A Hitchhiker's Guide to Seaweed:

DON'T PANIC

Scott Hawley-Churchill Fellowship Report

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Acknowledgement: This project was made possible by the Churchill Fellowship and I am immensley greatfull for the opportunity they provided. If you are interested in joining the community of Changemakers I could not recomment exploring the opportunities more -The Churchill Fellowship

Table of Contents

Prologue: Why Seaweed and, Why Now?

This planet has - or rather had - a problem, which was this: most of the people living on it were unhappy for pretty much most of the time. Many solutions were suggested for this problem, but most of these were largely concerned with the movements of small green pieces of paper, which is odd because on the whole its wasn't the small green pieces of paper that were unhappy.

And so the problem remained lots of people were mean, and most of them were miserable.

Many were increasingly of the opinion they'd all made a big mistake coming down from the trees in the first place. And some said that even the trees had been a bad move, and that no one should have ever left the oceans.

And then, one Thursday, nearly two thousand years after one man had been nailed to a tree for saying how great it would be to be nice to people for a change, a girl sitting on her own in a small café suddenly realized what it was that had going wrong all this time, and she finally knew how the world could be made a good and happy place. This time it was right, it would work, and no one would have to get nailed to anything.

-Douglas Adams

An awful lot of people in the UK are unhappy. Stubbornly low levels of economic productivity, stagnant economic growth, increasing levels of rural deprivation, persistently high levels of environmental degradation and a sense of terrible economic resiliency make for a potent cocktail of social dissatisfaction. I think this is problem we should do something about, and I applied to undertake a Churchill Fellowship to look at a series of questions to help find a solution:

- What if the UK decided to use seaweed to drive economic growth and enhance the resiliency of coastal economies?
- What if we started to see the rich traditions of Welsh lawr, Scottish ceilp and Irish sleabhac as a starting point for a sustainable aquaculture (and agriculture) revolution?
- Could seaweed be the panacea to complex economic, social and environmental issues?
- And why is European Union and large governments across the global North so pro-seaweed but the UK is so ambivalent?

This document is my story about why the UK should not turn its back on the oceans or coastal communities when thinking about the future and bring seaweed back to the table. Coastal communities are the (stagnating) economic growth engines of the UK. That is not just my opinion, but the thrusts of the 'UK's Modern Industrial Strategy[1]' and the 'Industrial Decarbonization Strategy[2]' which are underpinned by extensive evidence. Grangemouth, Stockton-on-Tees, Hull, Liverpool, Swansea and Southampton i.e. the 'Industrial Clusters' need an economic overhaul if the UK is to start thriving. The question is HOW you overhaul these places and if you fuel that change entirely from land (and London) or there is role sea (and the communities themselves) to play. The idea of using seaweed production to support sustainable UK communities is nothing new but has recently been thrust back into the media spotlight due the links between seaweed and climate change e.g.[3],[4],[5]. Stealing the words and vision of SeaGrown[6], seaweed production in the UK offers a future where '*business, community and environmental stewardship can be powerful allies. A future where thriving oceans and thriving communities go hand in hand*.' But can the UK really make this happen?

As someone who is directly employed by the UK government with the explicit job requirement of knowing as much as possible about the science of Net Zero and economic growth, I think seaweed offers a compelling narrative that should be considered when envisioning the future of the UK. This document is framed around Douglas Adams and the Hitchhiker's Guide to the Galaxy, and I am acutely aware that won't translate well across all generations and segments of society. It is not everyone's cup to tea, but it is a distinctly British cup of tea—which is the point.

There is something non-linear, farcical and utterly British about the story of Arthur Dent and the destruction of this small planet that makes it the perfect framing convention for introducing people to seaweed in a UK context. Seaweed holds relevance beyond the British Isles but if the aim is to solve great British problems, then it's worth producing a Great British solution.

The individual and organizations who agreed to meet with me as part of my Fellowship are imbedded within their own communities and contexts. They are the best advocates for (or against) seaweed in their communities. I spent my Churchill Fellowship walking into bars in places with deeply troubling

[1] The UK's Modern Industrial Strategy 2025 - GOV.UK
[2] Industrial Decarbonisation Strategy
[3] The Climate Question - Can nature help us to store carbon? - BBC Sounds
[4] The Food Programme - A Seaweed Revolution in the UK? - BBC Sounds
[5] Laverbread: Seaweed-loving chef's bid to promote delicacy - BBC News
[6] SeaGrown - For Ocean Health

and violent histories around British imperialism, asking people to talk about society, politics and government.

People were brilliantly receptive, but some scars run deep, and the experience was a firm reminder of what happens when societies and cultures are bulldozed in the name of 'progress.' If you want to learn more, I recommend reaching out directly to those working at and below the water's edge. The following organisations (listed in alphabetical order) are who helped me along my journey. Rather than try and write introductions I have provided links, and I strongly encourage those interested in the sector to explore it in the words of those who know it best.

As a reference point, the exploitation of seaweed for economic growth has a long history in all parts of the UK. The idea of using seaweed production to support sustainable UK communities is nothing new but has recently been thrust back into the media spotlight due the links between seaweed and climate change e.g.[7],[8],[9]. I wanted to look into is what is actually happening behind all the hype. My curiosity was driven by two factors:

Adrigole Arts- pure-ireland.ie/pages/about-us

Bantry Bay Marine Research Station- Bantry Marine Research Station - Bantry Marine Research Station

Bantry Tourist Office- Contact Bantry - Visit Bantry - Bantry, West Cork, Ireland

BIM-Fisheries College, Castletownbere, BIM - BIM Locations

Blue Robotics- *Blue Robotics - Underwater ROVs, USVs, Thrusters and Sonars!*

Dr. Emily Kostas*,* University College London: Emily Kostas Profile | University College London

GreenWave- *GreenWave*.

Industrial Plankton- *Live Algae Culture Bioreactor Production Equipment for Sale*

International Seaweed Symposium/International Seaweed Association- Welcome to ISA | International Seaweed Association This happens every 3 years and I met far too many people to list individually but ISA is a wealth of information on seaweed.

Prof. John Church, Thompson Rivers University: Thompson Rivers University

Mungo Murphys- Mungo Murphy's Seaweed Co.

Norfolk Seaweed- Norfolk Seaweed | Commercial Sugar Kelp farmed in the UK

Sea and Believe- HOME | Sea & Believe

SeaGrown- SeaGrown - For Ocean Health

University of Galway, Socio-Economic Marine Research Unit- Socio-Economic Marine Research Unit (SEMRU) - University of Galway

University of Miami, Prof Helena Solo-Gabriell and Brittany McIntyre. *Helena Solo-Gabriele*

[7] The Climate Question - Can nature help us to store carbon? - BBC Sounds
[8] The Food Programme - A Seaweed Revolution in the UK? - BBC Sounds
[9] Laverbread: Seaweed-loving chef's bid to promote delicacy - BBC News

What is Seaweed? (And why its valuable)

Now it is such a bizarrely improbable coincidence that anything so mindbogglingly useful would have evolved purely by chance that some thinkers have chosen to see it as a final and clinching proof of the non-existence of God.

The argument goes something like this: "I refuse to prove that I exist," says God, "for proof denies faith, and without faith I am nothing"

"But, says Man, "[Seaweed] is a dead giveaway isn't it? It could not have evolved by change. It proves you exists, and therefore, by your own arguments, you don't.' QED"

"Oh dear," says God, "I hadn't thought of that" and promptly vanishes in a puff of logic.

"Oh that was easy," says Man, and for an encore goes on to prove that black is white and gets killed on the next zebra crossing."

-Douglas Adams

Disclosure: I am not a seaweed expert. I have a university degree in marine science from a place that has *School of Marine and Atmospheric Science* in the name i.e. The Rosenstiel School of Marine and Atmospheric Science, University of Miami. I have worked for the US government (NOAA) culturing marine algae[10], and going into the Churchill Fellowship I thought I knew enough to get the science right. I was wrong and I am hugely grateful to all the experts who gave me their time to answer dumb questions and correct misconceptions. Before you can try and put seaweed into a socio-economic context you need to know what seaweed is (and what it isn't). Given I didn't really understand what, biologically speaking, seaweed is, I don't expect most people will understand what seaweed is.

So, what is seaweed?

Botanists argue vehemently over whether you can or can't call seaweed a plant. World renowned seaweed expert a.k.a. phycologist Professor John Bolton told me to let that be their problem and call seaweed a plant if I want to. Land plants are 'special' in a couple of ways, but these are niche side notes in the evolutionary history of life on this planet. What is important is that seaweed is slimy in a way which land plants aren't and that slime is pretty magical.

Whilst most humans on the planet see the sliminess of seaweed as negative, seaweed experts lavish the slime with praise whilst discussing the magic of the ***holobiont***. Beyond scientific praise the concept of seaweed as a holobiont has garnered huge economic interest. The world bank has estimated seaweed could add $12 billion (USD) to the global economy by 2030 not including ecosystem services or cultural value.[11] Whether the number is right or not, seaweed is already hugely commercially valuable because it contains so many useful chemicals/compounds which aren't readily found in land plants. That is because these chemicals are associated with the way seaweed interacts with the world around it which scientists have refer to as a holobiont[12].

Simplistically algae and plants interact with the environment around them as part of a living ecosystem. Terrestrial plants do this exclusively through their roots in the soil which don't get harvested, processed or consumed by humans. Seaweed doesn't have roots and instead interacts with the environment via the slime that coats its surface. Whey you harvest a seaweed you take the whole organism including all the microorganisms that are living and thriving in the slimy 'biofilm.' Even when you process seaweeds, you are processing the whole plant which means to you concentrate or isolate chemicals/properties that originate from the slime. If harvested plant material is refined white sugar the harvested seaweed, in comparison, is whole grain bread. The sugar isn't bad, and is massively valuable to the modern food system, but the full value of whole grains can't be replicated with processed sugar. Seaweed also 1) grows really really really fast; and 2) grows in the ocean. This is pretty useful if you are trying to material in for the economy in coastal areas where there is very little free land laying around.

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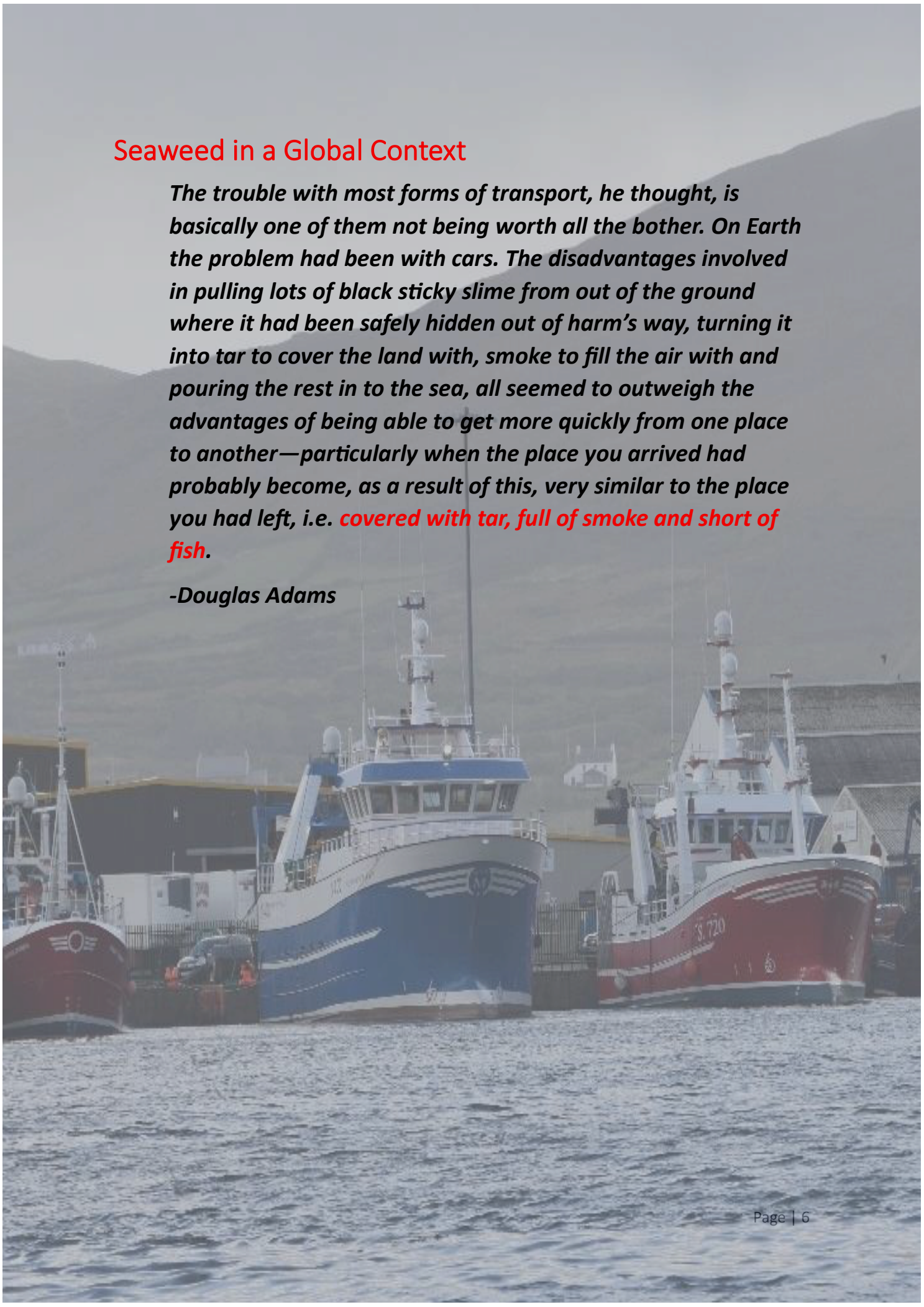
[10] Milford Laboratory Facilities | NOAA Fisheries
[11] World Bank Document
[12] Holobiont - Wikipedia

