by about 5% annually through 2025. A small proportion of customers will pay high premiums—up to 40%—in specialty stores for shrimp certified as sustainably produced and fully traceable.

Certification standards and practices are problematic for the following reasons:

- Certification standards vary, and each certifying organization establishes minimum or maximum limits for such concerns as antibiotics and chemicals, land use, and water pollution. And many fail to differentiate between essential and innocuous requirements.
- Shrimp farm certifications are not necessarily product certifications; they are, instead, focused on farming processes.
- Controls and audits on farms and at processing factories occur infrequently—at most twice a year. Furthermore, only a subset of farms are checked and audited in farm collectives, and there is no mechanism for confirming that all farms within a collective adhere to the stated standards. Even for those that are controlled, only one day's evidence is collected, and neither farming practices nor impacts are monitored over an extended time period.
- Many certifications have been awarded before traceability has been demonstrated.
- In many cases, the cost of adhering to certification standards and altering production processes is not shared along the supply chain, burdening only farms or processors. From a social-equality perspective, this represents a major pitfall.
- It is nearly impossible to compare one protein product—shrimp, fish, or meat—with another protein product, because certifications differ so much, depending on species.
- Shrimp from certified farms and noncertified farms are, in many cases, collected from a single middleman and mixed in a single batch, making it impossible to separate the sustainably produced shrimp from nonsustainably produced shrimp.

Certifications aim to provide transparency on sustainability and production standards, but implementation is close to impossible in Thailand's fragmented shrimp supply chain. To achieve reliable traceability, all players must participate and provide continuous transparency into their production methods and inputs. This can be achieved only with collaboration, constant monitoring, and a platform that captures tamper-free, truthful records. There are no shortcuts to traceability, and as previously stated, what has worked for the Thai shrimp industry in the past—providing certified products without proof of traceability detached from certification—will not succeed moving forward. More holistic approaches to supply chain integrity are necessary.

LONG TERM, INDOOR FARMING WILL DISRUPT THE INDUSTRY

Short-term value can be derived from immediate improvements to current production systems, traceability is rapidly becoming a business imperative, and Thai shrimp producers have an opportunity to overhaul shrimp production at its very core.

One of the most promising opportunities is the shift to high-intensity, high-volume, closed-system shrimp farming in indoor facilities—an approach that some companies in Thailand have already adopted. CP, for example, has invested in indoor farms and plans to shift all production to indoor ponds over the next five to ten years. With this shift, they expect to increase capacity to at least 100 metric tons per hectare compared with the typical 18 to 50 metric tons per hectare produced annually in traditional outdoor systems.

Similarly, in Vietnam, the shrimp-producing company Viet-Uc is investing heavily in indoor farming complexes and plans eventually to achieve 100% indoor production.

Because of the high capital investment, scale, and new construction required to implement indoor farms, these farms will likely become financially viable only for large-scale integrated players. Additionally, integrated players can combine indoor farming with full traceability if they exert power over their entire value chain. With indoor farming, integrated players could even build a state-of-the-art facility that combines all stages of shrimp production—from breeding to processing—under one roof, thereby guaranteeing total biosecurity and control over the culture environment. This approach offers the following clear advantages:

- Traceability as long as the entire production process is integrated and the shrimp are not sold to processors by middlemen
- Minimal or no dependence on middlemen
- Reductions in costs and logistics, because production can be located close to processing
- Simplified transportation and faster access to global markets
- Improved and stable revenue streams
- Consistent year-round production with a secure supply of high-quality commodity shrimp
- Higher yields and reduced operational risks that are the result of having complete control over input, lower disease rates, smaller land requirements, and efficient feed use
- Significantly reduced environmental impact due to using less water and land

- Control over inputs and no use of antibiotics
- Opportunity to increase control over social responsibility and ensure ethical conduct

The business case for indoor farming is still evolving. The investment costs—up to $200,000 per hectare of pond area and operational costs of up to $4.83 per kilogram of shrimp for large indoor farms in Southeast Asia—are high compared with current costs for conventional farming: $3.97 per kilogram of shrimp. And international sales prices for commodity shrimp are, at least for the foreseeable future, low, making the business case for wholesale transformation an uphill climb in the short term and midterm. (See Exhibit 15.)

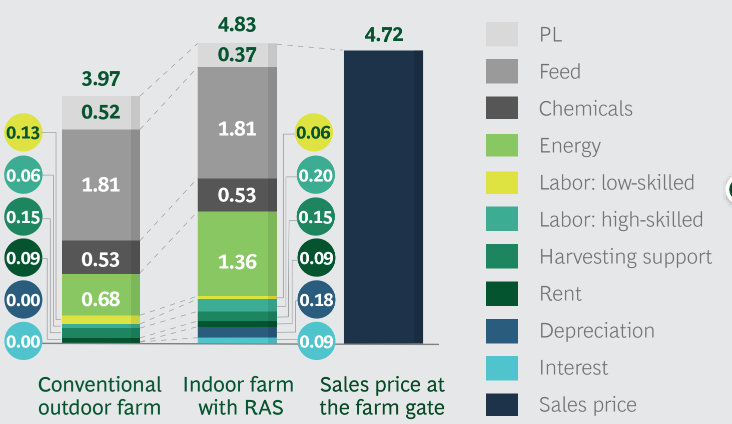
Although indoor-farming industry disruption will likely be led by large-scale industry leaders, small to midsize producers can begin moving in this direction by implementing closed-loop systems, such as RAS. When combined with removable pond covers, which add protection against external contaminants, even small to midsize players can create closed systems with better control and increased productivity, supporting the long-term industry shift to lower-impact indoor farms.

Thailand's shrimp-farming industry is progressing toward intensification, and indoor farming represents a natural next step. Throughout the history of shrimp farming, industry players have moved from basic extensive systems—characterized by low stocking densities and high land use levels per kilogram of shrimp produced—to more intensified systems.[9] With higher levels of intensification, stocking densities and farm output per hectare have grown, and the amount of land required to produce a kilogram of shrimp has typically decreased. In turn, there will be increases in the risk of disease, total energy use, and per unit energy use. The disease risk can be mitigated by closed-containment farm operations and indoor systems.

In terms of farm efficiency, Thailand is among the leading shrimp-farming nations. Stocking densities for average intensive farms in Thailand range from 180 to 250 PL per square meter compared with an average range of 60 to 300 PL per square meter in other countries and relatively low land use of about 0.2 hectares of land used at the farm level per metric

EXHIBIT 15 | In Thailand, Indoor-Farming Production Costs Are Higher Than Conventional Production Costs

A cost comparison of conventional outdoor and indoor farming with RAS ($ per kilogram of shrimp)[1]



Main cost driver: energy with additional higher labor, interest, and depreciation costs

PL costs are slightly reduced owing to improved survival rate (from 65% to 90%)

Feed and chemical costs are stable

Energy consumption and costs double with RAS and increasing use of technology solutions and automation

Labor costs increase slightly owing to a shift from low-skilled to high-skilled labor despite the overall reduction in the amount of labor required

