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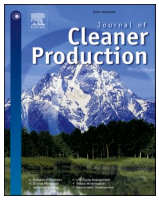

# Enabling factors and critical extensions for the algal-based bioplastics industry

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ABSTRACT

Emerging industries and technologies are made up of objective, practical requirements and ideas that encompass broad hopes for what future newness might enable. The bioeconomy is one such emerging industry. Its recent evolution has involved a complicated and dynamic mix of promises, reality checks and subsequent ambivalences. This article frames and investigates the emerging algae-based bioplastics industry as one niche within this broader system envisaged for social, technological, economic, political and ecological change. As such, our paper presents two categories of knowledge that in practice interrelate: 1) specific and practical recommendations that can assist a future algal-based bioplastics industry to develop in Australia in ways that are conscious of socio-ecological and socio-cultural dimensions, and 2) critical extensions that go beyond the attributes of newness, impact, suddenness and universality often emphasised in both popular and scientific research into emerging green technologies. In particular, our analysis highlights the importance of specific temporal, tonal and spatial factors when framing the contextual factors associated emerging industries, technologies and the different pathways for change they might help support.

## 1. Introduction

### 1.1. Algae, bioplastics and the bioeconomy

Hopes for the bioeconomy have expanded well beyond the economic and technological to encompass a broad range of social and environmental problems. In Australia the almost totemic quality exhibited by the banal utopian mantra of 'jobs and growth' has unsurprisingly shaped the way the bioeconomy is starting to be framed (see: Australia's Bioenergy Roadmap, 2021). As Wreford et al. (2019) highlight, the idea of the bioeconomy over the last two decades has been subject to a phased broadening of the transformative potentials rhetorically associated with and imagined of this supposedly new socio-technological-economic model. While different visions and agendas have been present in the pursuit of a bioeconomy globally (Bugge et al., 2019; Staffas et al., 2013), Wreford et al. (2019) names "three harmonising elements that can be identified across the literature" to define what a 'bioeconomy' entails: "the sustainable use of natural (biomass) resource and a reduction in waste and pollutants; coupled with a transitioning away from dependence on fossil fuel resources; to achieve economic and social growth, and employment" (185). As evident in the cascading clauses of this tripartite definition, the bioeconomy is now an explicitly technological, environmental and social idea.[1]

The extent to which the bioeconomy will in practice and actuality be

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[1] The use of the term 'social idea' or 'idea' here and throughout this paper follows the work of Hacking (1999) who uses the term as shorthand to help highlight the extent to which certain classifications are not straightforward and inevitable. Hacking analyses the extent to which certain phenomena are socially constructed, without taking the route of relativism: it makes sense to say the *idea* of a 'women refugee' can be said to be socially constructed, but less sense to refer "directly to individual women refugees" as socially constructed—to use just one of Hacking's many examples (1999, 11). Perhaps a simple point, but useful for orienting the storms and confusion that surround the science wars. Hacking stipulates: "I do not mean anything curiously mental by 'idea.' Ideas (as we ordinarily use the word) are usually out there in public. They can be proposed, criticized, entertained, rejected. Ideas do not exist in a vacuum. They inhabit a social setting" (1999, 10). In this context, referring to the social idea of the bioeconomy centres the discussion on complicated and contingent nature of ideas associated with emerging technologies and industries, which are often vaguely defined but used in a way such that the meaning and the sphere of reference is taken for granted. 'Idea' has the further advantage of being so commonplace that it avoids any unnecessary conceptual abstraction. It has the disadvantage of being somewhat imprecise.

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any more than an alternative resource base to the fossil fuel economy at this point however remains to be seen. Researchers have questioned whether the bioeconomic visions for world-shaping transformations are supported by the necessary imaginative and practical work envisioning accompanying transformations in business models, social support, infrastructures, logistics, practices of consumption, and community building (Eversberg et al., 2023a, 2023b; Ginsberg and Chieza, 2018). Others see the dominant bioeconomy discourse as further entrenching an extractive, cornucopian resource imaginary associated with neoliberalism, which comes at the expense of collective knowledge gains through farmer networks (Birch et al., 2010). No doubt many shades of grey and binary-breaking hybrids exist in-between imaginaries associated with the extractive, at one extreme, and the ecological, at the other extreme. In any case, what is apparent is that questions about the relationship between idea and actuality have grown more important as the aspirations of the bioeconomy have grown both more ambitious and more fuzzy-edged.

Algae has been a key focus of research and investment within the broader vision for bioeconomic change. Initially, the potentials of algae as one of several bio-based alternatives to fossil fuels offered a long, and what some researchers now suggest, false promise (Biello, 2011). The absence of significant continued government incentives has been highlighted as one key contributing factor to algae-based biofuels failing to take hold (Wydra et al., 2021). Biofuels more broadly have also faced ongoing challenges in achieving the scale and production efficiencies to be commercially competitive with fossil fuels (Araújo et al., 2021; Wydra et al., 2021), and have so far offered limited environmental benefits (Onen Cinar et al., 2020). Prospects for algae production have now shifted to higher-value, lower volume products, such as pharmaceuticals, food, cosmetics and bioplastics (Filote 2020).

The enduring interest in algae as a bio-based resource in significant part comes from how efficiently algae captures atmospheric carbon when compared to other photosynthetic organisms (Ralph and Pernice, 2023). Furthermore, as discussed in this article, algae offers potentials for wastewater remediation in particular contexts, thereby creating an authentically circular system that works on multiple levels.