Seaweed in a Global Context

The trouble with most forms of transport, he thought, is basically one of them not being worth all the bother. On Earth the problem had been with cars. The disadvantages involved in pulling lots of black sticky slime from out of the ground where it had been safely hidden out of harm's way, turning it into tar to cover the land with, smoke to fill the air with and pouring the rest in to the sea, all seemed to outweigh the advantages of being able to get more quickly from one place to another—particularly when the place you arrived had probably become, as a result of this, very similar to the place you had left, i.e. covered with tar, full of smoke and short of fish.

-Douglas Adams



In 2023 the World Bank published a headline grabbing report on the economic potential of global seaweed --£11.8 billion USD of additional economic growth by 2030 [13]. The preceding year the European Union published its own even more eye-catching assessment--€9 billion of growth, 85,000 jobs and removing tonnes (exactly how many tonnes was left ambiguous) of nutrients from polluted coastal waters in Europe alone [14]. Ireland, Norway, Denmark and other countries jumped on these numbers and created their own national strategies. Everyone in the North Sea was seemingly pro-seaweed. Everyone except the UK.

The Centre for the Environmental, Fisheries and Aquaculture Science (CEFAS) did publish a 'history' of the sector in 2022[15] at same time seaweed was getting hot elsewhere. The report is lukewarm at best. It acknowledges the long- and well-established history of seaweed in the UK but isn't clear whether or not this should just be left in the past. The slightly more recent Biomass Strategy 2023 is positive, but certainly not overly so, of seaweed. So, were/are we wrong? The answer is complex because it requires trying to connect two distinct and disconnected approaches to solving societal level problem.

For at least the past decade the UK government been focused on defining the key outcomes "we" want as a country and little if any time thinking about how we would reach those outcomes. Using political terminology, the government has developed s a series of "strategies" e.g. Food Strategy[16], Modern Industrial Strategy[17], England Homes Strategy[18] etc which say things like "we should growth the economy" and "we should build more houses". These documents fall also contain some concrete targets, but they don't say **HOW** these targets or ambitions will be achieved. Simplistically everyone agrees that if the UK were to have 1.5 million new high quality, affordable home and sustainably integrated homes the country would be in a much better position there is just no political consensus on how the achieve this goal. (I definitively not making a political judgment here as I have been privileged to support multiple government of different stripes, in the UK and US, and have yet to meet anyone who rejects the idea the UK could use more high quality homes, a stronger economy or a less polluted environment its just a matter of life on Planet Earth that different parties will have strongly opposing opinions on how to prioritise and deliver these targets).

Using a direct analogy to the Hitchhiker's Guide to the Galaxy reference the UK government has firmly agreed the answer the ultimate question of life, the universe and everything is 42, but no one can agree what to do with this information. Continuing this analogy the World Bank and Europe has firmly settled on seaweed because they have reached the consensus that the question they are trying to answer is SIX TIMES NINE. Does is matter that six times nine doesn't equal 42? To put it bluntly Europe has come nowhere close to realising billions of euros of economic growth from seaweed so maybe there is something to always making sure questions and answers are always matched. If you are have become totally lost all you need to know is that seaweed is not a magical panacea solution and so just throwing it into the equation doesn't fix all your woes.

At the International Seaweed Symposium, I got the opportunity to talk to the lead consultants commissioned by the world bank to provide the data for its report. I was surprised to hear them say *'I did not ever say there was a $11.8 billion growth potential for seaweed nor does any of the data*

[13] World Bank Document
[14] https://oceans-and-fisheries.ec.europa.eu/publications/communication-commission-towards-strong-and-sustainable-eu-algae-sector_en
[15] https://marinescience.blog.gov.uk/2022/05/05/the-developing-uk-seaweed-industry/
[16] A UK government food strategy for England, considering the wider UK food system - GOV.UK
[17] The UK's Modern Industrial Strategy 2025 - GOV.UK
[18] HE_Brand_Strategic Plan_ARTWORK_HR_single pages DIGITAL LR.indd

which underpins the report support that evaluation.' And if you look at the report, of similar EU reports, a very important single word stands out that is often ignored in summaries of these reports: **demand**. The reports suggest government driven interventions could drive **demand** for seaweed, but this demand displaces demand for other commodities and comes at significant government investment. So, does seaweed actually drive economic growth? And if it does what is link between government driven demand and economic growth? The EU and World Bank reports don't address these later questions. Before getting excited about the published numbers, it is important to understand how the seaweed industry works today and how it might change to really understand the relationship between seaweed and economic growth in the Western world.

At present 95%+ of the seaweed industry is based in Asia with China and Indonesia dominating the market. Most of this seaweed is grown so compounds called hydrocolloids can be extracted from the seaweed. You may never have heard of carrageenan, agar, or alginate, but you are probably consuming all three compounds daily. There is some room to continue expanding this market, but Asia is exceptionally good at producing seaweed and it will be impossible for the UK or Europe to compete.

Indonesia is a great case study to better understand the underpinning socioeconomics and geo-politics of seaweed. Industrial scale commercial seaweed production was introduced into Indonesia in the late 1960s as a poverty alleviation and economic development opportunity. Indonesian communities were literally blowing apart their futures thanks to dynamite fishing and seaweed was introduced to replace the TNT. The project has worked brilliantly in some respects but has faltered in others. Seaweed has become an economic lifeline for large marine communities which were facing devastation. Seaweed aquaculture is infinitely more sustainable and environmentally friendly than dynamite fishing and so seaweed farming did prevent total economic collapse of major communities. At the same time, these communities have not seen large scale economic development. People are no longer blowing up the ocean, but the communities are still living below the poverty line in extremely difficult conditions and limited opportunities for true socioeconomic uplift. Indonesia publicly believes its people and resources are being exploited and the nation has seriously considered banning seaweed exports to promote more investment in the domestic supply chain and higher levels of true economic growth in the industry.[19] Simplistically producing lots of seaweed is not a sure-fire rag-to-riches equation. Seaweed fits within the messy global economic system that has serious flaws when it comes to the relationship between community-based resource production and global value chains.

Returning to the World Bank's £11.8 billion assessment of future seaweed growth potential there is great information hiding below the headlines. The key message to Western consumers (and governments) is that driving demand for seaweed isn't so much about economic 'growth' as it is about making the world a better place as the below makes clear:

> *The seaweed sector has clear growth potential beyond its current markets and can help shape a world free of poverty on a liveable planet. Enhanced seaweed production and improved value chains can contribute to meeting at least nine of the 17 U.N. Sustainable Development Goals (SGD)s…At a time when global resources are incredibly overstretched, it is particularly important that the world makes the most of those resources—such as seaweed—that can both be swiftly regenerated and potentially regenerate the ecosystems*

[19] https://www.reuters.com/world/asia-pacific/indonesias-jokowi-push-domestic-seaweed-processing-including-fuel-2023-11-02/

that support them. Seaweed farming in new markets with new applications can support development, climate and nature work to generate value and uplift communities.[20]

There is so much good to unpack here but what it isn't is a promise of billions of pounds of growth to the UK economy. At a basic level the United Nations promotes the ***Sustainable Development*** Goals because the current global political/economic system continues to fail both true societal development and sustainability on many levels. Seaweed offers a way to introduce these ideals into the equation, but putting a monetary value on these more values is complicated at best. As an example, I got the chance to speak C-WEED MWANI[21] at the International seaweed symposium and it is very easy to see why seaweed production in Tanzania gained so much attention but the United Nations.[22] Yes these projects are economically vibrate and generating monetary value but they are also delivering: poverty alleviation, quality education, gender equality, decent work, innovation, reduced inequalities sustainable cities, climate action, marine recovery and partnerships (that is ten of the seventeen goals for those keeping count). The goal needs to be doing seaweed right rather than just doing seaweed keeping in mind that while what is going in in Tanzania is brilliant the UK isn't Tanzania and so the UK will need a completely different business model. In this sense the UK hasn't missed the boat yet, but seaweed doesn't fit easily into 'drill baby drill' model of resource exploitation that drives in the modern global economy.

[20] World Bank Document
[21] C-weed Mwani Home
[22] Unsdg | How Tanzanian women sow change with seaweed farming

Ireland: Lessons from a Neighbour

A scientist must be absolutely like a child. If he sees a thing, he must say that he sees it, whether it was what he thought he was going to see or not.

See first, think later, then test. ***But always see first. Otherwise you will only see what you were expecting.***

-Douglas Adams (The Hitchhiker's Guide to the Galaxy)

In 2023 the Irish government published its Irish Macro-Algae Cultivation Strategy to 2030.[23] The document follows from the EU assessment and declares:

> '*The industry is described as being "on the cusp of transformation" and there is strong conviction that Europe can accelerate and significantly grow production capacity*.'

I wanted to see for myself what that meant in practice. Was seaweed really about to transform Ireland's coastal economy? And, just as importantly, what did ordinary people think about this impending acceleration?

What I found was a fascinating mix. On one hand, there are small but passionate businesses and researchers working with seaweed, full of ideas and energy. On the other, there's a wider economy that feels pretty comfortable with the way things are and is absolutely indifferent about the capacity of the domestic seaweed industry. A bartender who was born and raised in Dingle summed it up:

> *'I was born with fishing in my blood and if there was still salmon to catch, I would be out on the boat. I love surfing and hate the damage we are doing to out seas. But you got to remember this area was poor—I mean really f***ing poor. It is easy to criticize Dublin, Brussels and London but there just isn't an appetite to bite the hand that feeds. The Irish people are incredibly tough and independent at heart and aren't shy of a fight but why should we be fighting for seaweed vs Facebook when Facebook pays so well and seaweed doesn't?'*

That attitude makes sense when you look around. Ireland's coastal towns are prosperous, and far less scarred by deprivation than many similar places in the UK. In the pubs and cafés of Castletownbere, Ireland's fishing capital, the conversation was dominated by the future of offshore wind, tourism, and big tech companies. When I asked about the future of Castletownbere I was told: "Its f***ing isn't fishing, is it?" In most people's eyes seaweed was just another form of fishing and so its best left in the past than integrated in Ireland's future. To those more in know seaweed was just another financial game being played by big-tech and is best left to Amazon[24] etc.

I don't know what the future of seaweed in Ireland will look like but the country offers an interesting case study of: 1) Where current marine resource policy isn't benefiting local communities, 2) What could work so much better, and 3) Why Ireland and EU are falling so short of the ambitions outlined in their strategies.

What isn't working for local communities

The Irish Fishing Industry (and why it's not the future)

Castletownbere, Board Iascaigh Mhara (BIM)

Castletownbere is Ireland's Fishing Capital and is home to a major commercial fishing fleet. It is also home to one of Ireland's two National Fisheries Colleges run by the Irish Seafood Development Board (BIM). BIM is the government agency behind the Irish Seaweed strategy, and they are actively promoting and supporting the Irish seaweed industry. I travelled to Castletownbere to gets a sense of what Fishing means for Ireland and where seaweed fits into that picture.