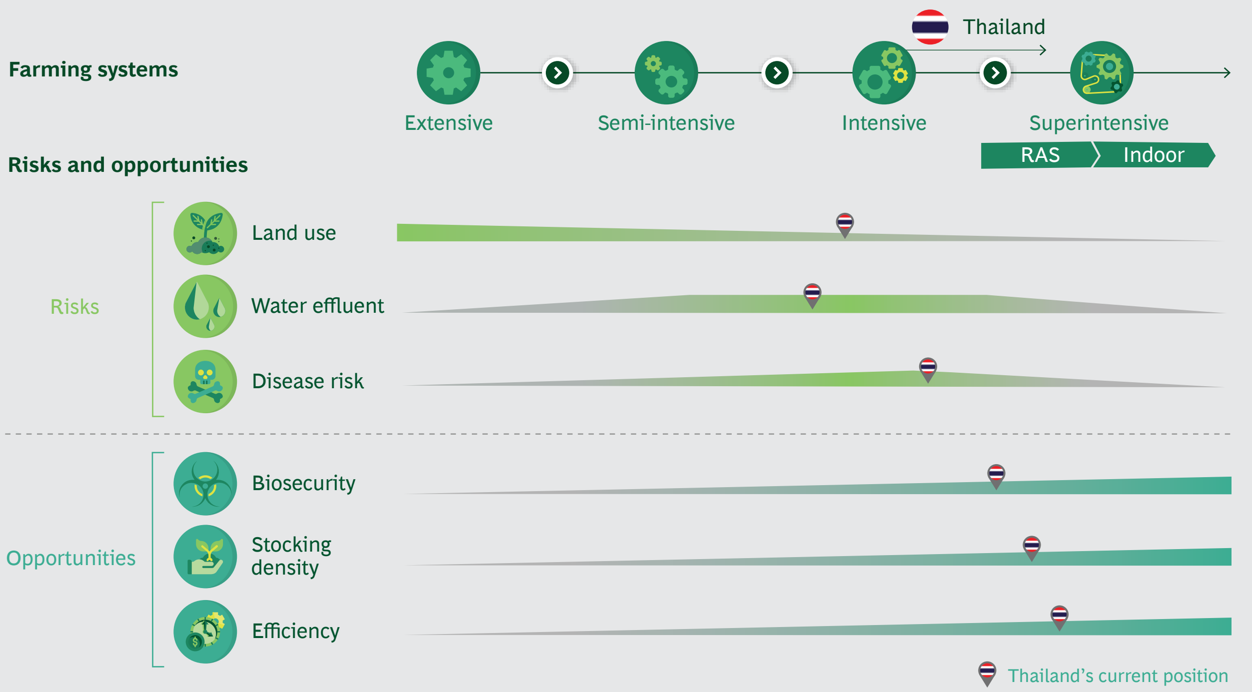
Depreciation reflects high investment costs of $20,000 per 1,000 square meters of pond, around $0.20 per kilogram, based on production of 10 kilograms per square meter annually over 10 years

Interest reflects financing through bank loans

Sources: Expert interviews; BCG analysis.
Note: RAS = recirculating aquaculture systems. PL = post-larvae shrimp. Because of rounding, not all numbers add up to the totals shown.
[1]Expert estimates.

ton of shrimp produced.[10] With a high degree of intensification and pilot tests of superintensive indoor shrimp farming, Thailand is poised to become a leader in superintensive, high-volume, high-quality, risk-free shrimp farming. (See Exhibit 16.)

EXHIBIT 16 | Farming Systems for L. Vannamei: Intensification Mitigates Environmental Impact While Boosting Productivity and Quality



Source: BCG analysis.
Note: L. vannamei = Litopenaeus vannamei; RAS = recirculating aquaculture systems.

THE TIME TO ACT IS NOW

THE SHRIMP-FARMING INDUSTRY IS at an inflection point. Thailand, among the most mature and technologically proficient shrimp-producing nations globally, is making important strides forward in providing sustainability that markets and buyers require.

Shrimp is becoming an increasingly popular source of protein worldwide. Some 3 billion people rely on wild-caught seafood and aquaculture products as their primary sources of protein, and these products are becoming an increasingly important part of the global diet. Considered a luxury product, shrimp has nonetheless experienced tremendous growth globally, becoming increasingly popular in low-income countries. By 2020 in Indonesia, for example, the domestic market for shrimp consumption will equal 45% of the country's shrimp production.

It is not just niche markets that demand traceability and better quality. Even the mass market is moving in this direction. It is, therefore, increasingly important that Thailand differentiate itself by becoming a global leader in sustainably farmed shrimp.

This is not just a business imperative. In light of the growing global population, increasing demand for food, and need to demonstrate environmental and social responsibility, shrimp producers will face increasing pressure to safeguard the biodiversity and ecosystems that are vital to our planet's well-being. This challenge affects the entire food industry and requires all its participants to reduce their environmental impact.

Thailand must respond. A number of players in Thailand have started, and they are already blazing the trail toward product traceability and improved productivity. Furthermore, they are reducing their environmental footprint and use of resources. Still, much more participation is needed to truly transform the industry. To regain a global leadership position and deliver lasting environmental and social impact, Thai shrimp producers must collaborate across the supply chain. In embracing this approach, they will find the opportunity to benefit all components of the value chain and satisfy market demand and regulatory requirements for food safety, sustainability, and resource-efficient business practices. If the industry successfully navigates these transitions, participants will reap rewards for generations to come.

APPENDIX

This Appendix provides an overview of the technical details of functional feed, water improvement systems, and solar energy, including a discussion of the business case for solar energy, as well as the market dynamics and short-term business case analyses of the various value chain participants: feed mills, hatcheries, farmers, and middlemen, as well as processors and exporters.

APPENDIX

FUNCTIONAL FEED, WATER IMPROVEMENT SYSTEMS, AND SOLAR ENERGY

This section of the Appendix focuses on three factors—functional feed, water improvement systems, and solar energy—that can drive improvements to both the economics and environmental footprint of shrimp farming.

Details on Functional Feed

The costs and operational requirements associated with functional feed vary among farmers. (See Exhibit 17.)

Growth enhancement functional feed is a complete feed (rather than an isolated compound) that is designed to promote specific physiological effects that allow farmers to grow larger shrimp faster and more efficiently. Many varieties of functional feed are available on the market, and companies are competing to develop the most effective products. We define growth enhancement functional feed as feed that includes a variety of additives—such as special proteins, vitamins, and probiotics—that promote faster growth.

For example, bioactive powder (Novacq) can improve growth rates of farmed shrimp:

- It reduces reliance on harvesting wild fish for feed.
- Its use promotes up to 20% to 30% faster growth.

This improvement in growth, which helps farmers increase the number of production cycles per year if they use the feed continuously, can lead to significant improvements in biomass and productivity.

Health enhancement functional feed aims to improve shrimp survival and to increase productivity by optimizing the shrimp's digestive efficiency. This type of feed is especially useful for mitigating risk when the threat of disease is high.

For example, phytobiotic additives can promote better health:

- They can be used in functional feed or as separate additives.
- Phytobiotics produced from herbs and organic acids are known to be effective at boosting immunity and improving functional properties of the compounds in the gut.
- Similarly, additives such as Digestarom improve gut health and improve FCR.
- In tests with CP basic feed in Thailand, Liptofry increased FCR and survival rates under normal conditions and led to stable survival rates when challenged by EMS bacteria.

Exhibit 17 | Functional Feed: The Impact, Costs, Requirements, and Results

	FOCUS: Growth enhancement functional feed	FOCUS: Health enhancement functional feed	Transportation and storage	Feeding method and technology	Farming system and management
Operational impact	Potential for FCR improvement Possibility of larger shrimp	Avoidance of crop loss at times of high risk of disease	Appropriate storage important to maintain feed quality	Method and technology relevant to FCR and survival rate	Critical for overall operational success and controlling risk of disease
Cost impact	Higher feed costs; less feed required	Higher feed costs; crop loss avoided	Minor cost factor	Possibility of high investment costs for new technology Potential impact on labor	High impact on costs based on efficiency and risk management
Requirements and assumptions	Larger shrimp; higher sales price possible	Consideration of the risk of disease and crop loss	Farmers have appropriate storage No known major issues	New technology to support new feeds and improve impact and success	Farmers rely on feed mills for information and best management practices
Results	✓ EBIT 70% higher for integrated players	✓ Loss from diseases avoided; higher revenues	✕ No significant impact on farmers' P&L	+ Support for successful introduction of new feeds	+ Critical for FCR, survival, and risks on farms

✓ Clear quantifiable business case + Prerequisite for quantifiable business cases ✕ Not relevant to the business case

Source: BCG analysis.
Note: FCR = feed conversion ratio.

Details on Water Improvement Systems—Biofloc and RAS

Water treatment systems aim to improve water quality, reduce water use, and recycle water. They vary in application and effects, terms of sophistication, levels of water reuse, and cost. Many systems use microbes to regulate water quality and imitate natural water conditions. Exhibit 18 provides an overview of commonly used closed-loop and microbial systems.

Two approaches to improve water quality during shrimp production—biofloc and RAS—have been modelled in detailed scenarios. (See Exhibit 19a.)

With biofloc, carbohydrates are added to the water, increasing the carbon-to-nitrogen ratio. The nitrogenous waste blends with other bacteria, algae, and fungi, creating a biofloc that improves water quality while reducing FCR as it can also be used as a feed source for shrimp. (See Exhibit 19b.)