The Seaweed Manifesto (Safe Seaweed Coalition, 2020) is an example of the hopes being articulated for the algae industry within the broader bioeconomy. Beyond quantitative greenhouse gas (GHG) reduction at the global scale, these aspirations include: regenerative engagements with local habitats, the creation of socio-economic opportunities for poor communities, supporting nutrition and health outcomes, and poverty reduction. Prominent seaweed advocates, such as GreenWave in the US (2022; Smith, 2019), argue the need for conscientious design of the algae industry to maximise the potential social and environmental benefits; their vision is one that favours a system of small-holder producers practicing multi-species aquaculture rather than traditional industrial models of large and efficient monocultures.

Of the higher-value algae-based product streams, bioplastics[2] potentially has the most significant implications for the circular economy[3]—a related though distinct concept to the bioeconomy— due to the linearity of much of the plastics economy, and the adverse environmental and health impacts associated with the production, use and disposal of conventional, fossil fuel derived plastics. As noted by Ralph and Pernice (2023) "carbon capture and manufacture (CCM)" can create more economic value than the related carbon capture and storage (CCS) through value-added products and algae-based bioplastics, which represent a potentially significant income stream as part of this new manufacturing model. Longer lasting, durable CCM products in this sense offer more benefit than bio-based products that are single use or that have a relatively short life-span.

This transformative agenda has sparked the interest of product designers worldwide, who are exploring the feasibility and desirability of algae-based bioplastics in a range of products and through a range of manufacturing processes (Camere and Karana, 2018). As with the case of the bioeconomy broadly, however, it is important to keep a keen eye on the nature of the desires and ideas associated with a bioplastics industry, and how these relate to complex and diverse actualities.

### 1.2. *The bioeconomy, algae-based bioplastics industry and transitions planning research*

The bioeconomy has been the source of significant interest worldwide from the perspective of scenario planning and transition pathways research (Bayne et al., 2021; Delzeit et al., 2021; Hausknost, 2017; Lokesh et al., 2018; Priefer et al., 2017; Staffas et al., 2013; Wreford et al., 2019; Wydra et al., 2021). Different approaches in this field range from research drawing on Geels' (2002) multi-level perspective (MLP) (Wydra et al., 2021), story and simulation approaches (SAS) (Delziet 2021), quadrant analysis (Hausknost 2017), and Theory of Change (ToC) frameworks (Staffas et al., 2013). While distinct in detail, scenario and transitions research centred on the bioeconomy broadly converges on an array of key factors that experts argue will shape the future bioindustry, including: fluctuations in global oil prices, technological and scientific developments, and climate change related policies and principles, particularly those aimed to support circular economies.

The present article makes a further contribution to existing qualitative scenario planning and transitions pathways research in the broader bioeconomy through particular attention to the niche of an algae-based bioplastics industry. Research into a future algae-based bioplastics industry is presented as combination of key enabling factors for socio-technological transitions, and a series of critical extensions intended

[2] Bioplastics remains a vague and contested term. According to Dominish et al. (2023): "Bioplastics is a broad term that includes both bio-based and biodegradable plastics. Bio-based plastics are derived from plant-based feedstocks or other biomass, such as corn, sugarcane and algae. Biodegradable refers to the ability of a plastic to break down by micro-organisms into elements found purely in nature, but does not specify the timeframe. Compostable plastics are a subset of biodegradable plastics that break down in a composting system within a relatively short timeframe … Some bio-based plastics are biodegradable or compostable and some are chemically identical to recyclable conventional plastics. Biodegradable and compostable plastics can be either bio-based or fossil-based, or a mix." In this paper we are primarily referring to bio-based plastics.

[3] According to the Ellen Mcarthur Foundation:The circular economy is based on three principles, driven by design: 1. Eliminate waste and pollution, 2. Circulate products and materials (at their highest value), 3. Regenerate nature, and is "… underpinned by a transition to renewable energy and materials. A circular economy decouples economic activity from the consumption of finite resources. It is a resilient system that is good for business, people and the environment." (Ellen McArthur Foundation, 2022).

to provoke reflection on the various contexts and rhetorical framings relevant to such a transition. The focus on a particular place—regional Australia, and the state of New South Wales (NSW)—allows for a more tangible and specific contextual account. Our selection of this context does not, however, suggest it has been identified as the most probable or profitable location for the industry to be centred, but one where interesting interactions and questions are beginning to emerge. The critical extensions are intended to retain the shadow of practicality and specificity while the analysis opens up to considerations of the ambivalent, ambiguous, mixed and modest realities that are often neglected when future promises adopt the amplified rhetoric of uniform, rapid, and large-scale change (dslb). The particular bodies of literature from which we draw in order to expand critical considerations include: the history of technology (Edgerton, 2008), sociology and philosophy of life sciences (Calvert and Schyfter, 2017; Hacking, 1999) and the geography of sustainable transitions (Murphy, 2015; Sengers and Raven, 2015; Coenen and Truffer, 2012).

The intent of this research is broadly congruent with scenario and transitions pathways approaches such as those of Wydra et al. (2021) and Bayne et al. (2021), that offer a structured analysis of both the practical and hypothetical or visionary dimensions of the bioeconomy, with aim of supporting strategic decision-making about given alternatives that might otherwise have remained inexplicit. In the case of the present research, the practical dimensions are limited to algae-based bioplastics, and the hypothetical dimensions are framed as an expanded series of conceptual domains intended to provoke reflection on the important role played by the dynamics of ideas and the specificity of context (i.e. the specific cultural, political, economic and geographic dimensions of a specific place) in shaping future industries. Rather than a formalised qualitative scenario methodology, or a singular theoretical framework associated with socio-technical change, the research is presented as the illustrative analysis of a particular emerging bioeconomic industry within a particular regional context and a series of related theoretical and disciplinary meeting points.