[23] BIM-IMAS-Strategic-Revie w.pdf

[24] World's first commercial-scale seaweed farm located between offshore wind turbines is now open in the Netherlands

The first thing to know about Castletownbere is that it is not a place to go to buy fresh local fish. The second thing is that the inability to buy local fish in a fishing capital is symptomatic of a broken relationship between a coastal community and its marine resources. Fish 'landed' in Castletownbere are offloaded on Dinish Island which sits just off the coast. Due to the nature of EU fisheries rules the fish are sold before they ever make landfall and shipped directly to the buyers from Dinish Island. The road off Dinish Island was built to ensure trucks avoid the town allowing all the fish to bypass Castletownbere. Whilst some fish might eventually make their way back to the local Super Valu, Castletownbere is treated no differently to any other Irish town when it comes to fresh fish. It's a minor and logical logistic detail but one not lost on the locals.

I did not meet anyone who was antagonistic towards fishing boats or fisherman but as a ferry boat operator told me '*I have mates in fishing and if the industry worked different everyone would be all for it. The issue is we need nature and beauty for tourism and locals alike. The EU boats have no reason to protect our fish and our waters our wellbeing. They are here to trawl the bottom until all the fish are gone and then leave us to pick up the pieces*.'

It's not hard to see why none of the locals saw a future in fishing given the industry operates with few if any connections that feed into local communities where the boats land fish. At the same time, it's an odd view when you step back and look at the economy of Castletownbere. The vast majority of the economy in Castletownbere is driven by fishing via the fisheries school, engineering, boat servicing etc. If everyone thinks fishing is the past, then what is the future?

The vast majority people told me the economy of Castltownbere is transferable to offshore wind and renewables, because it is really about boats and marine engineering skills not fish. I am sure there is some truth to this, but I also got the sense it was the answer because it is the only future those in the community want to consider. This is not a vision of an economically resiliency. Everything might still be working great in Castletownbere, but Irish history suggests that when the economy becomes critically dependent on a sector the consequences of a bubble bursting and communities collapsing are very real.

There is one massive caveat to the above. The biggest surprise for me about Castletownbere, and the West Coast of Ireland in general, was how well educated and informed locals were. I went into the trip expecting to find communities that were analogous or at least moderately comparable to the coastal communities up and down the North East coast of England where I live. Irish communities are on a different level, and it was a wakeup call to just how far communities around where I live have slipped into decline. Salary isn't everything but income and equality data is pretty stark when it comes to comparing Ireland[25] with the UK[26]. Northern Ireland is comparable to where I live in the North East of England meaning medium income is 30% less than the areas of Ireland I visited on my trip. This difference was absolutely noticeable in day-to-day life. The economy of Western Island is absolutely not failing the communities and fishing is a key piece of that economy. It is no wonder so many communities around the coast of the UK dream of a day when their fishing boats will return when you look at the income and wealth in Western Ireland. I think Castletownbere can be optimistic about its future because it has enough highly skilled and knowledgeable people to drive a vibrant economy. Places like Castletownbere are going to have to be allowed to transform and diversify if they are to grow. The fishing sector is only going in direction and that, in my view, won't support growth and investment on the Beara Peninsula.

[25] Workbook: AllIslandData200324
[26] Mapping inequality in the UK

Wild Seaweed Harvesting: Bantry Bay and the F***ing Kelp People.

When I pressed on seaweed most people had some familiarity that Ireland was trying to expand the industry and a common response '*I don't really know what I think about seaweed. As long as it's not those f***ing kelp people*.' In Ireland, the f word is common and not necessarily something that warrants additional attention. However, emphasis is critical and the use the f-word in this context was always stated in a way that indicated a specific distain for whoever these 'kelp people' were. It didn't take long to find out.

In 2014 the Irish government granted a private company a licence to begin commercial harvesting of wild seaweed in Bantry Bay. Think fishing but with seaweed and the proposal touched a nerve. An extensive legal battle pursued[27] and whilst I do not have the knowledge or expertise to pass judgement on the details, I can say it has left a lasting negative impression of the seaweed industry in the region. No matter how much or how little people I talked to knew about seaweed this situation was what stuck in people's mind. In their view big business and government and had tried to cosy up and further exploit local communities without any community engagement. That was fundamentally wrong, and, as I was regularly reminded, Ireland is a country where people value principles. The people fought back and were vindicated by the Supreme Court.

I went into the Bantry Tourism Office to talk to people about what they knew or. It was clear the case was viewed as part of a larger grievance. It might have just been a bit of seaweed to the people in Dublin sitting behind desks signing paperwork, but to those in Bantry it was their seaweed, and the government had no right to all it to be taken away from them without asking. People could provide a laundry list of other examples where they felt this had happened in the past, but seaweed was the straw that broke the camel's back. I have my doubts about the characterization of the Irish government's decision being made sole by people sitting behind desks in Dublin, but I am not surprised that is how locals felt. Sometimes perception is just as important as reality and by choosing not to consult with the community the Irish government chose to make themselves look distant and ambivalent.

The good news is that there is no reason the seaweed industry in Ireland or the UK would need to operate using this business model. It is not an issue of wild harvesting but a basic governance issue of allowing public consultations and creating a planning system that allows discourse without listening to the loudest voice in the room. Aquaculture based seaweed productions offers a fundamentally different model that can work with communities and the environment. The irony is that it is this alternative business model where Ireland absolutely shines already and they have done the hard work needed to take advantage of this transformation.

Where Seaweed is Offering an Alternative Solution.

Seaweed Innovation for Modern British Isles:

If you Google 'Bantry Bay Seaweed' the first result will link to the main community group which fought against the f***ing kelp people. The second result may take you to Bantry Marine Research Station (BMRS). Whilst the first result will have a lasting impact on seaweed in the local area, the second results may well change the face of rural economies across the world. It's a fascinating juxtaposition that underscores how intertwined and messy local community dynamics can become.

[27] Seaweed harvesting challenge sent back to High Court – The Irish Times

BMRS is a private research station that is driving innovation in seaweed production not just in Ireland but for the world. They link to their extensive publication record on their website for anyone to see and it is their work on something called *Asparagopsis aramata*[28] that might just catalyse a food systems revolution. A technical annex to this document explores the idea of 'methane suppressing feed additives' in more detail, but to me what stands out about BMRS is how they have approached the challenge.

Methane suppressing feed additives aim to cut the impact cattle and sheep have on climate change in a very targeted way. The main product in the field was developed using a 'Big Pharma' type approach which identified a synthetic compound when mixed in animal feed reduces animal methane emissions. Highly modern, highly efficient and highly integrated in the world's economy there is nothing inherently wrong with the approach, but it is a top-down solution that solves a problem in the narrow way that maximizes short term returns. Seaweed offers a fundamentally different business model to achieve the same outcome of methane suppression but where the benefits are spread differently so that livestock farmers and agricultural communities get a major stake in the game. I need to acknowledge my own bias here in terms of being deeply favouring this seaweed-based approach, not because of the seaweed per say, but because it delivers direct tangible benefits to livestock, livestock farmers and local communities.

The products/systems BMRS are developing are things that I can see farmers in Ireland and the UK legitimately wanting and promoting rather than just reluctantly adopting under duress. BMRS has thought about farmers and farming communities within the innovation and development cycle and in doing so are fulfilling the vision on sustainable development and economic growth which the World Bank/United Nations are promoting for seaweed. There is a choice here for consumers and governments but it's a choice that challenges individuals and societies to think about what they value and why.

Without exaggerating the implications of what is possible here we are talking about technology that: 1)Has been proven and validated; 2) Is scalable and deliverable albeit in need of further investment; and 3)Has world changing implications valued at trillions of pounds globally, billions within the UK alone, and that is before considering the offsetting value reducing methane has on climate adaptation costs. The race is already on here because the size of the prize is far too large to ignore, but there is no reason the end solution has to be compatible with economic benefits for farming communities of wider benefits for local communities. BMRS is one of a number of global players however showing that seaweed offers an opportunity to accomplish methane suppression in a way which is truly sustainable and pro-global developments. My personal view, which just so happens to be shared by the EU, Norway and the World Bank, is that the potential of seaweed here is too great to be ignored without significant further development. Ultimately consumers/voters can decide on the solution(s) that fits best their value system but that requires the choices to be fully developed.

Seaweed for Sustainable (and Elegant Consumerism)

There is a rich tradition of eating seaweed in Ireland but as a poverty food when times were rough. Beef production really took off in Ireland after the second world war and the country's food production systems have never looked back. The agriculture subsidy system was a major factor in driving this change and entrenched how food production is valued across the country, but the subsidy system reflected the large cultural values around food. (If you want a deep dive into the

[28] https://www.bmrs.ie/bmrs-projects/past/cultivation-of-the-seaweed-asparagopsis-armata-in-ireland

relationship between climate, food and politics I recommend Neil Ward's book on the subject[29]. Its UK not Ireland but in this case the history and politics read across). The point is that government policies and social values are linked when it comes to food and when it comes to seaweed both need to change if there is going to be a significant shift in seaweed consumption.

What Ireland is really getting right is sparking innovators who are challenging seaweed's cultural position as a poor person's food. This is important because if you move this cultural needle on seaweed, it will become far easier to move the political needle around correcting current market distortion.

Mungo Murphy's Seaweed is notable for a number or reasons but what makes them standout is their starting position: abalone. There are few if any foods that are more luxurious, elite and exotic to Ireland than abalone. Internationally abalone is also seriously stained by illegal poaching, environmental decimation and serious organized crime which exploits the luxury status of abalone at great expense to local communities. Solving the problem of sustainable and responsible abalone production wasn't enough for Mungo Murphy's and so they have decided to push on and shine a spotlight on seaweed. The company puts their seaweed products on the same platform as their abalone. Seaweed doesn't have to be poverty food it is the keystone piece of a food production system that works with the environment, not fighting it. More broadly Mungo Murphy's makes the pitch that consumers do not have to sacrifice quality or elegance to improve impact on the environment or on local communities. They are their own best advocates, and I recommend the farm tour if you get a chance and want to see how seaweed fits in the picture for yourself.

Sea and Believe's have a similar ethos although they are producing different products and leveraging different supply chains. Sea and Believe's founder Jennifer O'Brien started the business with a mission to make the most of what Irish seaweed can offer. Their profile has been highlighted by media outlets as a model example of the future of Irish seaweed e.g.[30].

The company's message is that seaweed is a great starting material for creating high value materials with excellent social and environmental footprints. It offers consumers a value prospect and the ability to have a more positive impact if they purchase different products. You can see why the Irish government proposes the seaweed industry is on the cusp of change. If consumers decide to change their purchasing habits, they can drive the growth of the business which interact with the world around them in a sustainable manner. Vitally, this isn't about asking consumers to make do with inferior products or making consumers feel guilty about their consumerism. It is about offering markets viable high-quality alternatives to products they already want and to buy so that consumers have a choice.

Where is the Seaweed Industry Exploding (and why this a uniquely Irish Solution)?

The Irish government's Seaweed Strategy takes the same design decision as the EU's Seaweed Strategy: it is 100% reliant on consumer driven behaviour changes to drive demand. The Irish government is letting the consumer decide. The complexity here is that consumer choice is strongly influence by government policy and markets are not as 'free' as they might appear. This is playing out in a very real way with seaweed in Ireland as companies pivot towards renewable energy.

