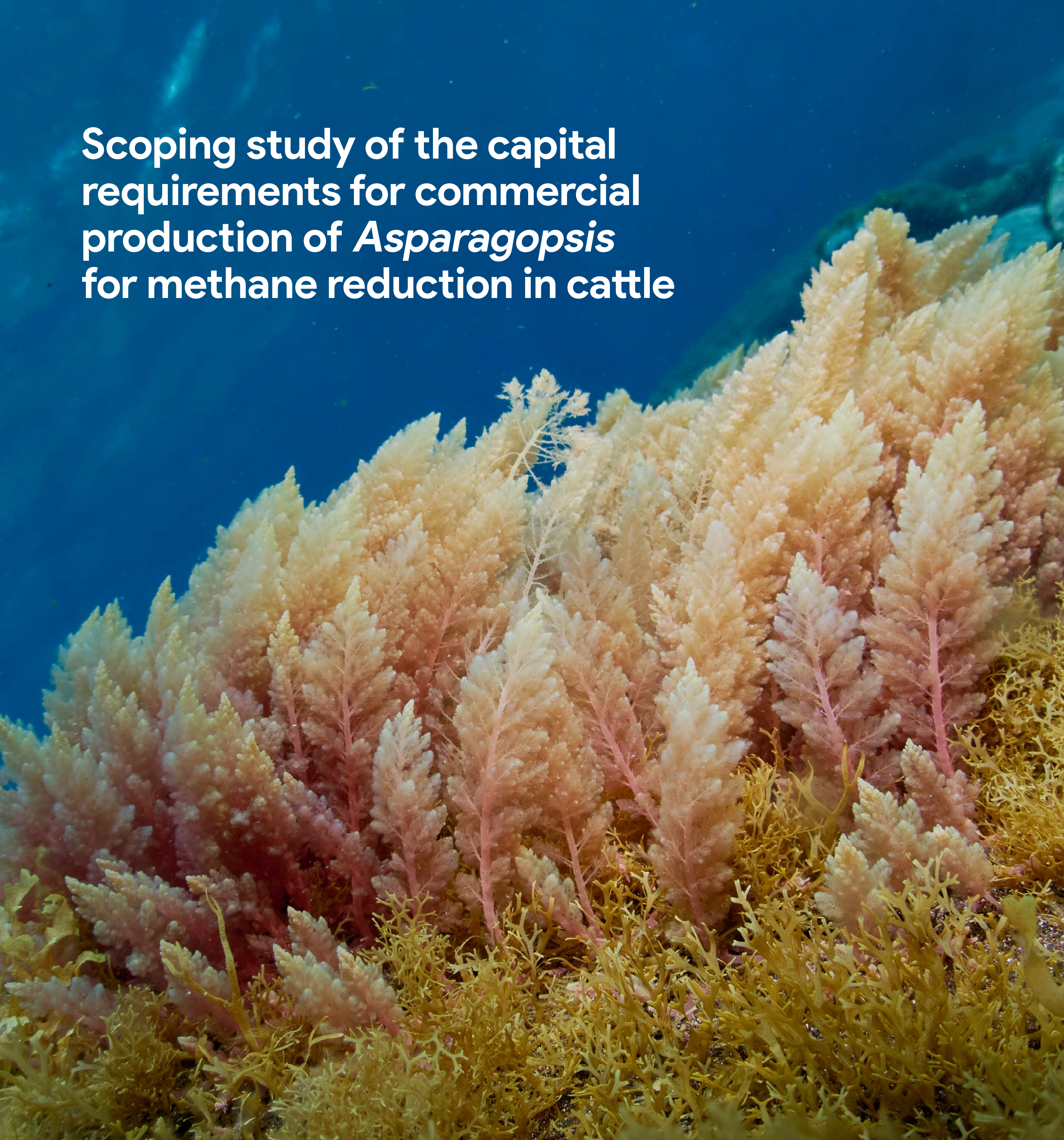
Scoping study of the capital requirements for commercial production of *Asparagopsis* for methane reduction in cattle



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Scoping study of the capital requirements for commercial production of Asparagopsis for methane reduction in cattle

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Cover image: *Asparagopsis* growing natively

Asparagopsis pre drying. Photo: CH4 Global

Foreword

As global citizens, we are continually encouraged to make sustainable changes that improve environmental outcomes while also boosting productivity. The Australian agriculture sector is highly mobilised around this challenge and none more so than the Australian red meat and livestock industry with its Carbon Neutral 2030 target and roadmap.

Methane emissions from the enteric fermentation of ruminant livestock is the largest source of greenhouse gas emissions in agriculture. Likewise, as custodians of more than half of Australia's land use, agriculture will play an enormous role in sequestering carbon dioxide into landscapes.

Cattle make up a key segment of Australian agriculture and are our largest agricultural export. The sustainable development of the livestock industry is recognised as an important part of the solution to address the complex challenge of sustainable food production to feed a rising global population.

Asparagopsis spp. is a group of native red seaweeds which, when incorporated as an animal feed, reduce methanogenesis and could revolutionise the world's approach to mitigating livestock emissions. Research into the effectiveness of *Asparagopsis* as a feed additive for cattle to reduce methane emissions is being keenly pursued.

This report has been co-funded by AgriFutures Australia and the Commonwealth Bank to explore the potential capital required for commercialising large-scale *Asparagopsis* production in anticipation of successful research outcomes.