The article is structured as follows: the next section outlines the characteristics of the broader research team, the approach, and the different methods used in this study. The following section is divided into two sub-sections, 3.1 presents the key enabling factors for an emerging bioplastics industry in regional NSW. Subsection 3.2 then offers two critical extensions broadly associated with the temporal and spatial dimensions of emerging technologies and associated industries. The concluding section recapitulates the key focuses, aims and gives an impression of how the findings might be applied and advanced in further research.

## 2. Approach and methodology

### 2.1. Transdisciplinary problems and multidisciplinary integration

Transitions to sustainable future industries involve a diversity of knowledges, capabilities and values. Disciplinary knowledges need to be integrated at multiple, strategically identified points in order to best innovate towards and manage such transitions. Academic disciplines are in part defined by the trained emphasis on and setting aside of certain questions and ways of finding out. As such, when describing emerging industries and economies, disciplines working in isolation will face greater challenges de-risking and adequately accounting for broader system complexities. For example, science and design projects with a disciplinary focus on material characteristics and product potentials can also be guided by sustainability and systems knowledge that informs circular economy principles and metrics. Likewise, projects focused on systemic concerns associated with sustainable production and consumption will benefit from understanding the way people interact with and attach specific meanings to things—a kind of knowledge acquired through design research (D'Olivo and Karana, 2021; Scardifield et al., 2023). New ideas will be less likely to hold unless they are rooted in practical, material realities and attendant to the challenges and paradoxes of ordinary experience.

While this paper primarily presents qualitative research, the assumptions, aims and scope of the work has received formative guidance throughout by technical expertise internal to the broader research team, including expertise in biopolymer science, marine biology and product design prototyping. The multidisciplinary composition of our team has enabled systematic sense-checking across disciplinary divides, early-stage alignment regarding quantitative and qualitative knowledges, and attention to phenomena with agency at a broad range of scales, from algal bioplastics experimentation in the science lab and design studio, to the consideration of visions for transformations in regional industries.

### 2.2. Regional focus

Regional NSW was selected as the focus of analysis to explore emerging and potential dynamics between relevant factors involved in the development of an algae-based bioplastics industry. Initial scoping research suggested that NSW has a number of regions that have indicated they could benefit from this type of initiative based on waste outputs produced, geographic criteria such as climate, and the expression of community and business interest in comparable sustainable industry being developed. Other settings with the required biophysical, economic and social characteristics could have been selected. The aim of our research was, however, to highlight enablers and critical ambiguities for a particular, promsing, indicative example, rather than conduct an exhaustive comparision. The single example of NSW allowed us to do this in greater detail.

### 2.3. Methods

We used a mixed-methods approach to research. The way these methods have been used in our research is briefly elaborated below.

#### 2.3.1. Desktop review

We undertook a targeted review of case studies and literature relating to the industrial and technical context to help identify and compare alternative options regarding the characteristics of a potential bioplastic production hub in regional NSW. We started with a high-level desktop survey of major themes (algal biotechnology, manufacturing and organisational models relevant to the context of the project) which deepened through iterative discussions within the scoping study group and the larger project team. Emergent focus areas included: algal production and wastewater treatment requirements; business models that might enable innovation and benefits to circulate through the local stakeholders and socio-technical and ecological systems in regional NSW; and exploring the potential and likely material characteristics of algae bioplastics grown from wastewater feedstocks. While we explored global literature on algae-centred design innovations, we focused the literature search relating to economic limitations, policy, and organisational models to Australian examples and drew heavily from recent research on the future bioeconomy in New Zealand, an economy that bears many similarities with Australia regarding its reliance on the primary sector, underdeveloped manufacturing and the lack of a comprehensive national bioeconomy strategy.

#### 2.3.2. Semi-structured interviews

Nine interviews were conducted from September to November 2021 with experts working in areas relevant to the technical, organisational and ecological areas of interest that emerged through the literature review and discussions with the project team. Participants were identified through the literature review, as well as in consultation with colleagues already researching on bioeconomies at our university. Their expertise included organisational development and policy in the regions, algae technology, microbial ecology, wastewater operations and the agribusiness sector. The interviews were conducted online and recorded

with participant permission. The research insights identified through the interviewing process were synthesised in combination with contextual research, schematised as part of a scenario visualisation process, grouped into key themes, and refined further into specific details relating to location, infrastructure, and policy-specific factors.