[29] Net Zero, Food and Farming: Climate Change and the UK Agri-Food System (Earthscan Food and Agriculture) : Ward, Neil: Amazon.co.uk: Books
[30] Female Founder: Jennifer O'Brien, Sea & Believe

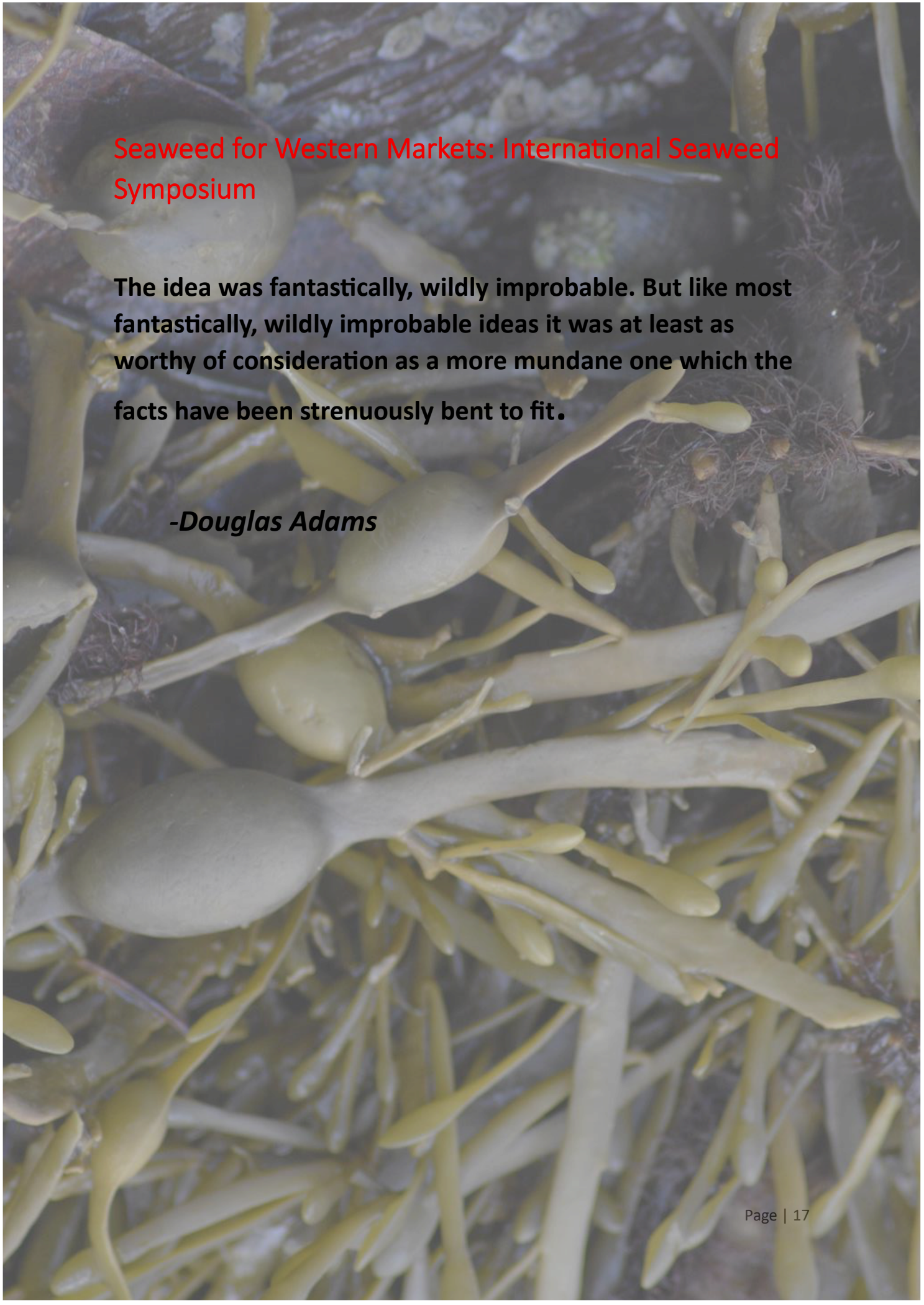
Irish companies are deeply involved in the North Sea Farm 1 project which will pioneer seaweed production alongside offshore wind. There are already plans to replicate the infrastructure in Ireland if all goes well. It is no secret Amazon is the financial powerhouse behind these projects[31] as Amazon's Ireland based servers are extraordinarily electricity intensive and powering these servers with cheap and reliable offshore wind is a goal for the business.

Seaweed has entered the equation as Amazon and others have looked to gain additional value from the investment in offshore wind. There is nothing wrong with deploying seaweed in off(near)shore wind farm environments and I think it is an excellent idea when it comes to fostering the bio stimulant industry, but when its being done explicitly so a major corporation can leverage carbon credits you lose a lot of the potential value of system models.

This is not a criticism of the North Sea 1 project itself. North Sea 1 is promising that seaweed will be used in food, packing, cosmetics and biofuels and there is serious scientific fire power in the research group leading the climate and biodiversity team. If the project delivers on the promise to use the seaweed to drive sustainable production of major products, it will be a model that the UK needs to seriously consider replicating. At the same time, the line between greenwashing and true environmental value is defined by who is buying the seaweed and what they are doing with that seaweed. Growing it isn't enough, and success depends on doing the hard work of generating viable products out of the seaweed.

This brings us back to the quote from the barman at the beginning of this section. In an affluent country like Ireland, why would consumers spark a revolution when they can just go with the flow? Why would the Irish government risk intervening in an economic model that is working to promote an unproven model of growth? Why not just keep the tax incentives flowing to Amazon and then let consumers push Amazon to invest in seaweed (or not)? I don't feel the need to try and address these questions because the UK is in a different economic position. The lesson from Ireland is that investment and growth in the UK needs to be based around a business model that works in the overall context of the UK economy (more on that later).

[31] World's first commercial-scale seaweed farm located between offshore wind turbines is now open in the Netherlands



Seaweed for Western Markets: International Seaweed Symposium

The idea was fantastically, wildly improbable. But like most fantastically, wildly improbable ideas it was at least as worthy of consideration as a more mundane one which the facts have been strenuously bent to fit.

-Douglas Adams

Ireland provides a snap shot of current market dynamics around seaweed in the Western world. We can grow seaweed and there are extraordinary compelling arguments as to why we should be growing more of it. The lesson from Ireland, and the wider EU, is that production of seaweed isn't the issue. The issue is producing seaweed-based products that markets will actively buy.

I went the International Seaweed Symposium to get a better idea of the full scale of seaweed products on offer. Was there something that would change the game in terms of sparking market demand? A later section of this report fits various market pieces together to solve the UK puzzle, but before fitting together the pieces though it is important to look at them one by one.

Seaweed as a human (and companion animal) food

Could people in the UK be eating a lot more seaweed produced in the West? Yes. Should people in the UK be eating a lot more seaweed produced in the West? Probably. Should we be feeding our dogs, cats, horse and other companion animals more seaweed? Almost certainly. UK diets are notoriously unhealthy, high in calories but low in nutrients and environmentally dubious. The diets of our furry friends really aren't any better[32].Seaweed is one tool in the fight against all these problems, and the UK can absolutely grow the sorts of seaweeds that are widely consumed across the world.

Will people in the Europe and the UK start eating a lot more seaweed produced in the West? Probably not. Is human (or pet) consumption even all that relevant to growing seaweed at industry in Western Europe? No. The issues are scale.

Seaweed for human consumption is all about large production of 'red' seaweed. [There are three basic types of seaweeds: reds, browns and greens. All three are theoretically edible but global consumption is dominated by a few species of highly palatable reds.] Asia has already cornered the market here and could scale production to match an increase in global demand for human consumption. It is also true the UK's diet crisis is about how much we eat not just what we are eating. Food production still has place in the UK as seaweed is a necessary component of some aquaculture systems (see Mungo Murphy's in the previous section) and there is a strong argument it should be used far more extensively in salmon and fin fish aquaculture. The seaweed species we eat also overlap with the seaweed used in soaps and personal care/beauty products so there is no reason to not supply both markets at the same time. However, UK production of seaweed for human and pet food is likely to remain a niche market supplied as a bi-product of seaweed production for other purposes.

Seaweed as a Livestock Feed Additives (methane suppression or otherwise).

I have written a technical annex to this report to cover the ins and outs of seaweed as a methane suppressing feed additive and covered the highlights in a previous section. All that really matters though is that this is where there is enormous economic growth potential and seaweed could legitimately revolutionize elements of livestock farming in the UK. The UK could drive this growth, or we could allow production to occur further south and just import the final products.

Cows and sheep have a significant environmental impact linked partly to their biology and partly to the way we feed and rear them. Ultra-high processed diets promote weight gain in cows, pigs, dogs, cats and humans alike whilst requiring significant amounts of land to produce. Discussions around diet change rapidly descend into personal politics but there is no debate that what animals eat

[32] Dogs - PDSA

impacts them and the world around them. Governments and farm communities are increasingly finding themselves squeezed between a rock and a hard place. The public is demanding actions on environment impacts and livestock farming has a major environmental impact, but reducing this impact often comes with steep consequences.

Changing the balance of food production in the UK would drastically alter the character of communities across the UK and Ireland and so there is huge pressure to find a solution which allows farmers to stay famers. Governments like the UK and EU are already so deeply entangled in this discussion due to the size and importance of the farming subsidy system that there is no way for government to not get involved. Seaweed offers the potential solution that could work on multiple levels. The size of the prize is so big and government involvement is already so deep that the situation is very different to the human feed market. There is a degree of irony that rules, regulations and markets are so different depending on if we are buying seaweed e.g. Nori to wrap around our sushi of buying that same Nori to feed to livestock, but we are where we are. And yes, my vision of the UK contains a future where cows and humans are both eating seaweed from domestic farms, but I do understand the rules governing animal feeds and food for direct human consumption are always going to be different.

My vision of the agricultural UK communities in 2050 (a.k.a. when we reach Net Zero) includes near universal adoption of seaweed-based animal feeds produced domestically using native seaweed species grown in aquaculture via a co-operative model. Not everyone will agree with this vision especially as it come across more 1850 than 2050: co-ops, localised domestic supply chains and commercial exploitation of UK seaweed. But not everything that is old is inherently broken.

Seaweed as a Fertilizer and Fertilizer Replacement i.e. Biostimulant

Seaweed is rich in nutrients and rapidly decomposes releasing this nutritional value. This makes whole seaweed a great fertilizer, and the likes of Scottish government already produce official advice for using seaweed as a fertilizer[33]. Seaweed isn't just a fertilizer though as a number of species also are "bio stimulants" when processed for applications to agricultural crops.

The previous sections referenced the impact of ultra-processed diets on animals and animal health. An analogous process is also occurring with plants due to the way agricultural intensification has happened but it's less a far less discussed issue. Simplistically basic agricultural practices in the UK hasled to an issue of poor soil health and soil health directly links to plant health. The effects aren't profound at first glance but they are real and have led to a huge increase in efforts to improve soil health. An unusual ally in this fight seems to be seaweed and it is the soil/health improving qualities of some seaweeds that scientist call 'bio stimulation.'

By definition, a bio stimulant is a substance that increases plant yields by helping the plant use the resources it already has. Acadian Seaplants has a range of products[34] that have been shown to increase drought tolerance and increase plant nutrient usage. When the New Zealand kiwi industry was devastated by a disease called Psa they found spraying the plants with a seaweed product acted like a vaccine against the disease without the complex issues of synthetic pesticides.

Not all bio stimulants are seaweed based but there is a strong theory as to why seaweeds are uniquely powerful when it comes to bio stimulants. As described in the second section of this document, seaweed is like a rootless plant meaning is does what plants do with roots but in a

[33] fas.scot/downloads/cropping-case-study-use-of-seaweed-as-a-fertiliser-for-grassland/
[34] Agritech Solutions for Plants, Animals, and People | Acadian Seaplants

different way. Seaweed extracts therefore contain a highly potent cocktail of compounds that are bioactive in plants and help transfer nutrients etc. These compounds would naturally occur in healthy soils due to plant root-microbial interactions, but modern soil management practices are creating problems. Adding seaweed extracts is therefore a way to re-enrich soils in critical plant biochemicals and the fundamental biology of seaweed makes them a great source of these compounds.

Most biostimultants are currently created from wild harvesting of seaweed but it can very much be done by kelp-based aquaculture which is the future of the industry. From a market standpoint bio stimulants don't eliminate the need for fertilizers and because seaweed is also a great primary fertilizer the logical end products is both a fertilizer and a bio stimulant. Such an end product has significant value in reducing the reliance of a country like the UK on synthetic fertilizers. Synthetic fertilizers are produced using natural gas and, as such, their price is extremely volatile and directly linked to natural gas prices.

Over reliance on synthetic fertilizers is a perfect storm of food insecurity, energy insecurity, and food price volatility so a transition to bio stimulants goes well beyond environmental concerns. Furthermore, bio stimulant production is dominated by brown seaweeds which grow great in nutrient rich cold water and not the low nutrient tropical environments typical of South-east Asia. The biggest target species, Ascophyllum nodosum, thrives in Irish and British waters and is something anyone who visits beaches in the UK will immediately recognize. The photo at the start of this section is Ascophyllum.

Seaweed a Nutrient Pollution Sponge

Modern agricultural means countries around the world are pumping vast amounts of nitrates and phosphates into coastal waters i.e. nutrient pollution a.k.a. eutrophication. This creates so called marine dead zones. In the UK, and many other countries around the world, we make this issue even worse due the way we (don't) treat our wastewater and dump sewage straight into aquatic systems. Seaweed just so happens to love these nutrients and uses them to grow extremely fast, clean the waters and absorb carbon dioxide in the process.