Commonwealth Bank is committed to the transition to net zero emissions by 2050 and is proud to support research that drives innovation by Australian farmers and the agricultural sector to develop new techniques in sustainable farming.

The *Scoping study of the capital requirements for commercial production of Asparagopsis for methane reduction in cattle* has been produced as part of AgriFutures Australia's Emerging Industries Program, which focuses on new and emerging industries with high growth potential. Emerging animal and plant industries play an important part in the Australian agricultural landscape. They contribute to the national economy and are key to meeting changing global food demands.

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This report has been co-funded by AgriFutures Australia and the Commonwealth Bank.

The Commonwealth Bank is steadfastly committed to playing a role to help the transition to net zero emissions by 2050 and achieve the goals of the Paris Agreement. The Commonwealth Bank proudly fosters innovation by Australian farmers and the agriculture sector to develop new techniques in sustainable farming, and will continue to support ongoing research that drives greater sustainability in this key sector of the Australian economy.

Acronyms and glossary

ALFA	Australian Lot Feeders' Association
DOF	Days on feed – the number of days cattle are fed a grain-based diet in a feedlot.
DM(I)	Dry matter (intake). Dry matter is the portion of something, in this case livestock feed, that remains after all water is removed.
Greenfield	Not previously developed, in this context referring to the establishment of a farm or hatchery on a virgin site – as distinct from repurposing (for example) a mussel farm.
Hatchery	A facility in which juvenile forms of seaweed species are grown on ropes or string that are then suitable to be farmed. A given hatchery may supply multiple farms.
MLA	Meat & Livestock Australia
OM	Organic matter – the portion of something, in this case food, that comprises carbon-based compounds.
Terrestrial cultivation	Production of water-based products such as seaweed or fish in land-based ponds or tanks (as distinct from natural marine or freshwater environments).

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Asparagopsis from tank. Photo: CH4 Global

Harvested *Asparagopsis* at Sea Forest's production facility in Tasmania. Photo: Sea Forest

Executive summary

The report provides preliminary estimates of the capital required to scale up production of the red seaweed *Asparagopsis* to meet the demands of the Australian feedlot industry.

Asparagopsis has generated considerable interest with its potential to greatly reduce methane emissions, particularly when fed as part of a concentrate diet to beef cattle in feedlots. Methane is reduced by the compound bromoform in *Asparagopsis*. One study showed that the inclusion of *Asparagopsis* at a rate of just 0.4% of the dry matter of the diet reduced methane emissions by 98%. *Asparagopsis* may become an important contributor to meeting the Australian red meat industry's target of being carbon neutral by 2030. As a result, extensive research into the steps required to commercially produce and process *Asparagopsis* has commenced.

The aim of this project was to estimate the capital investment required to enable scale-up of *Asparagopsis* production to meet the feed demands of the Australian feedlot industry, on five- and 10-year timescales, and the operating costs (cost/unit feed) associated with *Asparagopsis* production. The project was required to include a minimum of two sensitised scenarios relative to base assumptions.

In consultation with AgriFutures Australia, the consultancy team identified and approached several key individuals and organisations likely to have relevant data on the parameters required for the review. These stakeholders were involved with research or commercialisation of *Asparagopsis* in Australia and/or the red meat industry. The data was compiled and cross-checked against that available from selected peer-reviewed references. There is no large-scale commercial farming of *Asparagopsis* species from which to derive data, nor any substantial modelling of datasets, benefit-cost analysis or gross margin analysis. Much foundational research is still being carried out on all aspects of the value chain, from cultivation to processing and product formulation. Pioneering companies are understandably reticent to reveal commercially sensitive information and, in many cases, are still very much in an early pilot commercialisation phase.

Given these constraints in obtaining validated real-world data, estimates of the capital required to establish an *Asparagopsis* supply chain to meet the methane reduction requirements of the Australian beef feedlot industry vary widely. If yield estimates at the upper end of the currently quoted range are applied, and the cost per hectare to establish farming and processing infrastructure is at the lower end of stakeholder estimates, the estimated capital cost at 100% adoption by the cattle industry is $132 million. Conservative yield and higher cost estimates push this figure up to $1,062 million. The wide range in estimates reflects the fact that the *Asparagopsis* industry is very much in its infancy.

The estimates provided in this report are approximate and should be treated with great caution. They are based on a very small number of published and anecdotal estimates. Much depends on whether and how greenfield sites are established, or existing facilities (such as mussel farms) are re-purposed. Whether the latter occurs will depend on the relative value of *Asparagopsis* against alternative products. It also appears likely that terrestrial cultivation of *Asparagopsis* will be investigated to determine production potential, commercial viability and environmental impact. With greater control over the operating environment (water quality, temperature and harvesting frequency) within a terrestrial aquaculture system, it could become the dominant production system for *Asparagopsis*. Terrestrial aquaculture systems are likely to have quite different establishment and ongoing cost structures to ocean-based systems. However, interviewees believe that the set-up costs are going to be at least the same magnitude as ocean-based systems. Those companies were also very reluctant to share commercially sensitive information.

There is even greater uncertainty around the cost of hatcheries and processing plants. Scale will undoubtedly drive down the costs of establishing and operating these facilities.

Some stakeholders were emphatic that capital is not expected to be a constraint for this industry, given its significant promise and attractiveness to ethical investors. The demand for *Asparagopsis* and its availability to beef producers could also be substantially influenced by competitor products (methane mitigation), competitor countries and competitive applications for *Asparagopsis* itself. Important performance attributes of *Asparagopsis* are also yet to be resolved before being translated to the commercial sphere.