#### 2.3.3. Research synthesis: enabling factors and critical extensions

The research synthesis presented in this article shares in the broad ambitions of qualitative scenario and technological pathways research regarding the integration of explicit, meaningful information aligned to an area of focus, with different conceptualisations of uncertainty (Crawford, 2019). The enabling factors outlined in Section 3 of this investigation focus on an adaptive strategy to navigate dynamic uncertainty that is broadly aligned to a local/national context of a future algal bioplastics hub in regional NSW, while Section 4 highlights structural uncertainties that are arguably more difficult to resolve and to some degree inherent to any emerging industry or technology. The research does not provide an evaluation of specific place-based regional attributes at this point, nor does it offer in-depth exploration of important but ultimately uncontrollable factors—also known as 'critical uncertainties' or 'known unknowns' (Crawford 2019)—such as the broader political environment, oil price volatility and so on. The scenario context for the enabling factors is a snapshot in time in an assumed growth-oriented transition pathway informed by a synthesis of trends, identified through the literature reviews and interviews with subject matter experts. The research does not in this sense focus on the "disruptions, surprises, or difficult possibilities" associated with "peripheral" or "extreme" scenarios (Crawford, 2019; Ducot and Lubben, 1980). The critical extensions in Section 4 do however aim to open up the scope for exploratory thinking and push the research insights beyond existing mental models, two drawbacks associated with an exclusive focus on trends and plausibility (Wright and Cairns, 2011).

## 3. Key findings and discussion

### 3.1. Enabling factors for an emerging bioplastics industry

This section highlights key enabling factors identified as holding the most important scope for influence and which present opportunities for investment and further action in a regionally led, algae-based bioplastic industry. These were identified through an iterative process focused on (i) identifying existing systems and (potentially) connected systems that might relate to a future algae bioplastics industry in regional NSW, and (ii) discussing alternative organisational configurations, their role in system intervention and their relationship to different aspirations for change. Considerations included partner and stakeholder selection; how algae might be grown and what social, ecological and economic functions this might serve; how the produced bioplastics might coincide with other technological trends in bioplastics and manufacturing; and specific socio-ecological contexts and production constraints where the hub might feasibly be located. We iteratively progressed the development and identification of alternatives, prioritising options that had the most promising leverage points to accelerate an emerging industry towards viability.

The conceptual, analytical and communicative aspects of the enabling factors are focused on plausibility and immediate legibility across disciplines and for different stakeholders. The transition pathways described present a snapshot in time in an assumed growth-oriented transition pathway that synthesise trends identified through the literature reviews and interviews with subject matter expects, rather than the "disruptions, surprises, or difficult possibilities" associated with "peripheral" or "extreme" scenarios (Crawford, 2019; Ducot and Lubben, 1980). We note that a focus on trends and plausibility can "limit the scope of exploratory thinking and/or (2) serve as a feedback loop for existing mental models" (Wright and Cairns, 2011), and that future work, once credibility has been established, might employ more speculative and extreme scenario planning approaches.

#### 3.1.1. Site location and characteristics

Site location and characteristics will significantly influence the extent to which algae-based bioplastics are a viable, feasible and desirable option for biomass generation from wastewater treatment. Important site characteristics we identify include: existing regional industry and economic landscape and its relationship with community values; climactic and geographic conditions, particularly rainfall; existing wastewater characteristics and processing infrastructure; and the capacity to adequately measure, monitor and evaluate key variables at a regional level. Comparative and evaluative research into the specific benefits and drawbacks of different sites regarding circular economy principles and community benefits is crucial in future research.

#### 3.1.2. Algae types and technology

The bulk of research into algae as a wastewater treatment technology in Australia has been focused on microalgae. There is a niche of expertise into macroalgae research as a wastewater treatment option at the Centre for Macroalgal Resources and Biotechnology (MACRO) at James Cook University (Ellison et al., 2014; Cole et al., 2016) and some research into combinations of micro and macro as a wastewater treatment option, with inconclusive results (Vadiveloo et al. 2019). We suggest there is significant scope for future site-specific research into macroalgae production systems for a circular bioplastics economy in the regions, whether using farm, manufacturing or community wastewaters. Associated research into algae pond and wastewater management technology and operations might include investigating configurations of micro and macro algae in High-Rate Algal Ponds and open-air systems in the treatment of different wastewater sources.

#### 3.1.3. Stakeholders, their values and the role of research and development

Important research remains to be done on comparing and evaluating business models, governance structures and values of stakeholders against criteria for regional development. Our process identified that the scope given to research and development within organisational structures and in accordance with stakeholder values and commitments is an important feature that ought to be represented in any criteria for system interventions seeking transformative change and normative outcomes. Different benefits will flow to different stakeholders and innovation will take different forms depending on the values and capability of the organisations that share in leading change.

#### 3.1.4. Plastics needs, product potentials and circular economy principles

The existing and unmet plastic needs and end-of-life processing infrastructure within a given community, and how needs and bioplastic products map onto circular economy principles is a crucial consideration that will demand future research. This might include product-related and partner-selection criteria to help determine whether any algae-based products proposed can contribute to a circular economy based on their impacts at end-of-life. There is a risk that a switch to bioplastics for single-use plastic products may legitimise their continued use, and preclude innovation and adoption of 'higher order' replacements that promote dematerialisation and reuse. In addition, factors such as current processing systems and infrastructure for waste, and the types of product use and disposal practices they encourage would be expected to inform such a criteria. For example, large-scale composting infrastructure and education will be required if compostable plastics are to represent a sustainable alternative to fossil fuel based ones. Designing the system within which new materials products are stewarded through their life has been further highlighted in a recent report investigating the market and sustainability potential for algal bioplastics in Australia (Berry et al., 2022).

#### 3.1.5. Policy, funding and supporting cross-sector innovation

Policy and funding measures enacted by different levels of

government and different hybridised private and public models will play a significant role in whether algae-based bioplastics are a viable alternative to traditional plastics in the future bioeconomy. Policy measures that we identified as useful to supporting regional NSW through algae bioplastics might include: the design and implementation of circular economy principles; wastewater nutrient and contaminant targets; climate protection policies and certification programs. Incentives and governance models ought to be designed with the right amount of detail and openness to ensure credibility, broad engagement and support long term outcomes for less well-off, innovative and sustainable businesses and research partnerships.