Biofloc can have positive environmental impact. It leads to a statistically relevant decrease in nitrite levels in pond water by about 73% to 0.13 milligrams per liter of nitrite-nitrogen. This represents a significant improvement and is in line with the maximum nitrite level—0.18 milligrams per liter—mandated to protect freshwater aquatic life.

With RAS, water is treated through multiple filters, allowing for its reuse, and no unfiltered wastewater is discharged into the local ecosystem. The most common systems include a mechanical biofilter and a degasser. The water is enriched with oxygen and disinfected with ultraviolet light before it is readmitted to ponds.

Exhibit 18 | Overview of Water Quality Enhancement and Closed-Loop Systems

Nonexhaustive

Water discharge

- Low-to-no water discharge
- Better than conventional systems
- Emphasis on microbial manipulation
- Use of microbial loop system to remove toxic nitrogen compound
- Microbial consortia added regularly to the system
- Microbial component kept dominant in the system
- Need for additional compartment for separated microbial cultivation

Biofloc

- Low-to-no water discharge
- Better than conventional systems
- Addition of carbon source to enhance heterotrophic bacteria consortium
- Emphasis on the system's carbon-to-nitrogen ratio
- Conversion of "waste" nitrogen to highly concentrated total suspended solid (microbial biomass) that can act as high-protein feed for cultured animal
- Optimal aeration and biofloc ingredient mix required

Periphyton

- Low-to-no water discharge
- Better than conventional systems
- Need for organic substrate such as bamboo for periphyton attachment
- Organic input such as manure and chemical fertilizers to trigger periphyton growth
- Occasional need for additional carbon source to maintain the carbon-to-nitrogen ratio
- Periphyton acts as toxic nitrogen removal system and food source for cultured animal

Biofilm

- Low water discharge
- Better than conventional systems
- Use of formed biofilm to remove toxic nitrogen compound during culture period
- No control of microbial consortia
- A potential food source for cultured animal

Defined biofilm

- Need for additional reactor and attachment substrate
- Defined microbial consortia in biofilm (predominantly nitrifying bacteria)
- Main purpose: removal of toxic nitrogen substance from the system
- Applicable in the system or in an external unit such as a biofilter

RAS

- No water discharge
- Involvement of many treatment processes, including physical and chemical treatments
- Microbial compartment in the biofilter
- Biofilter has defined microbial consortia
- Isolated, clear-water system
- Main purpose: biologically secured and hygienic aquaculture product
- Higher investment and operational costs than for other systems

Green-water technique

- Low water discharge
- Use of batch system
- Use of primarily autotrophic microalgae as microbial component in the system
- Utilization of chemical fertilizer and organic waste to trigger phytoplankton growth
- No control of the system's microbe community
- Main purpose: to provide natural food for cultured animal

Sources: Gede Suantika et al., *Aquaculture Engineering,* 2018; BCG analysis.
Note: RAS = recirculating aquaculture systems.

RAS offers significant advantages for farmers:

- The various filters and treatments improve water quality.
- Water conditions are continuously monitored and, if necessary, automatically adjusted, reducing the stress level of the shrimp and enabling farmers to increase stocking densities.
- RAS reduce the need for chemicals, and automation decreases labor requirements.

Exhibit 19a | Capital Investment and Operating Costs Are the Main Concerns in Method Selection

FOCUS

	Water treatment: biofloc system	**Water recycling: RAS**	**Integrated aquaculture: integrated multitrophic system**
	Inserting bacteria or chemicals to reduce water pollution	Treating water to allow for water reuse within farms	Introducing additional species that use waste as a source of nutrients
Advantages	• Improved feed conversion rate • Decreased required protein content in artificial feed • Increased growth rate	• Increased survival rate • Increased stocking densities • Decreased disease risk • Stabilized water conditions	• Diversified economic income
Disadvantages	• Increased energy costs (energy outtakes critical) • Advanced technical skills required • Constant monitoring needed • Further research necessary	• Significant initial investment costs from $15,000 to >$300,000 • Increased energy costs • Advanced technical skills required • Constant monitoring needed	• Decreased shrimp productivity • Disease spread among additional species or plants • Advanced technical skills required • Further research necessary

Source: BCG analysis.
Note: RAS = recirculating aquaculture systems.

Exhibit 19b | The Addition of Carbohydrates to the Water Leads to the Assimilation of Nitrogenous Waste

Input: carbohydrates

Farmers add carbohydrates in the form of molasses or cornmeal to water

Chemical reaction

Increases the carbon-to-nitrogen ratio

Owing to the additional carbohydrates, the ratio of carbon to nitrogen increases

Stimulates heterophobic microbial growth

The nitrogenous waste (unused feed and excreta) is assimilated and together with other bacteria, algae, and fungi compounded as biofloc

Shrimp use biofloc as a feed source

Similar or higher protein levels (25% to 50% compared with 35% in regular feed) and fat content (0.5% to 15% compared with 4% to 6% in regular feed) of biofloc

Improved water quality

The reduction of nitrogen improves the water quality

Reduced FCR

Because it has nutritional value, biofloc reduces the amount of additional feed required

Source: Aquaculture; BCG analysis.
Note: FCR = feed conversion ratio.

RAS poses challenges to wide implementation:

- Installation of the necessary filters and treatment tools imposes high upfront investment costs that vary depending on the overall size of the farm (larger farms benefit from economies of scale), sophistication of the system, and the equipment

EXHIBIT 20 | Evaluation of Four Types of Renewable Energy Sources for Shrimp Farming

	FOCUS Solar power	Wind power	Biomass	Solar thermal power
Location requirements	Evaluation of solar radiation required	Evaluation of average wind speed required	Evaluation of available biomass in region required	Evaluation of solar radiation required
Advantages	Potential synergies with aquaculture in the case of floating PV systems	Relatively small land footprint in the case of small-scale wind turbines that can be placed close to the ponds or on the aerators	Potential synergies: biomass can be grown in same ponds as shrimp; seaweed also improves water quality	Can be stored more efficiently than electrical energy
Disadvantages	PV has a relatively large footprint and occupies land that could be used for ponds	Shrimp farms located in flat coastal areas that offer only light sea breezes instead of strong winds	Limited commercial small-scale projects and technologies; environmental impact of generated gas	Limited commercial small-scale projects and technologies; required land is a potential issue (similar to solar power)

Sources: Commonwealth Scientific and Industrial Research Organisation; BCG analysis.
Note: PV = photovoltaic.

used (some of which requires higher energy use).

- Basic biofilters that are integrated into existing production systems without further investments in equipment can be obtained at a low cost that ranges from $15,000 to $50,000 per hectare, which could be high for farmers.

- Investment costs for more sophisticated systems that use filtration systems and specialized pond equipment range from $50,000 to $150,000 per hectare.

- Sophisticated recirculating aquaculture systems that include significant alterations to the production facilities, equipment, and possibly even involve indoor operations, can cost $300,000 per hectare or more to set up.

- With greater control over the culture environment, it is possible to mitigate the outbreak of disease. However, should an outbreak occur, it would affect a larger amount of shrimp as a result of increased stocking densities, resulting in greater losses.

Details on Solar Energy

In Thailand, energy is generally sourced from the electricity grid, which offers cheap and reliable energy. Although there is no pressing need to improve farmers' energy mix, the shrimp industry has an opportunity to reduce its environmental footprint by shifting toward renewable energy. Four types of renewable energy are available—solar power, wind power, biomass, and solar thermal power. Our analysis focused on solar. (See Exhibit 20.)

There are three types of solar energy available to shrimp producers: photovoltaic (PV) cells that can be installed on the ground in close proximity to ponds, PV cells that can be installed above the surface of ponds, and PV cells with a tracking system that can be installed above ponds.

Each option has different implications in terms of land use, water evaporation, electricity production, and investment costs, which range from $1.7 million per megawatt to $1.9 million per megawatt, including storage costs. Farm size, location, and regional characteristics—including the cost of fuel, reliability of the energy supply from the grid, and solar irradiation—should all be taken into account prior to making an investment.

APPENDIX

MARKET DYNAMICS AND THE ENVIRONMENTAL IMPACT OF IMMEDIATE CHANGE

To calculate the business case for each player in the Thai shrimp value chain, the base case (today's average) was derived from BCG knowledge, proprietary data, and industry expertise and was subsequently validated in expert interviews and with secondary research. The analysis then identified key parameters affected by changes to current operations and estimated their business impact. Each business case calculation is displayed as a relative delta to today's average, the base case. For each player along the value chain, we also analyzed the overall market structure and the environmental impact of immediate change.