Introduction

AgriFutures Australia and the Commonwealth Bank commissioned this scoping study on the capital likely to be required to scale up production of the red seaweed *Asparagopsis* to reduce methane emissions from the Australian cattle feedlot industry.

The Australian red meat industry contributes about 10% of Australian methane emissions (McCauley *et al*. 2020; Black *et al*. 2021). The industry has a publicly stated aim to be carbon neutral by 2030.[1]

A growing number of research studies have demonstrated that *Asparagopsis taxiformis* has the potential to greatly reduce the methane emissions of farmed cattle (Kinsey *et al*. 2020). The feeding of *Asparagopsis*, especially as part of the concentrate diet of beef cattle in feedlots, could be an important contributor to meeting the red meat industry's 2030 target.

Asparagopsis has a complex life cycle (Batista 2020), which will not be explained here. For the purposes of the report, it should be understood that commercial seaweed value chains generally include hatcheries that provide seedstock, such as seeded string or seeded rope, for one or more commercial farms. Seeded rope is anchored to the seafloor and the seaweed grown out. The seaweed is then harvested and processed to a form that is suitable for the end market. This process may involve sun drying, freeze drying, mechanical chopping and/or various other processes, such as oil emulsion (see, for example, Lane 2018).

At the time of this study (late 2021), there was no large-scale commercial farming of *Asparagopsis* species in Australia but there is public and private research underway around the world, including in Australia, into *Asparagopsis* cultivation methods. Several commercial players are positioning themselves to be large-scale *Asparagopsis* suppliers. It must be emphasised, though, that knowledge about the commercial production of *Asparagopsis* is very much based on research-scale trials only, and most of the intellectual property associated with *Asparagopsis* cultivation is held by private interests.

The *Asparagopsis* value chain is very much in its infancy. Even basic questions – such as whether terrestrial cultivation systems will prove more productive and profitable than ocean-based systems – are some years from being answered. Notably, the Australian Government has recently made available $5 million in grants to support "the development and commercial readiness of technology solutions to deliver low-emission feed supplements to grazing animals".[2] This includes an objective to "fast-track the development and commercial readiness of technology solutions to deliver low-emission feed supplements to grazing animals at large-scale".[3] The funding is for phases 2 and 3 of a program that has already provided $4 million of funding for research in this area.[4]

It should be noted that another species of *Asparagopsis*, *A. armata*, also has the potential to reduce methane emissions when fed to livestock. However, this report has focused only on *A. taxiformis*, given the very limited information available on *A. armata*, particularly as a farmed species.

[1] https://www.mla.com.au/research-and-development/Environment-sustainability/carbon-neutral-2030-rd/cn30/

[2] https://business.gov.au/grants-and-programs/methane-emissions-reduction-in-livestock-stage-2

[3] ibid

[4] https://business.gov.au/grants-and-programs/methane-emission-reduction-in-livestock/grant-recipients

Objectives

The objectives of the project were to:

- Estimate the level of *Asparagopsis* production needed to meet the methane reduction requirements of the Australian feedlot cattle industry.
- Identify the capital investment and infrastructure needed to enable scale-up of *Asparagopsis* production to meet the feed demands of the Australian feedlot industry.
- Identify the potential production systems for *Asparagopsis* in Australia.
- Identify the production characteristics to service the beef feedlot market with *Asparagopsis*, considering factors including location, size, processing capacity and logistics.
- Estimate the operating costs (cost per unit feed) associated with *Asparagopsis* production.
- Identify the rate of production growth needed to meet cattle feed demands on five- and 10-year timescales.
- Include a minimum of two sensitised scenarios, covering at least one optimistic and one pessimistic scenario, relative to base assumptions. The conditions and factors underpinning each scenario should be outlined and the assumptions detailed.

Methodology

The consultancy team developed a framework for calculating the capital required for a cultivated *Asparagopsis* value chain to service the Australian cattle feedlot industry. The primary parameters that have been estimated are:

A. Number of cattle on feed currently and expected in 2030

B. Inclusion rate of *Asparagopsis* in the diet (g/head, calculated from % dry matter intake (DMI))

C. Yield of farmed *Asparagopsis* (t DM/ha/annum)

D. Cost to establish farms ($/ha)

E. Cost to establish hatchery and processing facilities ($/ha of farm)

F. Annual operating costs ($/kg or $/ha).

From these parameter estimates, the following were calculated:

G. Total *Asparagopsis* needed = A*B (t DM)

H. Total production area needed = G/C (ha)

I. Total capital needed to establish production area = H*D

J. Total capital needed to establish processing capacity = H*E.

In addition, the scoping study required that certain qualitative data be obtained:

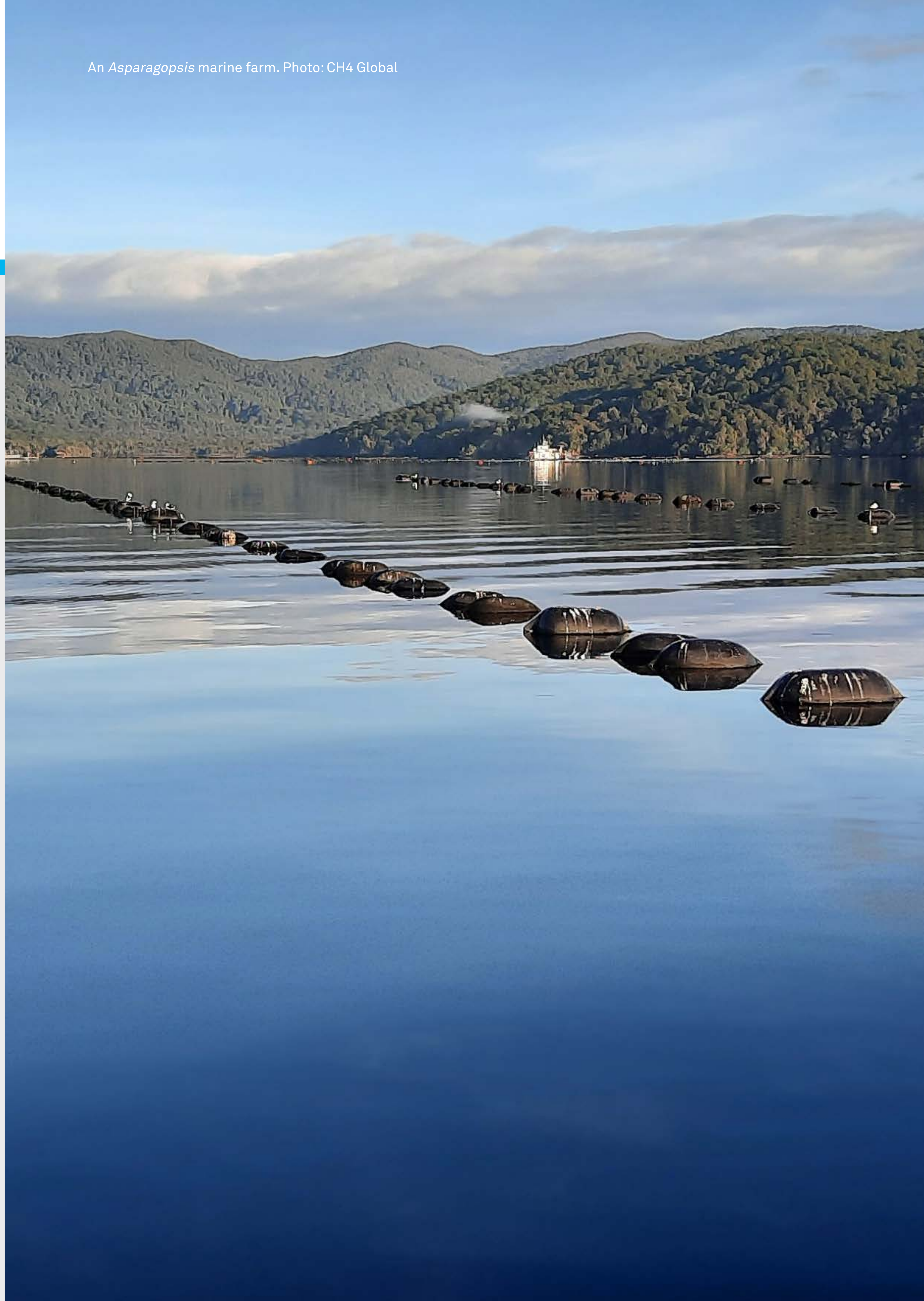
- Potential production systems in Australia
- Production characteristics to service the beef feedlot market with *Asparagopsis*, considering factors including location, size, processing capacity and logistics.

In consultation with AgriFutures Australia, the consultancy team identified and approached several key individuals and organisations likely to have relevant data on the parameters required for the review. These stakeholders were involved with research or commercialisation of *Asparagopsis* in Australia (and potentially globally) and/or the red meat industry.

The data was compiled and cross-checked against that available from selected scientific and grey literature references (see References).

Total capital costs were then estimated from the individual parameter estimates as described above. The two most uncertain parameters – yield (t DM/ha/annum) and production and processing establishment costs – were then subjected to sensitivity analyses to provide optimistic and pessimistic scenarios as required by the terms of reference.

It is important to note that this study did not involve any original work to generate data, nor any substantial modelling of datasets to provide interpolative or extrapolative estimates, except in respect to basic feedlot industry demographics, the quantum of *Asparagopsis* needed to feed cattle, and some partial sensitivity analyses. The review does not provide a benefit-cost analysis nor gross margin analysis of any part of the *Asparagopsis* value chain.



An *Asparagopsis* marine farm. Photo: CH4 Global

Results

Individual parameter estimates

Number of cattle on feed currently and expected in 2030

According to the Australian Lot Feeders' Association (ALFA), there are up to 400 accredited cattle feedlots in Australia with capacities ranging from 500 to more than 50,000 head. At any one time, 2-3% of Australia's total cattle population are in feedlots, and lot-fed beef contributes 30-40% of Australia's total beef production for either domestic consumption or export.

In 2020-21, ALFA reported about 2.9 million animals were grain-fed, from 70 days (short-fed) through to 450 days (long-fed). It is important to distinguish this annual turnoff number from the number of cattle that are on feed at any given time. Most lot-fed cattle are on feed for much less than a year, and are then replaced by a new cohort. There is a total on-feed capacity of about 1.45 million at any one time (although this is continually expanding), at an average utilisation rate of about 70%. Over the past 10 years, the number of cattle on feed at any one time has increased from 750,000 to a peak of 1.22 million, which is still below the national capacity.[5]

Given national herd forecasts of a strong rebuild continuing towards 2030, it is likely that the number of cattle on feed will increase to about 1.4 million head at any one time, or about 3.1 million cattle annually. These forecasts of the number of cattle on feed (i.e., in feedlots) in Australia in 2026 and 2030 were verified with key stakeholders from Meat & Livestock Australia (MLA) and ALFA.