#### 3.1.6. *Designing transitions*

Environmental and social outcomes need to be carefully designed as much as technological solutions and new consumer products. Barrett et al. (2022) use the concept of "socio-technical bundles" to highlight the necessity for a variety of systematically aligned actors to be engaged in change processes. Research approaches designed to represent and empower local communities in knowledge creation is a crucial part of this process. Genuine co-design is increasingly advocated in calls for socio-technical change in the regions (Barrett et al., 2022; Whitehead et al., 2019) and across broad fields in sustainability science (Fazey et al., 2020; Caniglia et al., 2023). The capacity to meaningfully represent otherwise intangible, complex or difficult to imagine alternatives in a multi-phased research process is in this sense a valuable part of doing justice to human agency and multiplying positive outcomes that emerge from the meeting of different forms of expertise.

[Figs. 1 and 2 caption: Visualisation workshops produced three alternative systems that might be configured from these factors (Fig. 1) and a speculative map of potential stakeholders important to future pilot projects for a bioplastics hub (Fig. 2). Whilst primarily a tool for sense-making within the team, they also serve as a basis for recording insights and communicating opportunities, priorities, and uncertainties in future stages of the project. ].

### 3.2. *Critical extensions: ambiguities, ambivalences and intricacies*

The former section presented a series of key enablers for the success of an algae-based bioplastics industry. Bracketed out from such framings are ambiguities, ambivalences and intricacies that emerge when the bioeconomy is considered as a 'social idea' (Hacking, 1999), or as series of 'promises' (Eversberg 2022; Hilgartner, 2007; Petersen and Krisjansen, 2015; Giampietro, 2019). This section outlines a series of critical extensions that might be used to help make explicit certain background assumptions regarding the temporal, tonal, psycho-spatial and organisational dimensions of socio-technical change associated with the emerging algae-based bioplastics industry. These critical extensions might be described as 'noise' in the signal of an emerging technology encountered when stepping away to broaden the focus, or moving so close that the focus blurs.

#### 3.2.1. *Ambivalences, ambiguities and accretions: the temporal and tonal dimensions of emerging technology*

In the Australian context specifically and the global context more broadly, algal biotechnology is often reflexively associated with "ill-conceived promotion" (Wreford 2019), "the false promise" (Biello, 2011) and "the eternal promise" (Luque, 2010) of biofuels. Negative sentiments, of differing degrees of force, were shared by several of our interviewees about this historical aspect of algae biotechnology. One interviewee noted, *"the algae thing has been going on out here for a while"* and another reaffirmed that *"algae has gone by the wayside in bioenergy in Australia"*. For one interviewee the ambivalent sentiments about algae generally as the driver of innovation in their region was in part shaped by a previous champion for algal biotechnology who was something of an "eccentric" and struggled to engage people, despite being highly intelligent. Technologies, particularly in their emergent or ambiguous states, are given meaning by the different actors engaged in the process of prospective worldbuilding. This is a world of efficacy and evidence, but also a world of character and tone.

The emerging technologies have become a focus of scholarly work and the popular media since the late 1990s (Rotolo et al., 2015). They are defined by Rotolo et al. (2015) as possessing five key attributes: radical novelty, fast growth, coherence, prominent impact, and uncertainty or ambiguity. Different aspects of these attributes are emphasised in different contexts. It is common to hear far more about radical novelty, fast growth, coherence and prominent impact than ambiguity or uncertainty when an emerging technology is being reported in the popular press. Ambiguous, yet to be stabilised forms of emerging technologies are open to the projections of different, sometimes vaguely utopian imaginaries—an effect likened to Rorschach inkblots apropos the seemingly limitless fantasies of Industry 4.0 (Seprea 2021). For example, the *Scientific American* 'Top 10 Emerging Technologies Of 2019', describes each technology (bioplastics, social robots, tiny lenses, cancer targeting proteins, smart fertilisers, collaborative telepresence, food and package tracking systems, safer nuclear reactors, DNA data storage, and utility scale energy storage) in positive terms, using declarative rhetoric that implies imminent, laudable and "world changing" arrivals (Spera 2019).

This is often no less true of scientific research. Highly competitive research environments and a sense of belatedness concerning action in policy and public awareness often compels scientists to use rhetoric that frames change as needing to take place quickly, uniformly and at scale: "Save the planet with green industries using algae" (Ralph and Pernice, 2023). Lee and George (2023) describe the tension between the technical specificity of scientific experimentation and the often ambiguous, though ambitious and often misleadingly straightforward imaginings of broader world-shaping potential as a 'promises paradox' whereby scientists are "on the one hand required and trained to promise relevance, novelty, and broad social or environmental benefit based on the potential of their work, and on the other hand, given little scope within traditional scientific methodologies to spend time exploring the complexity of the future worlds their work promises to shape" (3). One might also argue that humanities research with similarly aspirational agendas for change are equally guilty of swiftly confected, convenient imaginings of the needs, desires and limitations of particular contexts where such agendas are supposed to take root.