Feed Mills

Market Dynamics. The shrimp feed market in Thailand is stagnating at about 500,000 metric tons, owing to flat shrimp production, improved genetics, and improved FCRs, which allow farmers to use less feed. As a result, construction of new feed mills in Thailand is improbable over the next five years. The existing mills are already underutilized, and demand is unlikely to increase.

The feed market is currently dominated by four players with a combined market share of 80%: CP, Thai Union, Grobest, and Inteqc Feed. For the most part, these producers focus on basic feed, but they are working toward innovating basic feeds as well as feed ingredients.

Functional feed has around 5% of today's market share, and, given all the benefits for shrimp farmers, it is poised to grow. However, most farmers have not received guidance on how to adjust their farming methods to optimize their use of functional feed. Feed mills could use their existing distribution networks to educate farmers on the benefits of functional feed.

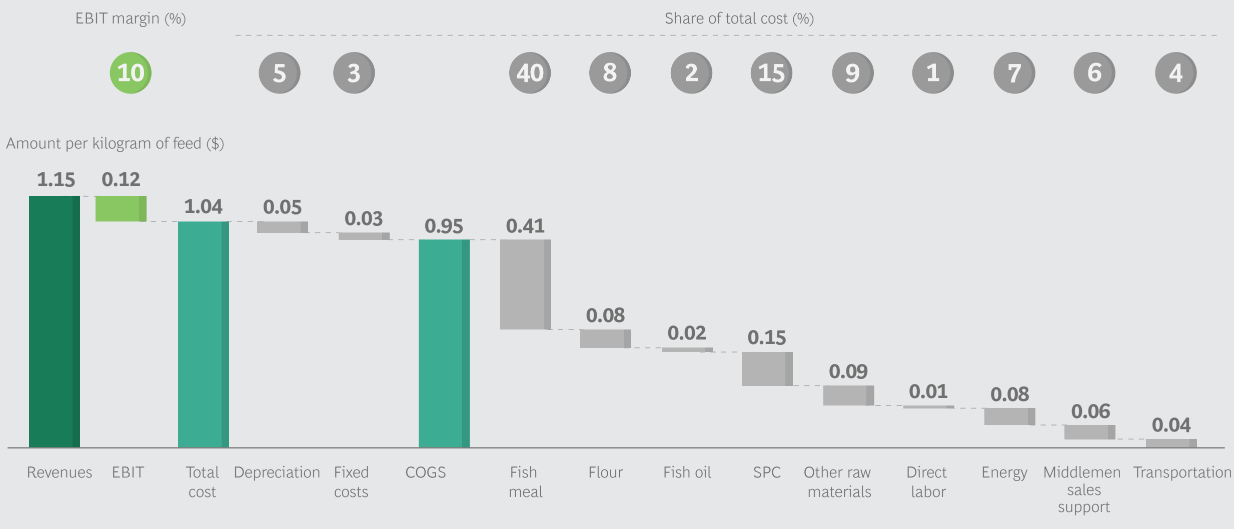
Business Case. Exhibit 21 shows the average economics of today's feed mills. We looked at two types of functional feed: growth enhancement and health enhancement.

Growth Enhancement Functional Feed. This enables higher efficiency in shrimp farming, which means demand will fall when farmers use functional feed, and revenues could decline by as much as about 15% owing to lower feed mill sales. However, there is the possibility of doubling today's EBIT margins, and as farmers will not use functional feed continuously, the impact on feed mill revenues is expected to be marginal.

The following are the assumptions on which we based the business case calculations for growth enhancement functional feed for feed mills:

- Revenue increase per kilogram of feed sold through a price premium of up to 20%

EXHIBIT 21 | The Economics of Today's Average Feed Mill



Source: BCG analysis.
Note: SPC = soy protein concentrate; COGS = cost of goods sold; Because of rounding, not all numbers add up to the totals shown.

- Production and input cost increase of about 6% per kilogram of feed produced
- Potential FCR improvement at the farm level: 30% reduction for half of the growth cycle, leading to an overall FCR of 1.36, causing the reduced demand

Health Enhancement Functional Feed. Feed mills can achieve a revenue increase of up to 50% owing to high price premiums. The premiums result in about triple today's average EBIT margin. (See Exhibit 22.)

The following are the assumptions on which we based the business case calculations for health enhancement functional feed for feed mills:

- Revenue increase per kilogram of feed sold through a price premium of up to 50%
- Production and input cost increase of about 15% per kilogram of feed produced
- Disease survival rate increases from a range of 20% to 30% to a range of 70% to 80% (This is particularly relevant for farmers who deal with high risk of disease.)

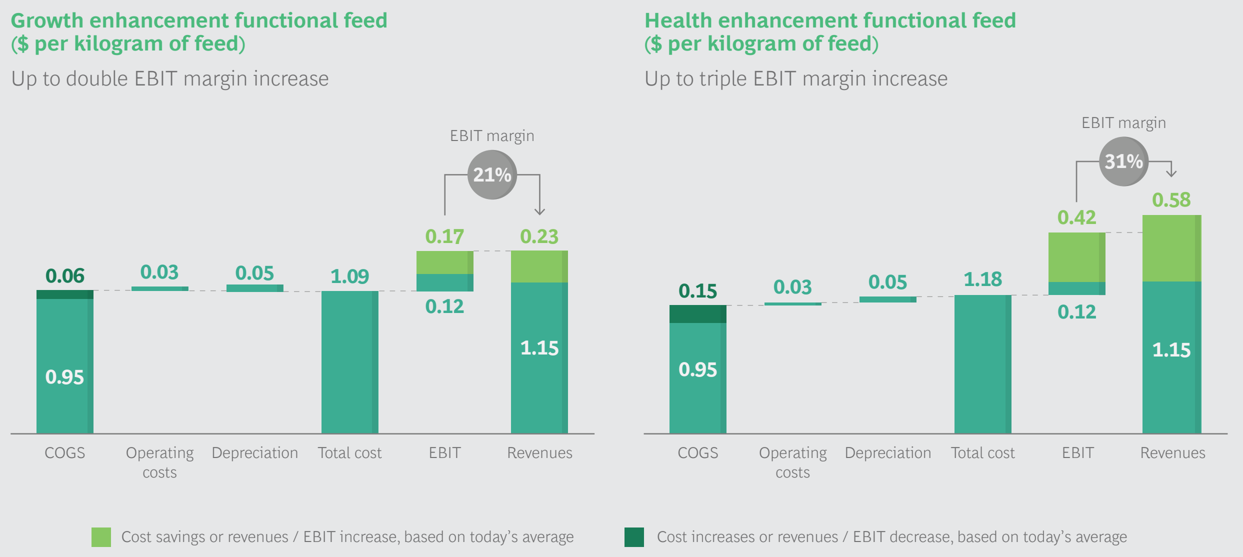
Environmental Impact. The overall impact on the environment is limited, but feed mills enable positive change at the farm level:

- Improved efficiency and reduced farm waste (With lowered mortality rates, for example, less feed goes to waste.)
- Reduced use of land, water, antibiotics, and need for wild-caught fish for fish meal and oil through reduced feed use in general and through the inclusion of ingredients that replace fish meal and oil (See Exhibit 23.)
- The need to further consider ingredients used in functional feed—as a substitute for fish meal—in terms of their effect on the environment (Greater dependence on soy, for example, has negative implications for the environment because soybean production is causing widespread deforestation.)

Hatcheries

Market Dynamics. The overall market volume for PL shrimp is about $3 billion per month from more than 550 registered hatcheries across 24 provinces in Thailand. Since its 2012 peak—about 80 billion to 90 billion PL annually—production has been cut nearly in half to 35 billion to 40 billion PL per year.

EXHIBIT 22 | Feed Mills Could Increase Margins Threefold



Source: BCG analysis.
Note: COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.

CP dominates the PL market: 65% of PL comes from CP, 25% from smaller players, and 10% from family businesses and unregistered backyard hatcheries. In the wake of the EMS disease outbreak, many farmers switched their sourcing to larger hatcheries with higher PL quality and better survival rates.