Inclusion rate of *Asparagopsis* in the diet

The mechanism for the reduction in methane emissions by *Asparagopsis* has been attributed to the bromoform and di-bromochloromethane content of the seaweeds. Natural variation in content of these compounds and processing methodologies combine to influence the methane-reducing capacity of *Asparagopsis*, which is evident in a number of published *in vitro* studies.

Despite the widespread global interest in feeding *Asparagopsis* to reduce methane production, the number of published *in vivo* studies in beef cattle is still low. In a recent meta-analysis, Lean *et al.* (2021) estimated methane reduction effects of −5.28 ± 3.5 g/kg DMI from feeding *A. taxiformis*, which is a marked reduction, although the authors did note wide variance within the small sample of results. They concluded more evidence from *in vivo* experiments was required to strengthen knowledge of effect, identify sources of heterogeneity in methane response, and evaluate practical applications and potential risks of seaweed use.

The most definitive and most cited *in vivo* study in feedlot beef cattle is that of Kinley *et al.* (2020), who included *Asparagopsis* at rates of 0.05% organic matter (OM; or 0.09% DM), 0.10% OM (0.18% DM) and 0.2% OM (0.38% DM), and showed that methane was reduced by 9%, 38% and 98%, respectively. This result would suggest that the optimal inclusion rate is 0.2% OM or 0.38% DM. This is consistent with the estimate used by Jia *et al.* (2021) in modelling requirements for 50% of the Australian feedlot industry. This inclusion rate of 0.38% DM, confirmed in consultation with several key stakeholders, has been adopted for this report.

It should be noted that the bromoform concentration of the as-fed *Asparagopsis* product will significantly affect the required level of feed additive because higher bromoform concentration is likely to be more effective in reducing methane emissions. Literature estimates of bromoform concentration in *Asparagopsis* range from 3.4 to 43 mg/g DM (Jia *et al.* 2021). Several literature sources and stakeholder consultations indicated that the bromoform concentration will improve through selection of strains and techniques that preserve the efficacy of the bromoform through processing (e.g. Jia *et al.* 2021). In addition, several stakeholders indicated that the efficacy of bromoform (and therefore feeding *Asparagopsis*) on methane mitigation is also the subject of significant research and development. It is likely that complementary additives may reduce the actual levels required.

The inclusion rate of 0.38% DM adopted for this report equates to a conservative estimate of bromoform concentration of 4 mg/g DM. One of the stakeholders interviewed suggested that beef cattle in a feedlot will require 250 mg/head/day of bromoform to effectively mitigate methane. At 4 mg/g, this quantity of bromoform would be supplied by 62.5 g of *Asparagopsis* (equivalent to a low to medium level for cattle in the study of Muizelaar *et al.* 2021). This, in turn, equates to 0.4% DM as fed for an animal consuming 15 kg/day.

Yield/unit area of farmed *Asparagopsis*

A. taxiformis is a poorly domesticated and difficult species to farm (Zhu *et al.* 2021). Currently, there is no successful historical precedent for large-scale *A. taxiformis* production (Taylor 2021), which makes it difficult to estimate likely future production yields.

In the literature reviewed for this report, there was an absence of published estimates of yield. Stakeholders indicated that it was too early (and potentially commercially sensitive) to predict commercial *Asparagopsis* farming performance. Furthermore, companies that have started to explore production potential in ocean and terrestrial systems were generally hesitant to provide specific estimates, given the complexity of the production system (multi-phase life cycles) and the rapid acceleration of new knowledge and practices that will improve overall production efficiency and quantum. Examples of such innovation include biomass monitoring, intelligent water management systems, computational fluid dynamics, novel substrate development, automation in harvesting and processing (Araújo *et al.* 2021), and integrated whole management systems such as Aquaculture 4.0 (García-Poza *et al.* 2020).

There are references in media releases and on company websites that suggest commercial production activities have started. For example, CH4 Global[6] has stated that it is in the process of building the world's first commercial *Asparagopsis* farm in South Australia – a 20-hectare water site coupled with a two-hectare land hatchery and processing site that will have the potential to feed 10,000 cows annually. Sea Forest[7] is another seaweed production company that has begun commercial-scale developments. The Sea Forest website indicates that it has begun marine cultivation with an 1,800 ha marine water lease that aims to produce 7,000 tonnes of *A. taxiformis* annually (or 3.88 tonnes DM/ha) from 2022.

A few stakeholders provided some approximate estimates of yield. They indicated that current estimates of 2-2.5 t DM/ha are realistic, but probably conservative in the longer term. These stakeholders indicated that targets of 10 t/ha for ocean production systems and up to 60 t DM/ha from terrestrial (Ulva) systems are possible. Estimates of 2.5 t DM/ha for currently achievable yield, and 10 t DM/ha for an optimistic future scenario (combined ocean and terrestrial production) were adopted for this report.

Cost to establish farms

For similar reasons to those described for yield (complexity of life cycles, evolving technologies and commercial confidentiality), good estimates of the costs to establish a unit of production (ocean or terrestrial) were difficult to obtain. The consultancy team found no published literature estimates. A few stakeholders indicated that establishing a 'greenfield' ocean site would potentially cost from $25,000-50,000/ha. Repurposing existing aquaculture infrastructure such as mussel farms would be significantly less expensive, but still at the lower end of that range. This range of estimates was used in the calculations provided in this report.