Scientific and technological visions for future progress tend not to explicitly emphasise the differing affective or tonal dimensions of

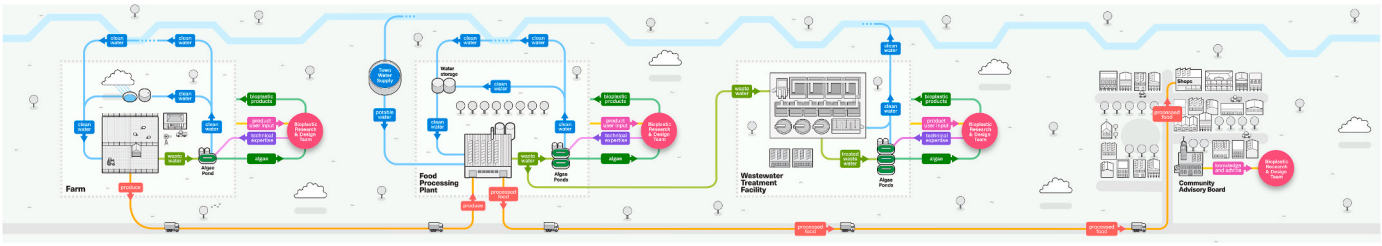


**Fig. 1.** Visualisations of alternative models to deliver a viable algal bioplastics hub in regional NSW (Visual designs: Chris Gaul, Parallel Lines Design)

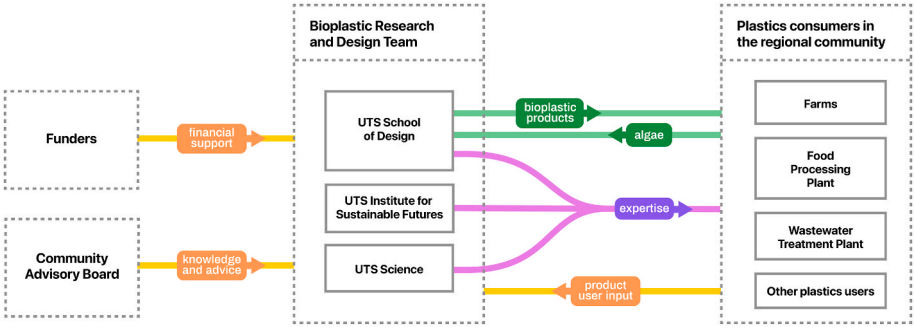


**Fig. 2.** Potential stakeholders and their relationships to govern a future hub (Visual designs, Chris Gaul, Parallel Lines Design)

research propositions, nor the accretion and variation in the sentiments directed towards technologies in their emergent states over time. Even in the now established research area associated with 'sociotechnical imaginaries' literature (Jasanoff and Kim, 2009) 'the imaginary' tends to be framed primarily as a realm of contest and potential, rather than jostling of dreams shaded by different dimensions of tone and feeling. Nonetheless, in the case of many emerging technologies, like algae-based bioplastics, there is an affective economy of hope in tension with histories of false promises, mild decline, partial successes, persistent ambiguities and nuanced ambivalences. This results in peculiar and intricate patterns of positive and negative emotion, the intensity and purity of which grow more complex the more an emergent state is prolonged. Understanding the particular consistency and dynamics of these affective and tonal histories is particularly important in a world where false or variously misleading narratives are an increasing problem with regard to green agendas.

Radical novelty might suggest coming from nowhere. But this gives the wrong impression. When investigated more closely, even seemingly unprecedented technological developments bear the shades of a journey from someplace, to someplace. Historians of technology such as Edgerton (2008) have in this sense sought to challenge a dominant focus on innovation in academic historical and popular conceptions of technology, and instead argued for a focus on 'creolisation', 'technology in use', the slow exit of older technologies, and the similarly slow, sometimes infinitely drawn-out promise of the new (Edgerton, 2008).

The uncertainty, ambiguity and ambivalences associated with technological change conventionally might not be considered attributes conducive to promoting emerging technologies. Based on our interviews there was, however, a clear indication that modulating tonal and rhetorical approaches through humility, reticence, and the expression of mixed feelings might nonetheless contribute to building a more resilient and trusting investment landscape—particularly when considering audience segments and decision-making environments at a greater level of granularity. Exclusive or dominant emphasis on attributes such as radical novelty, fast growth, coherence, and prominent impact can have detrimental effects on directly and indirectly related emerging technologies. The promise of future success helps scientists "gain scientific, social and political commitment, investment and capital" (Calvert and Schyfter, 2017, 360). Unmet promises regarding future success are, however, also influential. In this sense, strategies for communication and conceptualisation attuned to the context specific factors shaping public sentiment towards emerging technologies is important, both for the ambitions and accountability of those advocating emerging technologies. Similarly, visioning work associated with understanding the broader social and cultural implications of the emerging technologies can benefit from greater attunement to the differing tonal registers in which newness can be wrought and the potential openness of those registers to distinctive or unconventional local shaping.

### 3.2.2. *Spatial and organizational granularity*

Our research suggests that attention to specific relationships between regions and organisations is a crucial part of understanding the form, pace and meaning of socio-technical change—in addition to national and international factors that are more commonly discussed in qualitative scenario work focused on the bioeconomy (Wydra et al., 2021). Local champions and 'cranks', biophysical and bio-psycho-physical features, and the different way different organisational models configure stakeholder relationships across space, all contribute to the distinctive qualities of particular regions and give form to socio-technical change. As Truffer and Coenen highlight, socio-technical systems and transformations are not "footloose cognitive and institutional structures that influence actors largely irrespective of their geographical location" (2012, 6), rather, they are contingent phenomena with differing chances for success, and different qualitative and functional dimensions depending on the particularities of places.