Hatcheries require stable relationships with farmers since PL can be fragile and must be sold quickly. A delayed sale can cause a hatchery's expenses to climb 10% to 15% per day owing to extra feed costs and higher mortality rates.

Business Case. Exhibit 24 illustrates the average economics of today's hatcheries. Even with no quantitative business case assessment, it's clear that high-quality PL contributes to better results for the industry overall.

Environmental Impact. The hatcheries have only limited impact, and water treatment and antipollution measures could further reduce their impact. Better PL quality leads to better survival for shrimp, reducing the impact of failed production on farms. This is a key driver for future value.

Farmers

Market Dynamics. With a 60% share, small independent family businesses dominate the shrimp-farming market in Thailand. CP has a 30% share, while Thai Union has 10%. Although just 40% of farms are directly associated with one of the large players, most can be linked to a large player through their PL and feed purchases (60% bundled). Furthermore, although it owns only 10% of production, Thai Union processes approximately 40% of the shrimp.

The majority—70%—of the farms are small (less than 1.6 hectares) family-owned businesses with fewer than five ponds, using approximately 40% of the land area. The remaining 30% of farms are large (more than 1.6 hectares) with more than 30 ponds per farm, using 60% of the shrimp farm area. There is no difference between small and large farms in terms of stocking density, yield, feeding rate, FCR, harvest weight, survival, or days in crop.

Shrimp farmers are highly concerned about two issues—PL quality and farming water quality—since both are critical for optimum productivity. For L. vannamei shrimp, 75% of farms in Thailand are intensive (with a high

EXHIBIT 23 | A Shift to More Efficient Functional Feed Reduces Negative Environmental Impact

	Land use	Water use and pollution	Chemicals and antibiotics	Use of fish and wild catch
Nutrient content: growth enhancement	Up to 15% land use reduction for feed due to increased feed efficiency (during half of the growth cycle)	Reduced water pollution due to more efficient feed with less feed waste in water body	Replacement of antibiotics with probiotics	**For growth and health enhancement:** Substitution of fish meal and fish oil in development for both kinds of functional feed
Nutrient content: health enhancement	Improved resource use and reduced waste due to increased survival rate and shrimp loss avoidance	Reduced water pollution due to more efficient feed with less feed waste in water body	Replacement of antibiotics with probiotics; health improvements through, for example, phytobiotics and amino acids reduce the need for medical interventions	Ambition to replace all fish meal use with plant-based nutrients

Source: BCG analysis.

production weight per unit area), 25% are semi-intensive, and none are extensive (with a low production weight per unit area). The survival rate for intensive farming varies from 40% to 85%, which means that farmers have much to gain from health-improving technologies.

Most shrimp farms in Thailand are currently operating below capacity and are not utilizing all available ponds, so no new farms are currently being built and none are expanding. Rather, existing farms are consolidating.

The farming process has become increasingly technical, with innovations in aeration and oxygenation, water pumps, feeding machines, and tanks. Because investing in these innovations can be costly, they are used primarily on the larger farms, but they can greatly reduce risk and increase shrimp survival rates.

Business Case. Exhibit 25 shows the average economics of today's farms. We explored the impact of a number of factors related to farm economics and environmental impact, individually and in combination: growth enhancement functional feed, health enhancement functional feed, biofloc, RAS, and solar energy.

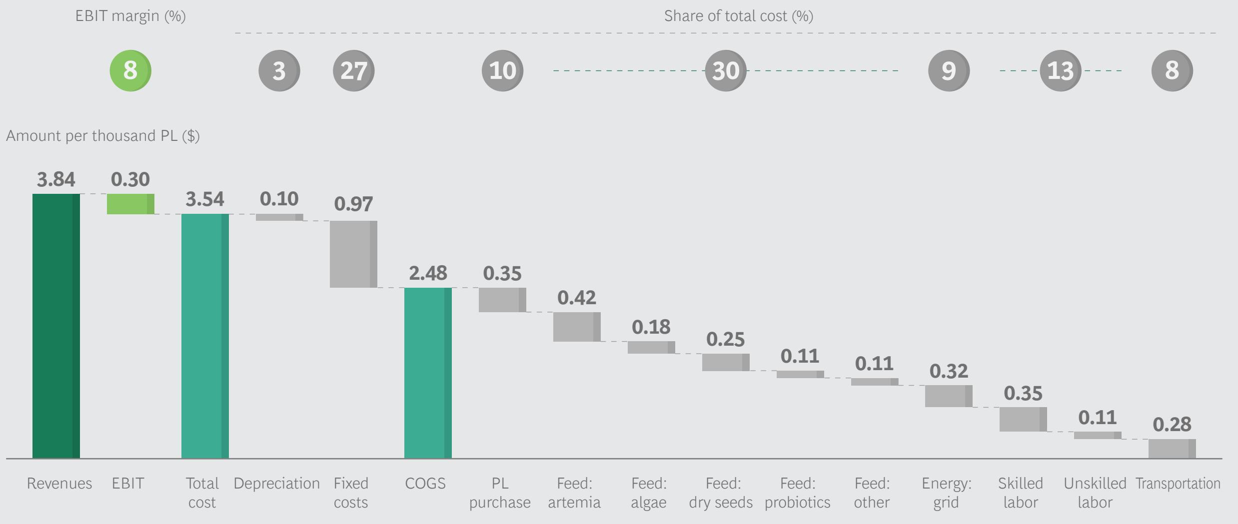
Functional Feed. The use of growth enhancement functional feed can lead to EBIT margins of up to 27% at the farm level, representing an increase of up to 41% in EBIT margins compared with today's average. (See Exhibit 26.)

The assumptions for the business case calculations for growth enhancement functional feed are the following:

- Shrimp that grow faster or to a larger size within the same timeframe can achieve price premiums of up to 6%.
- Growth enhancement functional feed lowers FCR by 30% in general, but because it is used during only half of the growth cycle, the FCR would be lowered by 15%, compensating for the 20% increase in feed prices (also used for half of the growth cycle).
- There is no need for a larger investment, but it is assumed that farmers can pay higher feed costs up front.

The use of health enhancement functional feed is not economically viable for farmers' continuous use: that would result in a steep

Exhibit 24 | The Average Economics of Hatcheries Today



Source: BCG analysis.
Note: COGS = cost of goods sold: PL = post-larvae shrimp. Because of rounding, not all numbers add up to the totals shown.

decrease in EBIT and possibly negative EBIT margins caused by a sharp increase (as much as 50%) in feed costs. However, if disease outbreaks are anticipated, it would be possible to achieve an EBIT margin of up to 21%, compared with 3% at today's average. This assumes that 20% of the harvest is affected by disease and is treated with health enhancement feed. Health enhancement feed serves as a risk management tool for farmers, and although it offers a clear financial incentive, to achieve its benefits requires long-term planning, management, and foresight.

The business case calculations for health enhancement functional feed for farms are based on the following:

- Feed sold at a premium of up to 50% above the price of conventional feed
- No change in FCR, but survival rates that rise from a range of 20% to 30% to a range of 70% to 80%
- Scenario 1. Using basic feed for the entire production: 80% successful crops with a 65% survival rate; 20% of crops hit by disease and a survival rate of only 20% to 30%
- Scenario 2. Using basic feed two-thirds of the time: successful crops with a 65% survival rate and health enhancement functional feed one-third of the time to avoid disease with a survival rate as high as 80%