[5] Cattle on feed assisting continuity of supply. ALFA Media release, August 2021

[6] https://www.ch4global.com/

[7] https://www.seaforest.com.au/

There was some mention of the potential of establishing terrestrial *Asparagopsis* production in land-based aquaculture systems. Establishment costs were not available for these systems, although estimates for other aquaculture industries are in the order of $100,000/ha,[8] so the capital required is likely to be of a similar magnitude.

Cost to establish hatchery and processing facilities

Interviewees for the review emphasised the importance of developing the hatchery and processing facilities in the *Asparagopsis* value chain. Hatcheries are one of the key steps in commercialisation of *Asparagopsis*, both for providing available biomass for replication and ensuring effective strain selection. Again, estimates of the costs of establishing hatcheries were limited. One stakeholder indicated that $5 million had been directed towards building a hatchery. Of note, they also indicated that hatcheries may in fact develop through collective ownership (with one hatchery supplying several farms), which could be expected to change set-up and operational costs, depending on scale.

Currently, there are two ways of processing *Asparagopsis* for feeding to cattle. The most common method is freeze drying (which is superior to kiln or air drying for preserving the active bromoform). The other method in development is to suspend the *Asparagopsis* in oil-based liquid and include that in the fed ration. Processing establishment and operating costs for the two methods are likely to be quite different.

The consultants were unable to obtain verifiable estimates of hatchery or processing establishment costs. However, two stakeholders indicated that for the purposes of this report and the calculations needed, it would be appropriate to include set-up costs that are equivalent in magnitude to the costs/hectare to establish a farming system. Therefore, a range of $25,000-50,000/ha of farm was used.

Operating costs/unit feed

As noted previously, commercial production of *Asparagopsis* is still very much in development. There is the potential for rapid and significant improvements in production and processing practices to reduce operating costs. Some important dimensions of the operating costs include the following costs: hatchery biomass; substrate for the grow-out phases; harvesting (labour and mechanisation); processing (drying or oil immersion); water movement; and lease of ocean or terrestrial areas.

One stakeholder indicated a current cost of $60/kg for freeze drying. However, this is probably inflated by the low volumes being produced, and costs are expected to decline significantly as more volume is available.

One stakeholder's indicative operating cost of $5,000/ha was accepted by others as a reasonable estimate; $5,000/ha translates to $2/kg DM if a yield of 2.5 t/ha is used.

> **"Hatcheries are one of the key steps in commercialisation of *Asparagopsis*, both for providing available biomass for replication and ensuring effective strain selection."**

Summary of parameter estimates

Table 1 provides a summary of the estimates, ranges (conservative and optimistic) and sources that have been used to either establish and/or verify the estimates provided.

Table 1: Estimates obtained from literature or from stakeholder consultations

	Parameter	Estimate		Source
		Current	**Forecast**	
A	Number of cattle on feed currently (conservative) and optimistic	1.1 million at any one time (2.9 million turned off annually)	1.2 million (3.1 million annually)	MLA, ALFA 2021
		Conservative[9]	**Optimistic**	
B	Inclusion rate of *Asparagopsis* in the diet (% DM)	0.38% DM		Kinley *et al.* (2020)
C	Yield/unit of farmed *Asparagopsis* (t DM/ha/annum)	2.5	10	Stakeholders pers. comm., Kelly (2020)
D	Cost to establish farms ($/ha)	$50,000	$25,000	Stakeholders pers. comm.
E	Cost to establish hatchery and processing facilities	$50,000	$25,000	Stakeholders pers. comm.
F	Annual operating costs ($/ha)	$2/kg ($5,000/ha)		Stakeholders pers. comm.

[8] https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/site-selection-production/getting-started/establishment-costs

[9] The term 'conservative' has been used here rather than 'pessimistic'. 'Conservative' is the highest cost estimate and 'optimistic' the lowest cost

Calculations

Total *Asparagopsis* needed

The total mass of *Asparagopsis* needed for the entire feedlot industry in Australia, in as-fed terms, can be calculated as follows:

Volume of Asparagopsis needed = number of animals on feed on any given day x 365 days x feed intake per day (assume 500 kg liveweight x 3%) x inclusion rate (0.38% DM)

= 1.1 million x 365 x 15 x 0.38%

= 22,885,500 kg

= 22,885 tonnes Asparagopsis per annum

An alternative method is to estimate the mass of feed needed by animals being fed for different time lengths (days on feed; DOF) and then to assume what proportion of the 2.9 million animals that are turned off annually fall within each DOF category. This method is shown in Table 2.

Table 2: Estimates of total *Asparagopsis* needed for the Australian beef feedlot industry

Days on feed	Entry weight (kg)	Average daily gain (kg/day)	Total number of kg fed (3% liveweight as DM)	*Asparagopsis* fed (kg) (0.38% DM)	% (2.9 million cattle fed)[10]	Total number of cattle	Total mass (kg)
70	400	1.5	951.8	3.61	25%	725,000	2,622,278
150	400	1.5	2309.6	8.78	61%	1,769,000	15,525,761
250	400	1.4	4317.8	16.41	7%	203,000	330,712
350	400	1.3	6595.6	25.06	7%	203,000	5,087,827
Total							26,565,578

[10] Percentages of animals in each DOF category were obtained from MLA, and were based on data supplied by ALFA, Australian Bureau of Statistics and MLA for FY2020 and FY2021

Using this alternative methodology:

Volume of Asparagopsis needed = 26,565,578 kg

= 26,565 tonnes per annum

Both calculation methods produce similar 'ballpark' figures. The latter figure is probably a more rigorous estimate and has been used in the remaining calculations.