The view that emerged through our interviews was of NSW as a state characterised by dispersed pockets or clusters of innovation enabled by a small number of larger organisations and catalysing efforts of state government to form innovation clusters. While different levels of government (Federal, State and Local) were seen to play a key role in supporting (rather than leading) innovation, the (now former) NSW State Government, under Premiers Gladys Berejiklian, Dominic Perrottet and Treasurer Matt Kean, was highlighted by multiple interviewees as the driving force of innovation in the regions. By and large, government funding schemes were seen as proscriptive and typically suited to organisations that have a well-defined and recognisable purpose, as opposed to organisations that might offer a genuine, innovative proposition. Local government was seen primarily as risk-averse, particularly smaller local councils, despite being important and often crucial stakeholders to have on side for access to resources, such as land and water. The (now former) Federal, Morrison Government was seen as unreliable and unpredictable, though in some instances offered crucial support for small businesses with a community orientation aiming to foster sustainable transitions.

This summary gives an account of regional innovation across NSW at a higher level based on our interview data. Looking more closely at regions within the state, however, highlights the ways in which innovation is constrained or enabled for different actors based on highly localised spatial and organisational configurations.

Geographic features shape particular regions in ways that cut across the imaginary, the infrastructural and the economic. Any effort to accurately describe a location according only to its physical features will be adequate only within a highly constrained realm of abstraction. For example, sometimes biophysical factors can drive a sense of connectedness even among diverse regional identities. One interviewee mentioned the high levels of cohesion evident in their region, even though the region was diverse in terms of economic activity. This was in significant part due to biophysical factors—such as valleys, mountain ranges, and coastal fringes—and the related psychological sense of the geomorphological features and existing infrastructure—such as roads—bounding and connecting the diverse social and economic activity in the region. By contrast, other interviewees pointed to the limited

possibilities for innovation in their region on account of "thinly spread" economic activity, lack of large business entities, and a lack of regional identity concerning locally-led innovation at scale.

Our research found that established, larger-scale businesses, with significant amounts of social capital, were typically far less constrained by often rigid emphasises of government funding schemes. Large businesses with endogenous, long-term, well-maintained local connections are able both to draw support from a diverse range of key local stakeholders and resources beyond the limitations of geography, with larger businesses often being networked across state and sometimes beyond national boundaries. Organisations of this type have the possibility of genuinely aligning different "place-frames" (Martin, 2003; Murphy, 2015), or visions of what a region can be; maintaining traditional local, cultural values, while innovating beyond these and achieving wider regional synchronisation.

By contrast, smaller, potentially more innovative organisations with shorter-term local connections need to work across different local stakeholder groups to establish trust, which can be particularly challenging with a smaller workforce. These challenges are further exacerbated if the form and purpose of that organisation isn't immediately legible to outside sources of social capital, such as government funding.

Different organisational models can be used to build trust, create or draw on a cohesive sense of local identity, and to deliver sustained benefits back into a given region. Cooperatives and unformalised cooperative-type organisations can attain scale through the multiplication of connections, while retaining local ties and trust through genuine stakeholder engagement and participation. Cooperatives and Mutual Enterprises (CMEs) have a history of creating organisational models that can enable better outcomes from economic growth for regional and rural communities in Australia (Business Council of Co-operatives and Mutuals and Mutuo, 2020). Examples in regional agriculture and manufacturing relevant to the focus of our research include the regional network of cooperatives in the Northern Rivers, which includes Norco (dairy), the Northern Cooperative Meat Company, Summerland Credit Union, NSW Sugar Milling Cooperative, and the Clarence River and Ballina Fishermen's cooperatives, demonstrating a thriving industrial system under formalised CME structures. The broader story of coops in Australia suggests that success is, however, is not guaranteed. Coop models are subject to the contingencies of a given region based on the particularity of natural and cultural interrelationships.

Organisational models also have cultural influences in ways that aren't necessarily formalised in business structures. For example, Bega Cheese, located on the South Coast of NSW, has a long history as a cooperative though is now ASX listed, in keeping with a broader, global trend of demutualisation (Patmore et al., 2021). However, Bega remains active in the community and is structurally influenced by local farmers due to historical context of its ownership and the continuity of local individuals in positions of power. The long-running history of Bega Cheese in the Bega Valley, its comparative large scale in the regional context, make it a distinctive example of an organisation with deep local and far-reaching global networks.

Other relevant models encountered in our research include private enterprise and not-for-profit hybrids, industrial symbiosis approaches that de-silo agricultural and manufacturing industries, and social enterprise models. Industrial symbiosis projects with multiple interfaces between different parties exchanging materials and services for a competitive advantage has theoretical and practical precedence from Australia and beyond, providing a further model to support long-term innovation in sustainable production (Li et al., 2021; Wreford et al., 2019). Clean Cowra is a relatively recent example of a community-centred organisation of this type, using an unformalised cooperative model informed by industrial symbiosis principles to aggregate local biomass from agriculture and local industry to generate decentralised sources of energy. Unlike Bega Cheese, which emerged from and continues to a significant extent to be led by agricultural businesses, Clean Cowra has emerged from outside the local agricultural industry. While cooperatives are common in the Australian agriculture, in the New Zealand context, Wreford et al. (2019) refers to the example of Industrial Symbiosis Kawerau (ISK) an Incorporated Society whose members "are organisations located, operating and employing in Kawerau who are invested in the future of the district." ISK facilitates opportunities and offers knowledge-sharing and support services across the themes of industry, environment and workforce.