This is why seaweed is such a great fertilizer and using seaweed as a fertilizer begins to create a closed nutrient loop that would have major environmental benefits. Beyond the fertilizers, the initial pollution mitigation potential of seaweed is valuable because alternative pollution treatment systems are expensive, complex or come with major compromises. The previously mentioned EU seaweed strategy plays up the pollution mitigation impact albeit in the most generic terms possible. Nutrient 'offsetting' is becoming a thing in the UK due to regulations like Nutrient Neutrality[35] meaning you could get paid to grow seaweed for pollution control.

Seaweed for Nature Restoration

Natural seaweed rich environments, such as kelp forests, are highly biodiverse ecosystems and important habitats for numerous commercially important marine species. Kelp restoration is occurring in a number of countries and has a real tourism value which is absolutely relevant to conversations on coastal economies. Kelp forests certainly exist in the UK, but their tourism value is not clear. The economic case for seaweed in the UK is very much around farming not restoring native seaweed beds.

[35] Nutrient neutrality: update - GOV.UK

The relationship between seaweed farming and nature is oddly polarized because the conversation has attracted strong opinions from two different viewpoints. Seaweed farming will never return degraded kelp forest to their natural state and for those whose passion is restoring nature to a fully natural state claims around seaweed farming and nature restoration ring hollow. Seaweed farming can be good for nature, biodiversity enhancement and communities where it displaces/excludes far more damaging practices like bottom trawling (or dynamite and cyanide fishing in the case of Indonesia). In heavily degraded coastal environments, of which the UK has many, seaweed farming can function as a stepping stone to stabilize environments and initiate improvements. However, seaweed farming isn't full restoration of natural habitats and so it needs to be considered in nature restoration carefully.

Seaweed for Liquid Fuels and Chemical Refining

Q: What is crude oil and why is it so valuable?

A: Crude oil is really old algae that has naturally transformed into a thick soup of chemicals. It is valuable because within the soup there are incredible useful and hard to replicate compounds. Oil was worthless until humans figured out how to 'refine' the crude oil into petro-chemicals.

Q: Seaweed is algae so is seaweed also 'fresh' crude oil?

A: Yes, and this is why you can make products like jet fuel from seaweed using existing oil refining equipment.[36] The term 'biorefining' sometimes gets used to describe the process of transforming seaweed in chemicals but the 'bio' bit can be confusing. The refining bit doesn't have to change between seaweed and crude oil but with seaweed there is an additional initial step required to skip a few hundred million years of geologic aging. This has massive potential advantages, but the initial step is still proving challenging and the economics of using seaweed vs crude oil just don't stack up.

Q: Could innovation or other changes open the door for seaweed bio-oil to displace crude oil as the feedstock for the oil refining and chemical production industry?

A: Absolutely, but it isn't clear just how realistic this vision is and/or what needs to be done to make it a reality. This is not a new concept, and vast investments have already been made into the processes of converting algae to fuel without economic success. The more modern question is whether we should even be trying to chase a direct displacement for crude oil.

Part of the issue in trying to replicate crude oil from seaweed might be that it is not something we should be trying to do in the first place. Should skip the oil production stage and go straight from seaweed to chemicals? Scotland hosted a large scientific project in 2023[37] to continue the development of the concept of a seaweed biorefinery, but it remains a nebulous concept to pin down. I talked to lot of experts with ideas of how it could/might/should work but there was no consensus around what exactly constitutes an economically viable seaweed-based refinery. This is okay in my mind though because it becomes a flexible piece in the puzzle with lots of potential. Seaweed can be converted into a vast array of chemicals that are, and will continue to be, critical to the modern economy. Seaweed has a future in the world of 'green chemistry,' but more work is needed to define what this future looks like.

[36] Is seaweed the future of flying? - BBC Future
[37] KELP-EU: innovative, sector-leading seaweed biorefinery - European Commission

Seaweed for Hydrogen

The UK government believes it needs huge quantities of hydrogen to drive long term economic growth[38]. The terminology and overriding logic e gets esoteric quickly with the hydrogen industry preferring to talk in colours e.g. black, grey, brown, blue, green, pink, purple, yellow and/or turquoise hydrogen and policy teams preferring acronyms that aren't actually acronyms i.e. H_2-BECCS which is short hand for hydrogen production for energy using a biological source for the hydrogen combined with carbon capture and storage. Behind this complexity is a need to settle on one of two options

Option 1: Produce more biological material that can be converted to biomethane and then continue with existing technology the current energy system infrastructure.

Option 2: Rebuild major parts of the energy system and energy infrastructure from scratch to support yet to be commercialized technologies.

There is no formal government position but the governments Biomass Strategy[39] outlines the case for Option 1. The UK could join Europe and build massive wind farms to generate energy to covert water hydrogen, then invest in building all new hydrogen production plants and then design and deliver a brand new hydrogen transport network and then develop large hydrogen storage facilities under the North Sea to move hydrogen around the system creating a so called 'green hydrogen' economy[40]. Or we could just upgrade the UKs biomethane production capacity using existing and well proven technology (anaerobic digestion) whilst simultaneously delivering the ongoing commitment to connect the UKs existing steam methane reformation plants, which is how the UK and world currently produce commercial hydrogen, to carbon capture and storage facilities. The only reason to even consider Option 2 is if you believe there is a fundamental problem with the supply/production of biological material that requires redesigning the UK's energy economy to allow hydrogen to be produced differently. Seaweed is a relevant biological material in this context and that is where it comes into the equation.

It technically possible to harvest seaweed and use it for direct generation of H_2[41], but the far more logical use of seaweed is to introduce it alongside existing waste streams to produce biomethane via anaerobic digestion. This biomethane is just added to the national gas grid, which is already done in the UK, and then ammonia/hydrogen is produced at the existing production plants which already rely on gas from the national grid.

I appreciate this all comes across as niche and hyper specialists but, as was the case with feed additives, the undisputed economics are staggering and will impact every person in the UK. The Department of Energy Security and Net Zero talks about hydrogen in units of tens of billions of pounds per year[18] and the cost will be borne directly by Brits through heat and electricity bills. The UK doesn't need seaweed for hydrogen but seaweed for hydrogen might just offer the UK an opportunity to deliver economic growth, lower energy bills and environmental improvement as a single package when compared to the alternative options. When, as is the case here, all that is theoretically required is for the UK to grow a bit more seaweed to vastly improve the impact of

[38] UK hydrogen strategy - GOV.UK
[39] Biomass Strategy 2023 - GOV.UK
[40] Mapping hydrogen storage capacities of UK offshore hydrocarbon fields and exploring potential synergies with offshore wind | Geological Society, London, Special Publications
[41] Alkaline thermal treatment of seaweed for high-purity hydrogen production with carbon capture and storage potential | Nature Communications

something the UK government is dead set on doing anyway its hard to not want to pursue this idea in more detail.

Seaweed for Carbon

Seaweed has gotten ensnared in various carbon market models that are attempting to make money selling carbon removal credits. Farming seaweed to turn into biomethane and/or hydrogen fuel via H_2-BECCS (see above) feels legitimate and robust within the confines of the policy constructs I live and breathe. I have yet to see any other business models that make the cut in terms of generating high integrity of robust carbon removal credits.

I am aware here that there is a project currently underway funded by big names in industry and science trying to sell seaweed to 'biochar' as the next great solution [42]. I have been wrong before so I am willing to let them prove me wrong again and demonstrate this is an idea with merit.

The problem is that biochar is just charcoal but made in a way that makes it two to five times more expensive than charcoal. Seaweed-based biochar will be at the high end of this spectrum, if not even higher, depending on the labour costs where seaweed is grown. I get to work with biochar projects in the UK and there are uses and business models for biochar that makes sense, but none would be viable if at the £2000++ ton price tag that seaweed-based biochar would have to attract. I am not saying the theory is bad, nor that biochar is bad, the economics seems to be off by orders of magnitude. This issue only gets worse when you consider the biochar markets would be competing with the hydrogen/biomethane markets for waste seaweed with these energy markets producing higher value commodities at lower cost and the same or greater carbon benefits.

Another hypothetic usage of seaweed for carbon is seaweed sinking. Seaweed sinking sits alongside ocean fertilization dead whale carbon as '*novel*' ways to biologically remove carbon from the atmosphere. I had the privilege to be taught marine chemistry by Prof Frank Millero who played a pivotal role in the testing validation of ocean fertilization[43]. This was more than thirty years ago which is why I struggle with the concept that these ideas still qualify as new, innovative or novel.

I remember talking to Prof Millero and hearing him say matter of factly that 'anyone who thinks ocean fertilization is a legitimate climate change solution needs to go back to school.' Intellectually seaweed sinking, ocean fertilization, or my personal favourite—dead whale carbon[44]-- are powerful thought experiments used as example to train scientists to think bigger. Dumping iron in the ocean or harpooning whales in deep water does kick off a chain of events which likely transfers carbon from the atmosphere to the deep ocean. Similarly farming seaweed in the open ocean and then forcing it into the deep sea will take some carbon from the ocean surface to the deep ocean. But the real impact here all depends on how you mine and ship the iron, hunt and harpoon the whale or grow and sink the seaweed. You need to think at the systems level, and I have ended on this example because it highlights that there are some systems where adding seaweed doesn't create a magic solution. When it comes to the agri-food and energy systems I think seaweed offers a compelling prospect but when it comes to pure carbon markets, I don't see a clear role for seaweed.

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[42] New seaweed farm off the Norwegian coast seeks to remove CO2 from the atmosphere - SINTEF
[43] Ocean fertilization - Wikipedia
[44] The role of whales in carbon storage

Seaweed and the UK's Future: "Modern" Industrial Growth

There is a feeling which persists in England that making a sandwich interesting, attractive, or in any way pleasant to eat is something sinful that only foreigners do.

``Make 'em dry,'' is the instruction buried somewhere in the collective national consciousness, ``make 'em rubbery. If you have to keep the buggers fresh, do it by washing 'em once a week.''

It is by eating sandwiches in pubs on Saturday lunchtimes that the British seek to atone for whatever their national sins have been. They're not altogether clear what those sins are, and don't want to know either. Sins are not the sort of things one wants to know about. But whatever their sins are they are amply atoned for by the sandwiches they make themselves eat.

-Douglas Adams

University of Galway produces an annual report on 'Ireland's Ocean Economy[45]' and I met Prof Stephen Hynes in Galway to talk about seaweed economics. I had a similar conversation with Kendall Barbery of GreenWave[46] in the US. At some point in the future, I will do justice to these conversations and if you are interested in anything to do with seaweed production then GreenWave's Hub is an immensely powerful resource. I also think what GreenWave is doing is the right solution for the USA and what they are doing will make waves around the world, but the UK needs to stay focused on making our own pubs sandwiches. This is because there are three problems with the economics of seaweed that cut across Ireland, the USA and the UK. The UK already has answers some of these issues, so we don't need to replicate other countries.

Problem 1: The market is stuck in a box. Small companies like Jenifer at Sea and Believe or Sinead at Mungo Murphy's (see *Seaweed for Sustainable (and Elegant* Consumerism) are forced into a position where they have to be the entire production, processing, logistics and supply chain. In the UK Norfolk Seaweed is in the same boat[47] To scale these businesses you have to scale every aspect at once which is a near impossible challenge. Whilst some may have access to small business loans seaweed farms are high capital investment and it is near impossible to get a loan against the equipment. As Prof. Hynes explained to me, you can end up in a place where these incredibly skilled businesses cannibalize each other for market share because their market forces keep them in a confined bubble.

Problem 2: Western government aren't helping open up the box. Asian government intervention is absolutely critical to the dominance of Asia in the global supply of farmed seaweed countries. China, South Korea, and Indonesia put seaweed production alongside critical agricultural and economic growth sectors and support the industry accordingly. The US, UK and Ireland take a very different view of how/where seaweed fits into their national economies. Seaweed is just scattered across government departments and different levels of government making the system a nightmare to navigate. Whilst all three countries aggressively protect and promote their own food production, energy production and environmental protection systems, seaweed has been cut off from the key subsidies. In the UK we have a Department of Energy Security, which directly intervenes and heavily subsidies energy and carbon markets and a Department for the Environment Food and Rural Affairs, which directly intervenes and supports agricultural markets and finfish/shellfish based aquiculture, and yet neither department is offering policy-based support for seaweed. The problem here isn't so much that seaweed isn't subsidized by the UK government but rather that seaweed is being forced to compete with heavily subsidised alternatives and therefore is starting from an economically disadvantaged position.