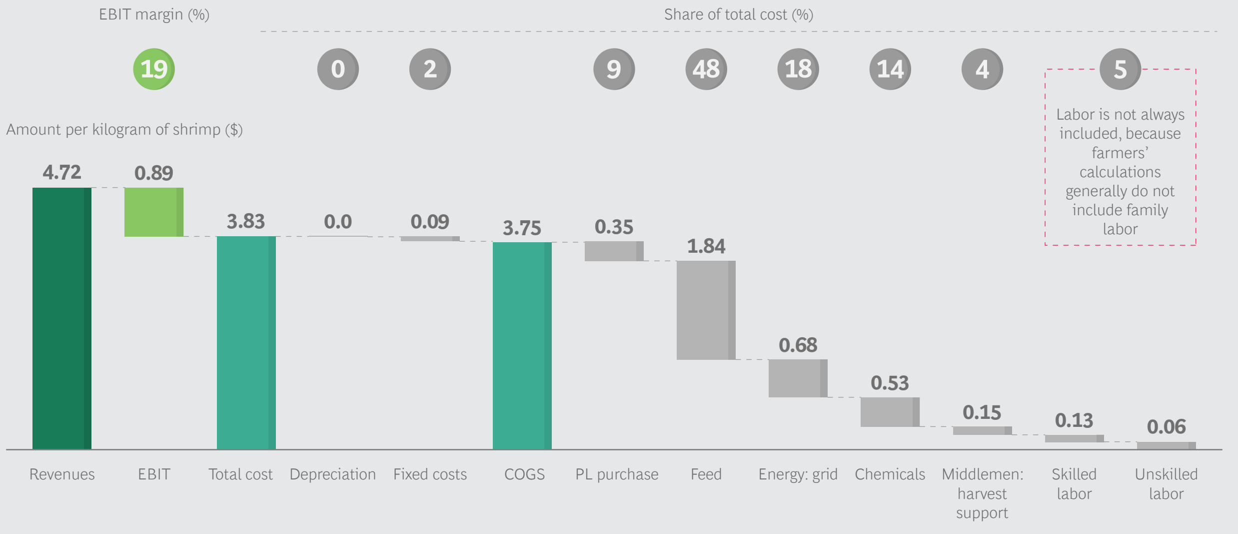
Environmental Impact. If farmers increase their efficiency, less feed will pollute the water, and the use of growth enhancement feed can indirectly reduce the impact of overfishing and lead to a positive environmental impact.

Biofloc and RAS. The business case for using biofloc depends on the farm's technical management, which influences prices, costs, and production parameters (such as FCR and growth cycles). In the best-case scenario, farmers achieve EBIT margins as high as 26%, increasing margins as much as 36%. By contrast, in the worst-case scenario, margins drop slightly, leading to overall EBIT margins as low as 19%. If farmers are knowledgeable and consistently monitor the system, they can expect to achieve the best-case scenario. (See Exhibit 27.)

The assumptions for business case calculations for biofloc for farms include the following:

- Energy cost increases of 20% to 40% due to the extended need for aerators

EXHIBIT 25 | The Average Economics of Farms with Successful Harvests



Source: BCG analysis.
Note: PL = post-larvae shrimp; COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.

- Increases in the cost of skilled labor of 5% to 10% due to the need for higher controls and constant supervision
- A 25% decrease in FCR because biofloc can be used partly as a feed source
- Reductions in the costs for chemicals of 3% to 7% as water quality improves through biofloc use
- The additional cost for cornmeal as a carbohydrate source ranges from $0.30 to $0.50 per kilogram (For a kilogram of shrimp, approximately 0.6 kilograms of cornmeal is a required biofloc ingredient.)
- The worst-case scenario overall, variable costs increasing by 2%; the best case overall, variable costs decreasing by 5%
- A survival rate that is similar to that of a system without biofloc
- Due to the protein content in biofloc, an increase of up to 27% in the growth rate, raising the sales price of the larger shrimp by 2% to 4%

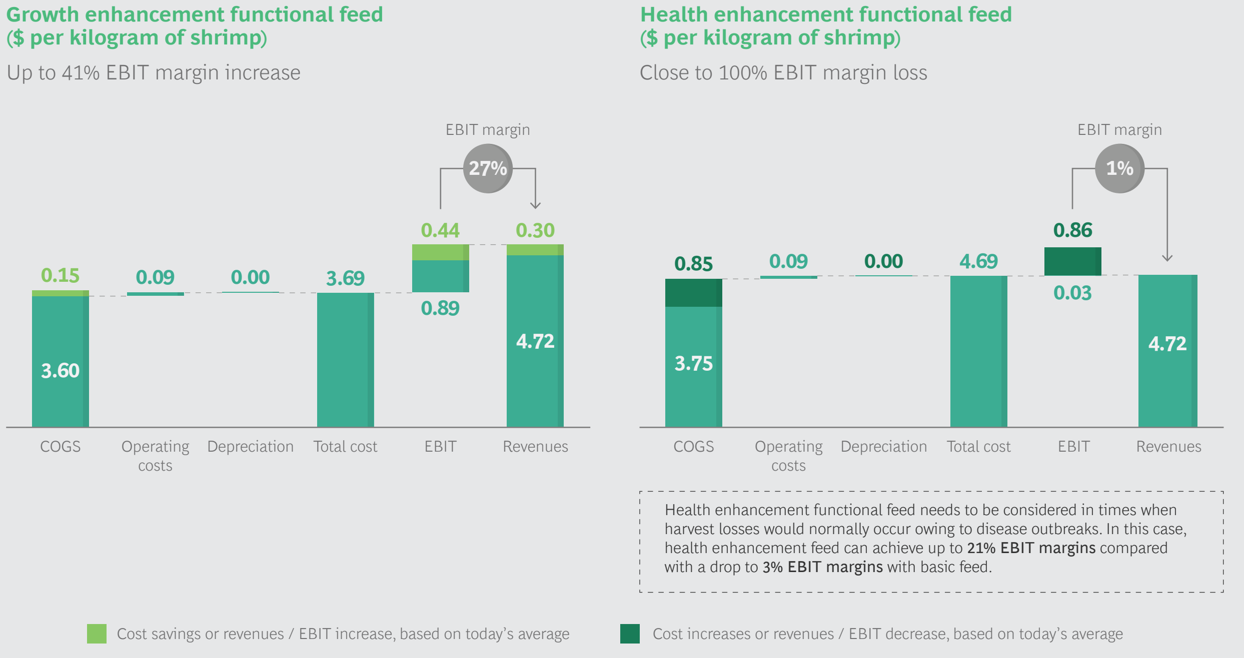
Several farms in Thailand already use biofloc. In 2018, Lim Shrimp Organization, one of Southeast Asia's largest shrimp-farming groups, established two Aqua Villages in Thailand. Aqua Villages are integrated farming projects that use sustainable farming principles, including the use of probiotics and biofloc systems. The organization aims to protect the environment and promote sustainable methods to grow shrimp.

Farms that use RAS can increase EBIT margins by up to 40% per kilogram at the farm gate, achieving a new EBIT margin as high as 26%. Additionally, overall revenues are boosted owing to higher stocking densities and, consequently, yields.

Assumptions for business case calculations for RAS include the following:

- The possibility of a twofold increase in stocking densities due to better water quality and monitoring of water conditions
- Investment costs of $150,000 per hectare, depreciated over ten years leading to an expected yearly yield of 60,000 kilograms per hectare (based on increased stocking densities)
- Lower disease risk due to superior water quality and higher biosecurity, leading to improved survival rates

EXHIBIT 26 | Growth Enhancement Functional Feed with an EBIT Margin Increase of up to 41%



Source: BCG analysis.
Note: COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.

- A 15% decrease in variable costs, reflecting increased energy and maintenance costs, reduced labor costs due to higher automation and higher stocking densities, reductions in the amount of chemicals required, and lower disease risk

- A 50% decrease in fixed costs due to higher stocking densities

The increase in stocking densities is maximized in indoor systems. Therefore, an investment in RAS is recommended only as part of a shift to indoor systems. With indoor farming, the water quality and shrimp conditions can be fully controlled to minimize contamination, allowing for even higher stocking densities and higher survival rates.

Environmental Impact. The environmental impact of biofloc and RAS is positive. With biofloc, better water quality leads to less pollution, eutrophication, and ground water contamination, permitting water recycling and reducing water intake. Lower FCR has an indirect impact on feed production and the potential to reduce the amount of wild fish used in feed. RAS reduces the use of new intake water (except to make up for seepage and evaporation), but because energy consumption is higher, there is the risk of higher air pollution. Still, the use of RAS has the potential to reduce land use, because the increase in stocking densities allows for higher output per hectare.