The question of how locality, scale and regional identity maps onto different organisational models in settler colonial nations such as Australia is far from straightforward. Organisations that might have a long history of supporting communities since white settlement, aren't necessarily viewed as benevolent, traditional or local when viewed through prism of Indigenous custodianship which extends across tens of thousands of years. Indeed, meaningful representation from and outcomes for Traditional Owners might be argued to be no more or less guaranteed from regionally, nationally or internationally driven agendas for socio-technical change in this sense.

Wider government strategies at different scales in this sense have an important role to play in shaping the extent to which Indigenous communities are engaged in local decision-making process about places. Wreford et al. (2019) refers to the South African Indigenous Knowledge-Based Technologies Innovation Unit and the place of indigenous knowledge as a "cross-cutting pillar within the South African Bioeconomy Strategy." Unlike Argentina, Germany, Malaysia, the Netherlands, South Africa and the United States, Australia lacks a national bioeconomy strategy (Food and Agriculture Organization of the United Nations, 2018). However, state and sector-based measures, such as the recent Queensland government law reforms and codes of practice for biodiscovery, are emerging that are intended to support collaborative relationships between custodians of indigenous knowledge, scientists, business, consumers and government officials (Jefferson et al., 2020).

Considering the long history of cultural significance of seaweeds to Indigenous Australians (Thurstan et al., 2018), it seems morally fitting to ensure any emerging industry that capitalises on this lifeform to simultaneously include and enable indigenous Australians. The partnership between US-based CH4 Global and the Narungga Nation Aboriginal Corporation establishing an *asparagopsis* farm on the Yorke Peninsula in South Australia is one early-stage, large-scale, internationally connected commercial collaboration where the stated aims are to deliver maximum sustainable social and economic benefit for local indigenous Australians. South Coast Seaweed, is a smaller scale, locally-led initiative by James Thomas, descendent of Tribal Elders of the Yuin Nation, which emphasises traditional uses of seaweed and sharing local knowledge. These two examples give an impression of the vastly different shapes an algal industry might take based on stakeholder priorities, scale and business model.

It is worth emphasising that a stated focus on engagement, representation and the sharing of benefits with Indigenous custodians does not always equate with economic and cultural benefits flowing back to indigenous communities—the research finding from Bushfood Sensations that only one percent of the twenty million dollar national bush foods industry is generated by Aboriginal Australians is pertinent reminder in this regard (Rooke, 2019). In the Australian context, Indigenous centred research of the kind exemplified in Te Momo (2007) in New Zealand, which highlights the importance of finding a common understanding across different language and cultural groups to initiate meaningful dialogue regarding the social, cultural and spiritual dimensions of biotechnology, should be an important part of any national bioeconomy strategy that supports algal-based industries.

Spatial and organisation aspects are more than just the background against which technologies and industries emerge. The dynamic between psychological, spatial, social and organisational elements witnessed in different locales can be highly particularised and varied in influence with regard to the shaping of new industry and technologies. As researchers in the geography of sustainability transitions have

emphasised (Sengers and Raven, 2015), the 'where' of transitions processes are far more complex and particularised than local-global conceptualisations or geographic framings limited to 'the national', or even more abstract regional boundaries. Our research has shown that highly distinctive, locally configured spatial and organisation networks *within* regions should be crucial considerations alongside framings concerned with how innovation travels *across* larger state or national borders. Furthermore, the question of 'the local' in settler colonial nations involves contested, multi-layered place-framings that implicate people, organisations and communities in a manner that complicates scales of spatial nearness and temporal duration that might typically be used to construe alliances.

## 4. Conclusion

As with the bioeconomy more broadly, the algae-based bioplastics industry can be understood as a set of objective requirements for success and a social idea, enlivened and distorted by a discourse of promises. This article has taken an approach to characterising this emerging industry based on these two dimensions. Findings have been sequenced in such a way so as to first present the broader context of the bioeconomy and a brief history of its various conceptual and rhetorical inflections, followed by particular enablers or levers intended to be of tangible use to interested stakeholders and researchers. Lastly, the research framing expands out again to reflect on complicating factors, which are perhaps inherent to all emerging technologies, on account of the tendency to decontextualise from time and space that tends to go along with technology when it is conceptualised as emerging.

While we have not used, tested or developed a particular conceptual framework, our findings point towards an orienting structure that might be further developed or reapplied in future work. At its most crude, this structure might first invite a dual consideration of the specific objective and ideational elements of an emerging industry or technology. Enfolded within these overarching categories would be practical considerations including but not limited to: site, technology, stakeholders and attitudes to research, consumption and disposal, policy and funding, and transitions. To help researchers build critical awareness of different pathways and their potentials, key aspects of the dynamics of ideas might then be raised. Considerations here might include the accretion of promises and tonal baggage associated with a particular ideas and applications, and the potential alternatives raised by different organisational and geographic configurations. Combining these practical and normative considerations, we hope, might enable greater dialogue about technological mobilisations and their ability to deliver on biophysical, infrastructural and social objectives. For algal bioplastics, it is our hope that such considerations will offer both practical and reflective benefit for a nascent industry where questions remain as to which opportunities will be realised, and what kind of innovation pathways will take hold.

## CRediT authorship contribution statement

**Thomas Lee:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Sam Wearne:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Rachael Wakefield-Rann:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Kate Scardifield:** Writing – review & editing, Project administration, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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