As an example, the vast majority of biomethane produced in the UK is driven by government subsidies. The subsidy, the Green Gas Support Scheme[48], is a complex piece of legislation but to be eligible producers must report 'land use and land criteria' linked to any biologic material used in the process using a specific methodology. This is impossible for seaweed because its not grown on land and no mechanism or exemption under law exists to allow marine resources to be included. Having spoken to relevant policy teams this was not intentional but was an oversight with the policy professionals never appreciating seaweed could be relevant to the conversation. As a result, the UK government is actively desensitising seaweed for biomethane and hydrogen for no reason other than it slipped through the cracks. These esoteric policy decisions have a huge impact on real world actions and create a chicken and egg situation. Seaweed is never considered as relevant to policy

[45] Latest Ocean Economy Report highlights €6.5 Billion turnover and Employment Growth | Marine Institute
[46] GreenWave
[47] Norfolk Seaweed | Commercial Sugar Kelp farmed in the UK
[48] The Green Gas Support Scheme Regulations 2021

because it is not currently relevant but its not currently relevant because policy doesn't consider it relevant.

Problem 3: Polluters don't pay (but they should). The UK government follows a principle known as 'polluter pays'[49]. The idea is that the cost of pollution should not be ignored, and its cost should be paid for by those who are responsible. The theory is that if polluting industries are forced to pass the costs of the pollution to consumers, then consumers have the incentive to change their behaviour, make a different decision and reduce pollution to reduce costs. The alternative is passing the cost of pollution onto the public tax bill which means the consumer still pays but they system hides the cost in a way which does not incentivise behaviour change. If every country on earth signed up to this principle is would work great but the real world complicates the picture.

Current environmental regulations force seaweed famers to do the right thing in West and so they incur full polluter pay costs no matter what. The same high standards aren't enforced on imported oil, natural gas or agricultural products even if trade agreements do set baseline standards. This is double whammy in cases where seaweed is mitigating pollution costs caused polluters who never pay in the first place.

I am not sure how Ireland or the USA will solve these problems but a major take away from the Churchill Fellowship is that the UK's existing roadmap for economic growth is really good here. If you want to plod through 160pgs of policy speak then all the details are here [50], but simplistically four forces are combining in a UK context that could change the face of domestic seaweed farming and usage.

Emissions Trading Scheme (ETS), Green House Gas Removals and Nature Markets.

> The UK government may not have a complete solution to forcing polluter pays at an international level but there is commitment, alongside the EU, to get better. This means an emissions trading scheme for energy emissions and nature markets for other industries. The cover photo for the 'nature-based carbon standard' is my photo[51] taken whilst on the Churchill Fellowship. What you see in the photo is saltmarsh grasses growing in seaweed that has washed onshore i.e. seaweed isn't front and centre but it's very much in picture.
>
> The big hitter here is hydrogen and the ability to make carbon negative hydrogen from seaweed at the industrial clusters (H_2-BECCS) (See Seaweed for Hydrogen). No one is doing hydrogen or seaweed in this way because its is a solution that only makes in a future market context. The associated green chemical and green product industries that seaweed for hydrogen would fuel are also solutions made for this future world.

"Modern" Industrial Strategy Clusters (IS-8 Clusters).

> Geography matters and the UK isn't starting from a blank economic slate. A firm principle of the UK's economic growth plan is that place matter and we need to be doing the right thing in the right place. UK's 'industrial clusters' are key to this thinking and because of the geography and history of the UK these are coastal communities. This works really well for seaweed in terms of logistics. Seaweed can be grown and processed in the exact places where the material is needed

[49] Environmental principles policy statement - GOV.UK
[50] The UK's Modern Industrial Strategy
[51] BSI Flex 703 v1.0 Supply of Nature-Based Carbon Benefits | BSI

without significant road or rail transport. When you factor in how carbon capture and storage is going to work and how the ETS is going to work the argument for seaweed being an ideal feedstock grows even stronger. Almost inadvertently the UK has centralized the logistics in a way that mirrors what happens in Asia and will work with seaweed.

Idiosyncratically there is nothing particularly "modern" about this solution in spite of the name. It is based around the ideology that the UK should just do what we already think we should do, using the material and technologies that already exist in these places. There is no need to fundamental restructure the UK economy we just need to be careful with transitioning and growing the economy. The very definition of Don't Panic! Keep Calm and Carry On.

Biomass Strategy and Biomass Sustainability Framework

The above points work extremely well for seaweed, but they aren't exclusive to seaweed in theory. So what are the other options and are they better? The government spent lots of time looking into this[52] there is nothing that clearly beats seaweed in a UK context. If we need sustainable material to generate chemicals, fertilizers and biomethane in coastal communities with robust marine infrastructure why not use the only material that can produce all these materials which just so happens to be locally produced.

Globally a huge amount of attention has been focused on burning trees/energy crops for electricity with carbon capture storage. If you work for the UK government, you will call this Power-BECCS but most everyone else just calls it BECCS (BioEnergy with Carbon Capture and Storage). The UK is likely to do some of this, but the Biomass Strategy is one of a number of documents that recognises it's not a golden solution to the UK. We are already dependent on trees from Canada for electricity and whilst burning trees might be ideal for many countries biomethane and hydrogen BECCS makes sense in the UK. This cycles back to the clusters and emissions trading scheme, but it means that while the rest of the world needs trees for fuel seaweed for fuel would work well in the UK.

Freeports and the Revival of the UK Marine Economy

At the risk of beating a dead horse the UK is an island with an economy developed around import/export at critical industrial cities across the UK. Even Birmingham and Leeds, completely isolated from the ocean, were developed around a marine economy which explains all the canals and docks. Freeports/Greenports are part of the official plan to revive this economy but to work well a couple of thing needs to come together. You ideally need to be able to easily import, process and store the raw materials you need. Realistically you also need to be generating highly exportable commodities for the global economy. Fertilizers, chemicals, personal care products, animal feed additives and ammonia (to be converted to hydrogen at source as a fuel) anyone?

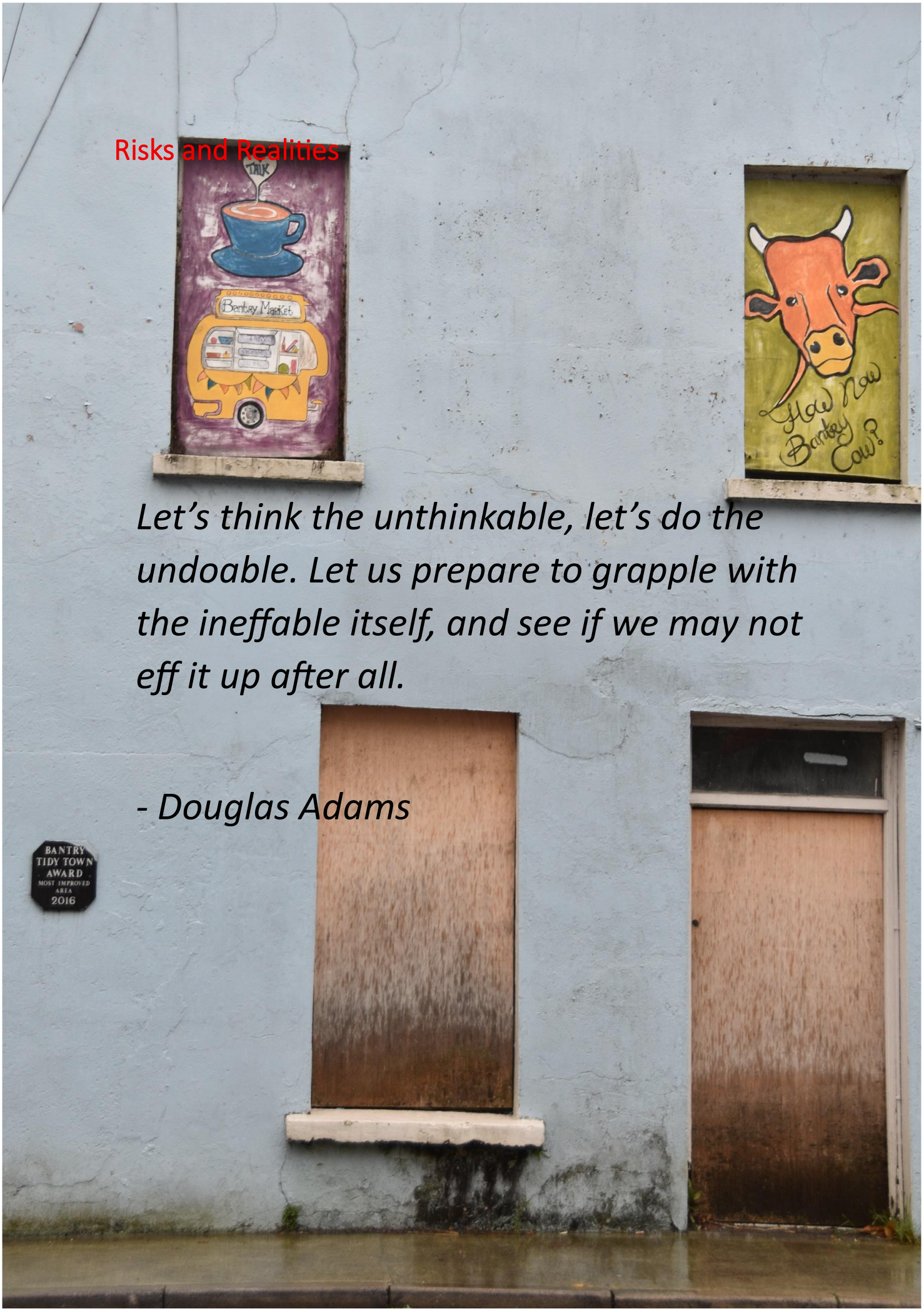
The UK Modern industrial strategy namechecks sectors like AI and Financial Services and Business Services. These sectors are great, but they won't drive growth at the freeports or industrial outputs of Teesside, Humberside, Merseyside, Grangemouth etc. The UK needs a truly industrial solution for industrial growth and seaweed works with this model.

Taking a step back I understand the desire to really dress up the vision of a 'Net Zero' economy where planes are flown using fuel made from air and rubbish and we all eat food grown locally in high tech urban vertical farms. 'The Line' in Saudi Arabia[53] has caught so much international

[52] Biomass Strategy 2023 - GOV.UK
[53] The Line, Saudi Arabia - Wikipedia

attention because it is interesting, attractive and anything but boring. Seaweed offers a different and altogether less radical way to build resilient coastal economies. We don't need to level Grangemouth and turn it into a Scottish Silicon Valley because we can simply transition from fuelling Grangemouth with Aberdeen oil to Aberdeen seaweed whilst allowing Aberdeen to continue doing what it does best i.e. supporting offshore infrastructure and the agriculture and fishing industries. It is up to the Scottish people and Scottish Government to decide the best way forward but there are some pretty good pubs in Aberdeen serving pretty good lunch on Saturdays.

Risks and Realities



Let's think the unthinkable, let's do the undoable. Let us prepare to grapple with the ineffable itself, and see if we may not eff it up after all.

- Douglas Adams

Seaweed isn't perfect. This document focuses heavily on the benefits but it's not all a good news story. New seaweed farming proposals are not exactly being celebrated across the UK.[54] Seaweeds can bioaccumulate iodine and arsenic at alarming levels. Scientist, including myself, are also deeply sceptical of some of the media reports suggesting open ocean seaweed farming will save the planet. It is important consider these risks and what they mean for the future of seaweed.

Health and Environmental Contamination Risks

There are two major health and environmental concerns when it comes to using seaweed: Iodine and Arsenic. Iodine is easy to deal with. Arsenic is a much more unfortunate and problematic issue, but it won't directly impact the UK.

Iodine is toxic to humans when consumed at very high levels and raw seaweed can contain high levels of the element. A number of countries including France have set national maximum limits for seaweed products for human consumption and the EU is developing a more standardized set of recommendations. The good news is that any number of simple techniques such as boiling and blanching significantly reduces iodine concentrations in raw seaweed so it's easy-to-get seaweed to safe limits. Furthermore, the risk of iodine is specific to brown algae i.e. kelps which are not traditional used for food. This limits the risk posed by direct consumption of current products but limits the ability to expand into future kelp-based products. Also, large parts of the world are iodine deficient and adding iodine to the diet would be beneficial[55]. This is why iodised salt became a thing and the levels of iodine found in seaweeds that people already eat is a good thing from a health perspective.