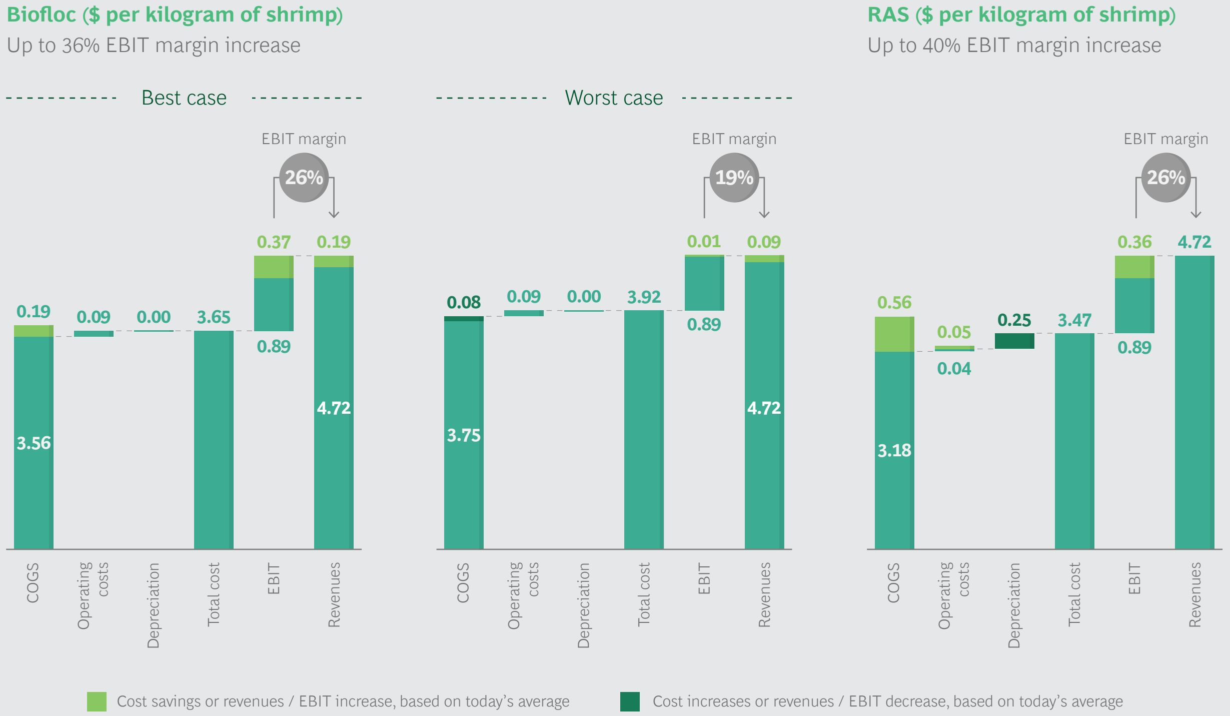
Combined Options: Growth Enhancement Functional Feed and RAS. The combination of growth enhancement functional feed and RAS yields EBIT margins of up to 33%, representing an increase of up to 77% over the base case and up to 25% compared with both RAS alone or standalone functional feed. (See Exhibit 28.)

The assumptions for business case calculations for the combined use of growth enhancement functional feed and RAS for farms include the following:

- Assumptions comparable to standalone solutions as both methods affect different variables

- Doubled stocking density possible due to higher water quality and improved monitoring of water conditions

Exhibit 27 | Biofloc Can Increase EBIT Margins by as Much as 36%, While RAS Can Increase Them by as Much as 40%



Source: BCG analysis.
Note: RAS = recirculating aquaculture systems; COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.

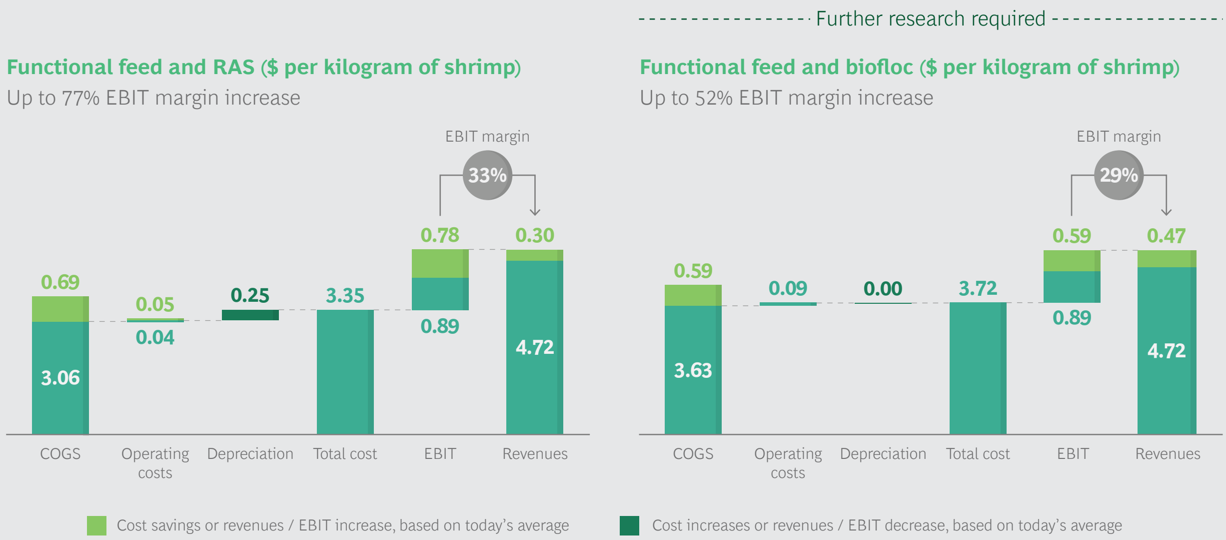
- Reduction of FCR by 15% due to the use of functional feed during half of the production cycle
- A 6% increase in the shrimp sales price due to larger shrimp, the result of using functional feed
- For half the growth cycle, a 20% increase in the feed sales price (and additional feed mill costs incurred)
- An 18% decrease in overall variable costs, the result of the combination of a cost increase due to the use of functional feed and a decrease in the cost per kilogram due to the use of RAS, in total leading to a cost decrease
- A 50% decrease in fixed costs due to RAS
- Investment costs of $150,000 per hectare depreciated over ten years with an expected yearly yield of 60,000 kilograms per hectare—double today's average

Combined Options: Growth Enhancement Functional Feed and Biofloc. The combination of functional feed and biofloc provides a better business case than today's average economics. Nevertheless, it is difficult to compare it with the standalone feed or biofloc business case as both improvement levers—growth enhancement functional feed and biofloc—affect the same production parameters (for example, FCR), and their combined impact has not been studied yet.

Assumptions for business case calculations for the combination of growth enhancement functional feed and biofloc for farms include the following:

- Up to 32% improvement in FCR, as the functional feed and biofloc can reduce FCR, compared with a 15% reduction through the use of growth enhancement functional feed and a 25% reduction through biofloc (The effect on FCR is not the sum of both standalone options, as the combined impact has not yet been studied in depth.)

EXHIBIT 28 | A Combined Solution Can Increase EBIT Margin by as Much as 77%, a Higher Potential Benefit Than a Standalone Solution



Source: BCG analysis.
Note: RAS = recirculating aquaculture systems; COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.

- The increase in the sales price of up to 10% because a higher price can be achieved for larger shrimp (Accelerated growth through the combined use of functional feed and the high protein content of biofloc leads to even higher prices achievable in the market if global shrimp prices are correspondingly high.)

- Additional assumptions for biofloc (averaged best and worst cases): skilled labor increase of 8%, energy increase of 30%, chemical decrease of 5%, and cornmeal as a carbohydrate source, priced at about $0.38 per kilogram—about 0.6 kilograms of cornmeal per kilogram of shrimp produced—needed for biofloc development

However, as indicated before, the combination of the two options still needs in-depth assessment, and these assumptions must be validated through further research.