The figures above assume 100% adoption by the feedlot sector. Because this target might not be reached, a sensitivity analysis has been applied showing the required mass of *Asparagopsis* if there is only 50% adoption (Table 3), which could be viewed as a 2026 target.

Table 3: Estimates of total *Asparagopsis* needed for the Australian beef feedlot industry for 50% and 100% adoption scenarios

	50% adoption scenario	100% adoption scenario
Total *Asparagopsis* (t)	13,282	26,565

Total production area needed

As noted earlier in the report, it is difficult to gain robust estimates of yield/ha of *A. taxiformis* under commercial conditions. This parameter may also change rapidly over time as production is scaled up and research improves cultivation efficiency. Estimates of 2.5 t/ha (conservative) and 10 t/ha (optimistic) have been adopted.

Table 4 shows estimates of production area needed for the 50% and 100% adoption scenarios.

Table 4: Estimated area of *Asparagopsis* farming needed to meet beef feedlot requirements for 50% and 100% adoption rate scenarios

	50% adoption scenario	100% adoption scenario
Conservative yield (2.5 t/ha)	5,351 ha	10,626 ha
Optimistic yield (10 t/ha)	1,328 ha	2,656 ha

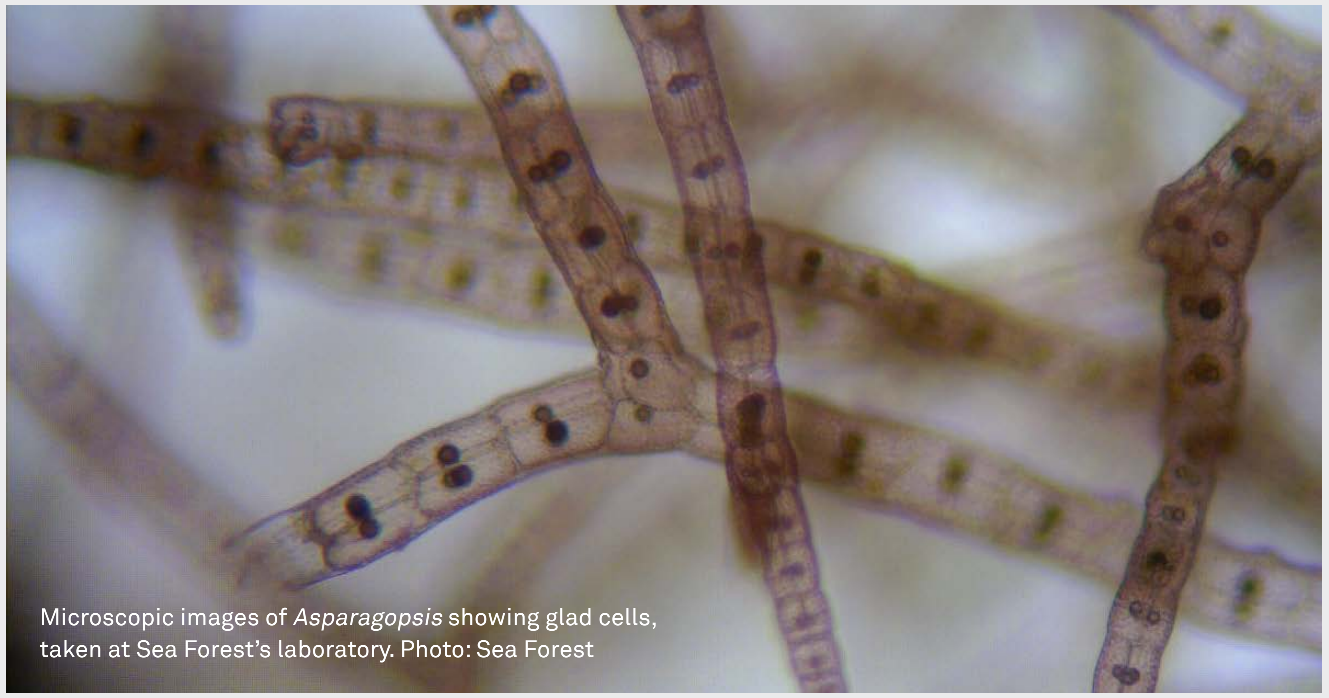
Capital needed

A similar approach has been applied to estimate the range of capital needed (Table 5). A conservative estimate of $100,000/ha ($50,000/ha farm establishment plus $50,000/ha hatchery and processing establishment) and an optimistic estimate of $50,000 ($25,000 plus $25,000) have been applied. To provide the full range, the four estimates from Table 4 are used.

As Table 5 shows, there is a very wide range in the estimated capital required: from $66 million for the most optimistic estimates of yield and costs, with 50% adoption, through to $1,062 million for the most conservative estimates of yield and costs, with 100% adoption.