The problem of arsenic is more acute and but is something what would never have entered the conversation if it weren't for a completely different quirk on the climate-seaweed continuum. Climate change is causing an explosion of a very specific type of seaweed in the middle of the Atlantic Ocean. This seaweed, Sargassum, has started washing onto beaches in vast volumes where it rots causing a number of issues. It seems like the perfect opportunity to take the seaweed and do something useful with it and certainly people are trying. However, sargassum has a major problem. Like all seaweed it craves a nutrient call nitrate to help it grow but it grows in areas of the ocean where it can never get enough. Sargassum has therefore evolved some biological tricks to maximize nitrate uptake which unfortunately, for humans for the seaweed, also directly lead to the bioaccumulation of arsenic in the seaweed. Arsenic bioaccumulation is theoretically possible with other seaweeds, but only when they grow slowly in nutrient depleted environments, and no one should be intentionally growing seaweed under these conditions for a number of other reasons. Ironically human activities are polluting the open ocean with nitrate effectively fertilizing massive sargassum seaweed blooms, but the seaweed still grows so slowly that is accumulates arsenic.

No one really knows what the risk of this arsenic accumulation is to humans, but it feels very real I called Professor Helena Solo-Gabriele at the University of Miami to understand the dynamics, and I have to defer to experts like her on the details. Professor Solo-Gabriele is an expert in the relationship between human health and the environment and her PhD student Brittany McIntyre on the sargassum arsenic question i.e. Seaweed's little secret.

[54] Locals 'relieved' after seaweed farm plan rejected - BBC News
[55] Iodine, Seaweed, and the Thyroid - PMC

Arsenic is a very dangerous chemical from a human health perspective. It can cause acute effects, but arsenic exposure is more likely to manifest as neurologic abnormalities and reduced cognitive development at a population level i.e. chronic and devastating impacts on communities where the damage is done well before the problem has been identified. Sargassum isn't directly consumed in the Caribbean, but it is turned into compost/fertilizer and applied to soils. The arsenic is further concentrated during this process and its then being taken up by the food crops grown in the soil. I am no expert here, but it was made clear to me the levels of arsenic being found in crops needs to be taken seriously. Even if other uses are found for sargassum you will still have to find a way to deal with the arsenic and that is not going to be easy. The BBC among others have noticed the desire to use sargassum[56], but it is this sort of media attention that is also driving the concern that a major health issue is being ignored.

As a side element of my day job I get to work in the area of 'forever chemicals' or PFAS (the main modern sources of forever chemicals are heat pumps, electric vehicles and the technologies we need for Net Zero but the story of fluorinated gases is for another day). I strongly suspect seaweeds will accumulate certain PFAS chemicals, based on my knowledge of the dynamics at play, and there seems to be evidence supporting this hypothesis on Google. This is something people like me will keep an eye on and may require more serious consideration in the future. If such accumulation does occur there may be an opportunity here to chemically extract the PFAS chemicals from seaweed offering a chance to remove chemicals from the environment that we have no good alternative way of mitigating.

Raising Investment

The single greatest complaint I heard from those working in seaweed in Ireland is around the difficulty in securing investment and the clear role government policy plays in this controlling this dynamic. Growing and processes seaweed required specialist equipment and is capital intensive to set up. This means the seaweed industry need access to loans/capital investment to grow which in itself is certainly not a unique position to be in. However, seaweed has a risk/return ratio that makes it unattractive to most Western banks and investors. The financial potential returns are too low to attract venture capital or private equity especially due to the tight regulations around securing aquaculture sites. The financial risk is too high for banks to provide the sorts of loans the industry needs. Both issues are directly linked to government policy, regulations, and growth but unlocking investment requires government policy moving in one of two opposing directions.

The problem basic problem is the evolving, uncertain and high complex nature of aquaculture regulations in Western Europe. The regulations prevent the sort of rapid expansion that venture capitalist crave and unlocking this sort of private sector investment would require large scale deregulations. The level or required deregulation poses significant challenges and the alternative solution is to formalize and streamline the existing regulations. The UK's traditional banking institutions have a long history of agricultural loans and are increasingly offering financial products linked to nature markets. The issue with seaweed is that the UK (and Irish) is that all regulation and permitting decisions are made on a case-by-case basis making it difficult to know what will and won't get approved. It is not dissimilar to forestry but for forestry the UK and Irish governments step in and offer direct forestry incentives for farmers massively de-risking the sector. Governments would need to step in and offer higher level of assurances to markets that the government does support seaweed and won't rapidly change policy to kill the industry.

[56] From eyesore to asset: How a smelly seaweed could soon fuel cars - BBC News

At the end of the day in places like Japan and South Korea governments view aquaculture as an extension of the farming sector, within government policy seaweed production works. The market/financial dynamics are not unusual or radical, they just require government interventions to be at the appropriate level to ensure a viable risk/return ratio. Currently Western government heavily intervene in regulations around planning, development and deployment but are hands off when it comes to providing any certainty to markets and that is going to have to change if the industry is to meaningfully grow.

Seeding the Lines

The plants we grow for food have little if any resemblance to wild plants due to thousands of years of selective breeding and an incredible specialist seed innovation industry. The seaweed grown for food is identical to the wild varieties found in the ocean. Whilst the approach taken by the agricultural industry is not with major risks and compromises it is an essential component to the viability of the global food system. Seaweed aquaculture will have to move in this direction, at least to some degree, if it going to be a competitive part of the global economy. Fundamentally growing seaweed as a natural resource requires treating seaweed as a resource and modern selective breeding technology offers the potential to rapidly improve commercial seaweed varietals. Implementation of this technology is however impeded by government regulations, including in the UK, which view seaweed aquaculture as more of a high-risk novelty than a viable natural resource.

A major concern around varietal optimisation is linked to invasive species risks. Seaweed can be 'invasive' with local sub-species being displaced by introduced sub-species[57]. The thing to note here is that seaweed evolved about 3 billion years ago and has always existed in highly interconnected oceans. The terminology and concepts around 'invasive species' need to be applied carefully with seaweed. You will find a vast amount of information online stating a genus of seaweed known as *Asparagapsis* is 'invasive' or 'non-native' to the UK and Ireland, but that terminology is not particularly helpful. *Asparagapsis armata* was formally discovered to science in 1855, by an Irish botanist as it happens, and was recorded in Europe in the 1920s and in Ireland in 1939. It has a complex life cycle and is a cryptic species meaning you really have to go looking for it to find it.

When it actually came to Europe and Ireland is not known and you have to use genetics rather than physical characteristics to make these identifications so historic 'first occurrence' information needs to be viewed with sceptics.[58] Ultimately yes moving species comes with a risk but the risk isn't equivalent to moving animal species between isolated islands. Regulations will be needed so that the risk can adequately addressed without unnecessarily hindering the industry.

Another risk around selective breeding of seaweed is the emergence of new diseases/pests. Seaweed is prone to disease in high intensity aquaculture systems, and the Indonesian seaweed industry is struggling with a disease known as ice-ice. Ice-ice has been found in wild populations of seaweed and it's the ability for a disease to start in aquaculture and then jump to wild populations that is of most concern. At the same time, the potential for novel disease emergence is not an absolute justification for preventing aquaculture based on improved seaweed varietals.

[57] Endemic or introduced? Phylogeography of Asparagopsis (Florideophyceae) in Australia reveals multiple introductions and a new mitochondrial lineage - PubMed

[58] Full article: Asparagopsis taxiformis and Asparagopsis armata (Bonnemaisoniales, Rhodophyta): genetic and morphological identification of Mediterranean populations

Displacing Demand

If seaweed had a significant place in the current UK economy, it would be happening at scale. The preceding section covers in detail why and how economic changes in the UK would switch the balance and we aren't talking about revolutionary changes. At the same time there are major economic risks and uncertainties associated with heavy industry transitioning to a bioeconomy.

Looking at the steel industry there are complicated questions around how, or even if, the UK should transition to a greener bioeconomy, abandon heavy industry or persist with fossil fuels to try and stay relevant in a globally competitive market. I have come to conclusion that the fate of seaweed, heavy industry and coastal communities in the UK are inextricably linked (As detailed in the Modern Industrial Strategy[59]). It will be the demand for carbon negative biomethane and hydrogen at the UK's Industrial clusters that underpins demand for seaweed and catalyses the seaweed industry.

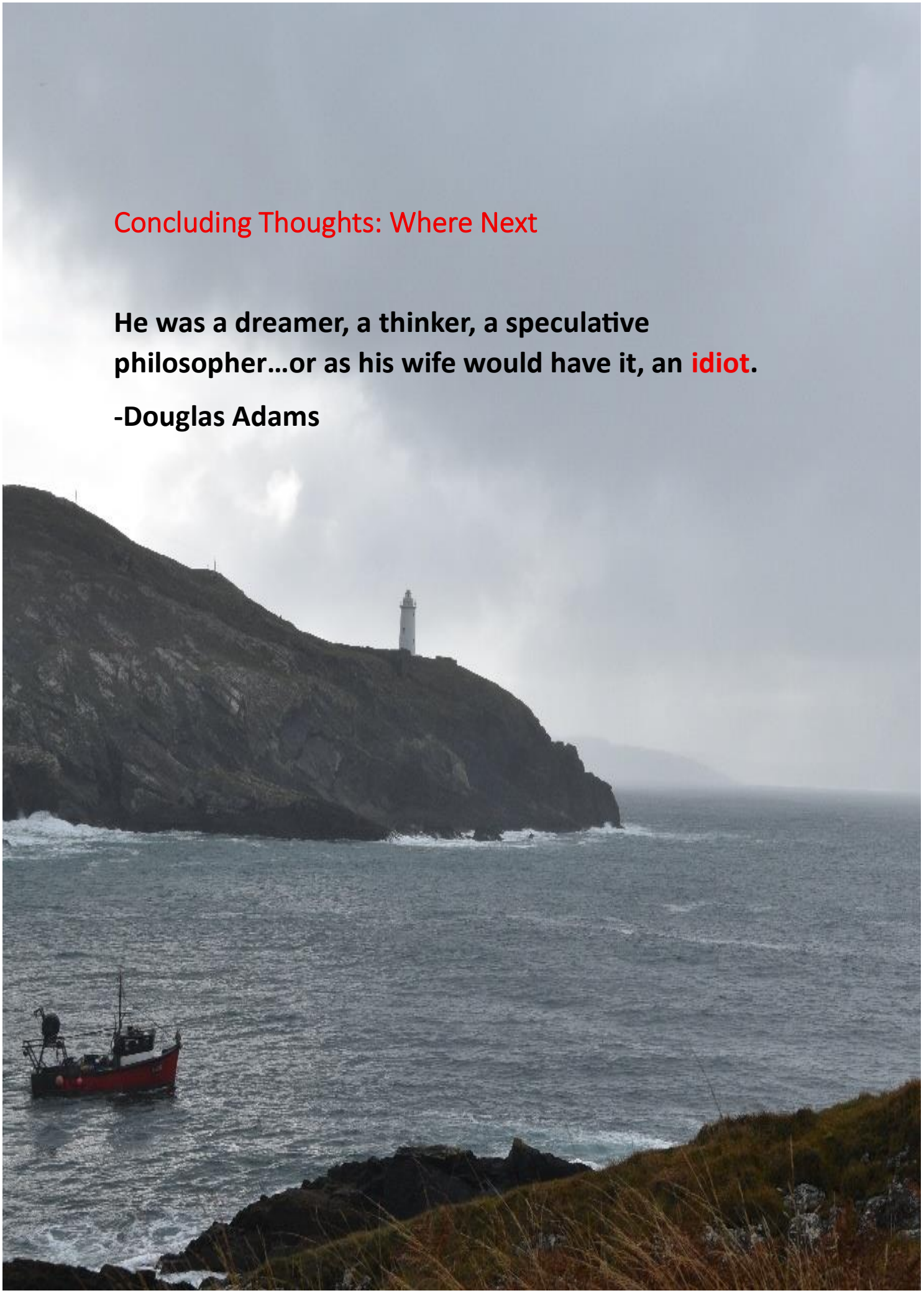
For the communities of Stockon-on-Tees, Hull, Southampton etc there is a massive ask to accept change and the risks associated with that change. This is not about adding a bit of growth to the local economy but overhauling the structure of the economy to reduce the reliance on fossil fuels. Jobs will be lost with the promise that even more and better jobs will be created.