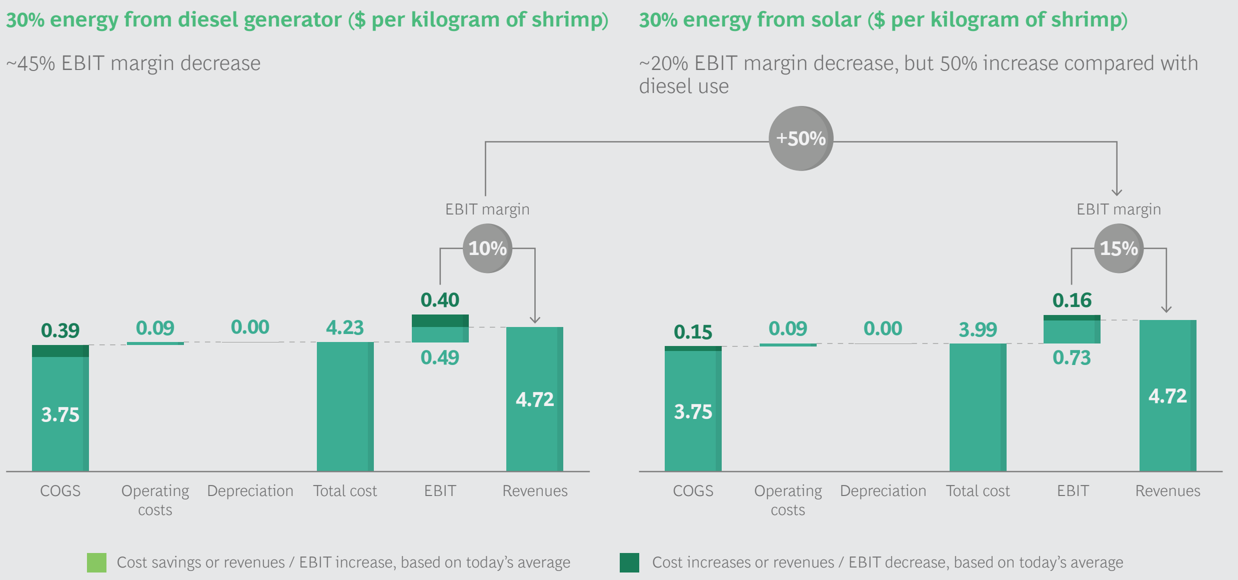
Solar Energy. In general, large shrimp farms in Thailand get 100% of their energy from the electricity grid. However, a small number of shrimp farms located in remote areas face frequent energy outages. As a result, they may use diesel generators, which are expensive and are sources of pollution. For these remote farms, renewable solar energy represents a reliable, economic, and clean alternative.

Although solar energy is more expensive than grid energy on the basis of the cost per megawatt hour, it is significantly less costly than diesel. Replacing diesel generators with solar energy can yield an increase of up to 50% in EBIT margins. This said, the initial investment for PV systems requires significant capex investments—up to $25,000 per hectare, depending on the system, and up to about $45,000 for PV systems with battery storage—which small farms in remote areas may not be able to afford.[11] But as the costs of batteries and solar power continue to decrease, this option could eventually become more affordable for remote farms as well as grid users.

The total EBIT margin can be up to 15% when solar energy is combined with grid energy—an increase of up to 50% EBIT margin over diesel combined with grid energy (10% EBIT margin)—but this represents a decrease of up to 20% compared with grid only, which has EBIT margins of up to 20%. (See Exhibit 29.)

Assumptions for business case calculations for solar energy for farms include the following:

EXHIBIT 29 | Use of Solar Energy Trumps Diesel Results for EBIT by as Much as 50%



Source: BCG analysis.
Note: COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.

- A levelized cost of energy for solar options, including batteries, estimated to be higher than grid energy but significantly lower than diesel generator use
- The shift to solar energy that is relevant and applicable only for farms in remote areas with high diesel generator use, which is the case for the minority of farms in Thailand
- Electricity that is 70% from the grid and 30% diesel generated
- A levelized cost of energy for solar of $160 per megawatt hour that represents the average cost for ground-mounted tracking, floating tracking, and floating PV systems
- A grid energy price of $91 per megawatt hour and a diesel energy price of $267 per megawatt hour
- Applicability for nonintegrated players only, as integrated players are usually connected to the grid

The number of farms that rely solely on diesel is declining. Most farmers are connected to a stable grid supply. Therefore, this business case is relevant for only a small fraction of farmers. Unless prices for solar and batteries decline, the situation is unlikely to change.

Environmental Impact. In terms of environmental impact, solar energy, unlike diesel generators and grid-sourced energy, reduces carbon emissions. But in some cases, construction of solar panels still affects land use.

Middlemen

Market Dynamics. Middlemen handle business interactions between the largely fragmented farmers and the processors and wholesalers.

The network of middlemen—which collects shrimp from multiple farms, aggregates them, and then delivers the regrouped batches of shrimp to processors—is one of the major points of nontransparency along the value chain. During this process, the origin of single shrimp products becomes untraceable. Owing to their practices and the sector's informality, middlemen represent a major challenge to progressing toward traceable supply chains.

Business Case. No quantitative business case was assessed, but middlemen can play a key role in moving the industry toward traceabili-

EXHIBIT 30 | Two Options for Shrimp Processing: Minor Processing or Value-Added Processing

Source: Expert interviews; BCG analysis.

ty. Currently, it is difficult to trace and track shrimp in Thailand because, in many cases, middlemen mix and sort shrimp from multiple farms.

Environmental Impact. If middlemen were to support traceability, there would be less land use as well as reduced water and energy consumption. They can decrease their environmental footprint by ensuring that no drugs or other illegal substances are injected into shrimp and by providing guidance to farmers on best practices.

Processors and Exporters

Market Dynamics. Most Thai shrimp is processed with either minor processing or value-added processing. (See Exhibit 30.) Value-added processed products make up about 40% of shrimp exports.

Approximately 70% of processing is for export. Thai Union, which dominates the processing and export market, integrates processing and exports.

Most shrimp processors currently operate below capacity, and no expansion or new processing plants are expected in the near future. Approximately 200,000 metric tons of shrimp, with a total value of about $2 billion, are exported from Thailand.

Business Case. Exhibit 31 illustrates the average economics of today's processors.

No quantitative business case was assessed, but there is an urgent need to act on the social issues—including slave labor allegations and unethical conduct—that currently threaten exports.

Because processors are at the intersection of buyers and retailers, they are directly affected if retailers refuse to buy Thai shrimp owing to environmental or social concerns or if retailers want better traceability and sustainable supply chains and are willing to pay a premium.

This opportunity for premium pricing currently exists only for niche markets: the mainstream market is competing on price. If processors drive positive change in the upstream supply chain, they will yield high benefits, including sustained access to larger quantities of high-quality shrimp, market access, and good relationships with buyer markets.

Environmental Impact. Processors' support for traceability would reduce land use as well as water and energy consumption. Additionally, processors have an obligation to improve social norms and concerns as well as labor conditions.

Exhibit 31 | Today's Average Economics of Processors

Source: BCG analysis.
Note: COGS = cost of goods sold. Because of rounding, not all numbers add up to the totals shown.
[1]At least 1.3 kilograms of raw shrimp are required to produce output of 1 kilogram of frozen shrimp.

Notes

1. This estimate is based on the export value Thai shrimp producers achieved prior to the disease crisis and the increase in tariffs for Thai shrimp products exported to the EU.

2. Litopenaeus vannamei, also known as whiteleg shrimp, makes up 95% of Thailand's shrimp market, and Penaeus monodon (black tiger shrimp) makes up less than 5% of market share. Since L. vannamei is expected to remain the dominant species for the foreseeable future, this report focuses exclusively on L. vannamei, unless otherwise specified.

3. This estimate is based on today's market value—5% functional feed—compared with market growth by 1 percentage point, solely attributed to functional feed. The value is based on feed prices for basic rather than growth enhancement functional feed.

4. The feed conversion ratio indicates how much feed is needed for the production of one kilogram of shrimp.

5. RAS provide the ability to reuse water, dramatically reducing fresh-water intake as well as wastewater discharge into the environment.

6. The effects on the feed market as well as the impact on land and fish use have to be examined separately.

7. This estimate is based on the export value Thai shrimp producers achieved prior to the disease crisis and the increase in tariffs on Thai shrimp products exported to the EU.

8. Li Li, Claude E. Boyd, Phoebe Racine, Aaron McNevin, et al. "Assessment of elemental profiling for distinguishing geographic origin of aquacultured shrimp from India, Thailand and Vietnam," *Food Control* 80 (2017): 162–69.

9. PL stocked per square meter in brackish water for the production of shrimp.

10. Additionally, as the shrimp-farming industry in Thailand contracts and laws for protected areas such as mangrove forests are more strictly enforced, Thailand is seeing virtually no land conversion for new shrimp farms.

11. This is based on the energy use per hectare of shrimp produced per year: 30 metric tons of shrimp with electricity requirements of 225 megawatt hours per year.

NOTE TO THE READER

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A Strategic Approach to Sustainable Shrimp Production in Thailand

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