Table 5: Range of estimates of total capital required to meet beef feedlot requirements for 50% and 100% adoption rate scenarios

	50% adoption scenario	100% adoption scenario
Conservative yield/conservative costs	$531 million	$1,062 million
Conservative yield/optimistic costs	$265 million	$531 million
Optimistic yield/conservative costs	$132 million	$265 million
Optimistic yield/optimistic costs	$66 million	$132 million



Microscopic images of *Asparagopsis* showing glad cells, taken at Sea Forest's laboratory. Photo: Sea Forest

Other observations

Discussions with stakeholders and this study's limited environmental scan revealed other qualitative information that is worth noting here:

- Some stakeholders were emphatic that the capital needed to establish and operate the *Asparagopsis* industry is likely to be in ample supply. Capital is not expected to be a constraint for this industry, given its significant promise and attractiveness to ethical investors. As noted above, government is also providing substantial research funding for methane-reduction technologies.

- There are major competition dynamics for *Asparagopsis* on the supply and demand sides. There are likely to be competitors to *Asparagopsis* for reducing methane production by livestock. For example, the product Bovaer® has been approved for use in some jurisdictions, including (recently) the European Union (EU). Bovaer® contains the active ingredient 3-nitrooxypropanol (3-NOP); trials in Australia have demonstrated its effectiveness.[11] On the supply side, there are other potential uses for seaweeds such as *Asparagopsis* in cosmetic products and nutraceuticals. Alternative markets may be willing to pay more for the product than the red meat industry.

- On a global scale, Australian cattle numbers are relatively small, hence the market for Australian-produced *Asparagopsis* is unlikely to be restricted to Australia. In 2020, world cattle numbers were estimated to be about one billion head, of which Australia holds 22.8 million beef and 1.9 million dairy cattle, equating to about 2.5% of the global total. It is likely that regulations and carbon markets in the United States (US) and the EU will drive demand for methane-mitigation products, resulting in strong competition for safe and reliable sources of *Asparagopsis* that Australia can potentially offer.

- Some performance aspects of *Asparagopsis* (and competitor products) have not been resolved; these could make a substantial difference to the economics of *Asparagopsis*, both positively and negatively. Most notable among these is the finding of at least one major study that *Asparagopsis* substantially increases weight gain in grain-fed cattle (Kinley *et al*. 2020). If this finding was to be confirmed, willingness among producers to pay for *Asparagopsis* would likely rise very quickly and independently of the carbon price. Furthermore, emerging technologies that could substantially improve delivery of bromoform into the rumen and its efficacy could change the amount of *Asparagopsis* that needs to be added to the feedlot diet.

"Capital is not expected to be a constraint for this industry, given its significant promise and attractiveness to ethical investors. Government is also providing substantial research funding for methane-reduction technologies."

[11] https://www.mla.com.au/news-and-events/industry-news/the-feed-additive-reducing-methane-emissions-by-up-to-90/

Discussion

To establish an *Asparagopsis* supply chain to meet the methane reduction needs of the Australian beef feedlot industry at 100% adoption, the estimated capital needed ranges between $132 million and $1,062 million. The huge range in estimates reflects that the *Asparagopsis* industry is very much in its infancy. Much foundational research is continuing on all aspects of the value chain, from cultivation to processing and product formulation. Pioneering companies are understandably reticent to reveal commercially sensitive information.

The broad parameters calculated in this analysis were sense-checked against comparable (albeit limited) estimates available from the literature. For example, Mayo-Ramsey (2021) estimated that 25,000 tonnes of *Asparagopsis* (DM) would be required to feed 30% of the almost one million feedlot and 1.5 million dairy cattle in Australia. The author quoted seaweed production yields of 30-50 t DM/ha, but the figure used was not precisely clear. These yields are an order of magnitude higher than the conservative estimate used in this report and are 3-5 times that of the optimistic estimate. At those yields, Mayo-Ramsey estimated that about 2,000 ha of seaweed farms would be required to meet the 30% target.

Vijn *et al.* (2020) calculated the potential volume of seaweed that would be needed to supply the 93 million US cattle at a 1% inclusion level to be 3-3.4 million tonnes of dry seaweed per year. If that number was scaled to the 1.1 million Australian feedlot industry, it would be 40,215 tonnes, which is of a similar magnitude to estimates in this report (about 26,500 tonnes). The key difference between the two estimates is the inclusion level Vijn *et al.* (2020) used and the one adopted for this report.

Because the estimates of establishment costs provided in this report are approximate, they should be treated with considerable caution. They are based on only a few estimates. Much depends on whether greenfield sites are established or existing facilities (such as mussel farms) are repurposed. Whether the latter occurs will depend on the relative value of *Asparagopsis* against alternative products. Given changing water temperatures, some existing aquaculture farms could become unsuitable for their current use, and may look at *Asparagopsis* as an alternative.

It also appears likely that terrestrial *Asparagopsis* cultivation will be investigated. With greater control over the operating environment within an aquaculture system, it could become the dominant production system for *Asparagopsis*. Terrestrial aquaculture systems are likely to have quite different establishment and ongoing cost structures to ocean-based systems.

There is even greater uncertainty around the cost of hatcheries and processing plants. Scale will undoubtedly drive down the cost of establishing and operating these facilities.

It is evident that there is abundant capital to establish and run an *Asparagopsis* industry. There are likely to be competitors to *Asparagopsis* in the livestock methane reduction market, just as there may be competing and potentially higher-value applications for *Asparagopsis* (in livestock, aquaculture and human nutraceuticals). It will be some time before these market dynamics are better understood. Finally, there are important performance aspects of *Asparagopsis* itself that are yet to be resolved, and these will require further research before translation to the commercial sphere.

"To establish an *Asparagopsis* supply chain to meet the methane reduction needs of the Australian beef feedlot industry at 100% adoption, the estimated capital needed ranges between $132 million and $1,062 million."

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