[59] The UK's Modern Industrial Strategy 2025 - GOV.UK

Concluding Thoughts: Where Next

He was a dreamer, a thinker, a speculative philosopher…or as his wife would have it, an idiot.

-Douglas Adams



Surely economic resilience in the modern age requires building high-tech data centres, quantum computers and hypersonic nuclear missiles? We live in the age of bitcoin, influencers and AI driven solutions not seaweed and cattle feed. But we also live in a society characterised by increasing inequality, environmental degradation and limited economic opportunities in many coastal communities. It is not impossible to grow the economy and address the underlaying social issues but maybe it is impossible to growth the UK economy via a model that matches that of Ireland or the USA and still address the social issues. When trying to solve a uniquely British set of circumstances the UK might need to consider a uniquely British solution and leveraging the resources that are already sitting on our doorsteps.

Seaweed production is hard work, and it will never happen at scale without a groundswell of community and societal support. Large scale seaweed production requires a near zeitgeist level shift around how we think about the UK's economy and what economic growth in this country should deliver. Gross Domestic Product (GDP) is part of the question but perhaps Scotland is on to something with the 'Just Transition[60].'

What makes seaweed so fascinating to me in this context is that is not revolutionary, or radical or foreign. It is an opportunity for the Welsh to reclaim the power of lawr, for Scottish to embrace ceilp and for Billingsgate not to be consigned to the annals of history. The cultural familiarity is powerful, and that is important because the problems of economic and community resilience have deep cultural implications. Seaweed offers a radically unradical, even boring and unsexy, pathway for the UK to grow the economy and improve the outlook of rural and coastal communities--but that might be exactly the approach the UK needs.

[60] Just transition - Climate change - gov.scot

Technical Annex: Cow Farts and Kelp

He almost danced to the fridge, found the three least hairy things in it, put them on a plate and watched them intently for two minutes. Since they made no attempt to move within that time he called them breakfast and ate them. Between them they killed a virulent space disease he'd picked up without knowing it in the Flargathon Gas Swamps a few days earlier, which otherwise would have killed off half the population of the Western Hemisphere, blinded the other half, and driven everyone else psychotic and sterile, so the Earth was lucky there.

- Douglas Adams

The Earth, and humans in particular, may have just gotten very lucky. Or, more accurately, humans may have gotten lucky about three billion years agon. That is when algae evolved on this planet and immediately started an evolutionary arms race with the bacteria. A weapon of choice for the algae was bromiform, plus a few other halogenated compounds, and fast forward a couple billion years and seaweed, plankton and other marine algae are still engaging in this form of biochemical warfare. You can think of it like an immune system response. When seaweed is exposed to biochemical stress indicators associated with potential bacterial infection it produces these compounds that kill off methanogenic bacteria in a specific way that protects the seaweed. If you want more information, I recommend googling 'bromoform production in seaweed from stress' and follow Google's AI overview and associated links.

Why are humans lucky then? Because the specific compound used by seaweed here is so effective and ferocious in its battle against methanogenic bacteria it continues to work even after being eaten by a cow. At the same time because this is a truly ancient process humans, cows and all other animals have been exposed to this throughout our entire evolutionary history and so we seem to have evolved to be none the worse off when we eat seaweed. Pure synthetic bromoform is not something you want to regularly consume but humans and various forms of livestock have been eating seaweed throughout recorded history without any sign of ill effects from the compounds involved. Long story short if you want to reduce methane emissions from cows, sheep and other ruminant livestock adding <1% seaweed to their diets is an all-natural solution backed up by science. It is this simple fact that has the potential to alter the course of livestock production across the globe.

Methane is a powerful greenhouse gas and is specifically problematic when it comes to an issue known as climate overshoot. Simplistically burning of fossil fuels releases carbon dioxide and it is this fossil fuel-based carbon dioxide which will determine the average impact of climate change over hundreds to thousands of years. On shorter time scales Earth's climate is very sensitive to net changes in the emissions of methane because methane behaves differently in the atmosphere. If we can reduce methane emissions at a global over the coming years, we can drive changes that will make a critical difference to Earth's climate within years not decades. This is why internationally we have something called the Global Methane Pledge[61] which sits separate from other agreements and has pretty short delivery timescales. The focus on reducing methane emissions is also putting massive pressure world to figure out a way to reduce methane emissions from livestock.

The problem goes a bit deeper than methane though. As a scientist with deep technical expertise in the carbon accounting and greenhouse gas emissions I frequently come across gross and unhelpful oversimplifications of the relationship between cows, sheep and climate change. The food system in the UK currently has deep and very significant flaws and I would recommend the "Mapping the UK Food Systems" report by Oxford for more information[62]. Ultimately eating a diet consistent with Public Health England's 'Eatwell Guide' would have massive environmental benefits in addition to all the health benefits promoted by the NHS.[63] Cows are not the problem but the way we rear, feed and treat cattle within the global food system has far reaching consequences. Seaweed offers an opportunity to begin to address these consequences, including but not limited to direct methane emissions, but it won't solve the very real and very serious wider issues of British diets. At the same time diet is not a magic bullet to addressing climate change because the main problem is carbon dioxide emissions from fossil fuel usage (don't shoot the messenger).

[61] Homepage | Global Methane Pledge
[62] Mapping the UK Food System – A Report for the UKRI Transforming UK Food Systems Programme
[63] The eatwell guide: A more sustainable diet | The Carbon Trust

Getting back to seaweed, the inclusion of seaweed in animal diets in an ancient practice and in the British Isles cattle and sheep have been known to eat seaweed for hundreds of years[64]. Seaweed on its own isn't an ideal diet for animals but seaweed contains soluble fibre, high-quality proteins and essential minerals that aren't found in high processed animal feeds. Because it is filling a clear dietary gap seaweed is known to have nutraceutical properties including prebiotic benefits. [65] The amino acid composition of seaweed also fills a biologic niche and improves the quality of meat, at least in cows, in a good way. I defer to Prof John Church[66] here but the research is published and it's something to do with fatty acid composition.

There is also a food security and climate angle to seaweed for animal feed in places like the UK which are heavily reliant on importing soy and maize as food supplements. The Uk is heavily reliant on imported maize and soy-based feed additives which have environmental and food security issues. Replacing even a fraction of these with more local and sustainable seaweed supplements would have benefits in the UK. Realistically we are only talking about a ~1% change when it comes to cattle diets, so it isn't a revolutionary change but it's a marginal change in the right direction of food security, animal welfare and environmental stewardship. It's also a change that promises to significantly alter the relationship between cows and climate.

Cows and sheep produce methane because their digestive systems work a bit different to the human gut. The methane is produced as the very final stage of digestion by bacteria, and it turns out these bacteria are susceptible to natural biochemical attack from seaweeds. In fact, feeding cattle natural raw seaweed reduces methane emissions from those cows more than any other known substance and there is plenty of evidence to suggest cows are none of the worse off. The biochemical arms race mentioned early is at play here whereby billions of years of evolutionary pressures have created an optimized natural solution that beats anything humans have so far tried to replicate. Unsurprisingly a huge amount of international attention is currently being focused on producing seaweed-based feed additives for methane suppression, but there is a problem.

Loads of seaweed species produces the essential halogenated compounds including the native UK red seaweed species already developed for commercial scale farming. However, to seaweed produces the compounds on demand in response to stress. It's an analogous to an immune systems response whereby the seaweed is only producing the anti-microbial compounds when it senses it is at high risk of infection. This means when seaweed is farmed under normal conditions is will contain very low concentrations of the key compounds and therefore not induce methane suppression in cows. A single genus of seaweed, *Asparagapsis*, has evolved a biologic trick which allows it to accumulate and store bromoform in specialist cells. This trick in incredibly useful if you are trying to produce seaweed for methane suppression and the industry has exclusively targeted Asparagapsis for further research and development.

Bantry Bay Marine Lab has already proven that it is possible to take wild UK *Asparagapsis* and turn it into a highly effective methane suppressing feed additive. This might be the future, but Asparagapsis hasn't been shown to have animal welfare benefits, it is not the easiest species to grow and has characteristics that are less than ideal for mass scale open ocean aquaculture. Asparagapsis ends up

[64] B Seaweed Products and Uses - Potential scale of Scottish seaweed-based industries: research paper - gov.scot
[65] Seaweed Potential in the Animal Feed: A Review
[66] Thompson Rivers University

in a direct arms race with the synthetic compound 3-NOP, sold commercially as Bovaer,[67] and there is an argument 3-NOP is just easier to implement.

It is worth acknowledging at this point that there is an animal and human health concern, which is being widely and significantly misrepresented, around the feeding seaweed to cows for methane suppression. There is a difference between poppy seeds and heroine even if both contain the opioids from the same plant. Whole seaweed falls in the poppy seed category, but it is possible to synthetically produce pure bromoform and other halogenate substances. Purified bromoform is associated with health risks and so due diligence is required before anyone is allowed to feed pure synthetic bromoform to cows or sheep. The further products move away from raw seaweed towards highly processed concentrates the higher the risk that negative impacts will arise.

This is also true from an ethical/animal welfare perspective at least based on the results of studies that have resorted to force feeding cows purified bromoform under highly controlled conditions. Not all raw seaweeds are highly palatable to cattle but from everyone I have talked to if you mix a bit of molasses with seaweed the cows will happily eat the mixture. Purified bromoform seems to a far less appetising prospect with studies reverting to forceful, and undoubtably stressful, dosing regimes. Ultimately if the feed process itself requires putting the animals under significant distress, then there is a problem from the start. Idiosyncratically you will see high controlled force-feeding studies cited as evidence against *Asparagapsis* when it appears the problem has nothing to do with seaweed and everything to do with the experimental protocols. A similar issue occurs where studies have monitored methane emissions from cattle using protocols that cattle will have found distressing. I am not an animal behavioural expert, but I have talked to the expert team at Newcastle University who designed their world class feed additive trial test system. There is no doubt in my mind you can develop, test and commercialize products maintaining without impact the welfare of cattle but I am not convinced all published international research has held itself to this high a standard. This means some care is needed when looking at 'evidence' presented in the media because not all studies are of equal quality. I do think it is worth emphasizing that facilities like Newcastle put animal welfare front and centre and feed additives are being developed in the UK in a way that do not cut corners.

Health trials on *Asparagapsis* continue and will continue but to date nothing worrying has turned up so far nor have negative effects been found for the synthetic 3-NOP compound that is working in a similar way. Along a similar vein the ability to integrate seaweed and/or 3-NOP within cattle diets in a way that does not induce animal stress is a real benefit for these substances.

A different problem is there is worrying large amount of misinformation circulating the media that growing seaweed will cause a hole in the ozone. What is true is the reactive bromine species can deplete the ozone layer and industrial activity is leading to high emissions of these reactive species. It is technically difficult for monitoring sites to identify industrial sources of reactive bromine from the naturally occurring halogenated compounds marine organisms which becomes a problem if you are trying to figure out the absolute scale of the industrial problem. As a result, scientist needed to sort out the details of natural emissions and ozone leading to very legitimate peer review publications that covered seaweed production of bromoform, global seaweed aquaculture and ozone depletion. If you read the papers, you will see it is firmly established seaweed is not depleting the ozone nor does increasing aquaculture have the potential to significantly impact the ozone. The problem is industrial production we just had to be 100% sure before pointing the finger.

[67] Bovaer cow feed additive explained – Food Standards Agency

Stepping back from the science the bigger issue is the over reliance on Asaragapsis. Dulse is already widely used in animal fodder and is a traditional human stuff in Ireland and across the UK. An article on the UK governments claims it tastes like bacon[68]. That hasn't been my experience, but I use dulse in a dried and powered form as a seasoning, and it works great. It is claimed to be a powerful prebiotic and is certainly marketed as such[69]. We have also started down the road of understanding how to make it express halogenate compounds[70]. I don't see any reason the future of UK agriculture could not include a domestically produced dulse-based feed additive that is good for cow, good for farmer, good for the UK farming sector and is also good for climate. For the sake of the title of my Churchill Fellowship it would be great if laver a.k.a. *Porphyra umbilicalis* a.k.a. Nori won the race to be the first super additive. Laver is already cultivated for food production and has the right biochemistry for methane suppression although I am not aware of anyone actively working to on methane suppressing feed additives based on laver.

[68] Emerging from the 'innovation valley of death': Opportunities and challenges for the seaweed industry in the UK and Europe. – Marine Science

[69] Acadian SeaPlus Unveils Cultivated Dulse for Health Products

[70] Assessment of hydrogen peroxide as a bioindicator of stress in seaweed aquaculture | Scientific Reports