CEPS EXPLAINER

EXPLORING PATHWAYS FOR A GREEN TRANSITION TO A BIOECONOMY

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SUMMARY

The bioeconomy will utilise renewable natural resources with advanced technologies, life science, digitisation, AI and prevision systems to produce food and fibre, and to recycle and reduce waste. The bioeconomy will unfold in any case – but the major challenge will be who will take the lead and how places and governments maintain prosperity and societal wellbeing whilst supporting the development of a sustainable bioeconomy.

This CEPS Explainer, specially prepared in advance of a wider discussion at the 2025 CEPS Ideas Lab, aims to offer some answers to this conundrum and does so by first discussing the bioeconomy in a historical context. It addresses the techno-economic and political challenges in the transition to the bioeconomy. By analysing case studies from diverse countries such as Denmark, Israel and Japan, it provides insights into how local communities can leverage their unique capabilities to build a successful bioeconomy.

Analytically, this CEPS Explainer aims to develop a general framework and practical strategies for fostering innovation, economic development and sustainability in specific locations, focusing on California's rural communities. To develop a bioeconomy globally in California, the case studies discussed should be integrated by identifying categories of developments required for transitioning to the bioeconomy and for innovative approaches in institutional arrangements and development collaborations. The lessons learnt will be just as crucial to Europe as to California in the years to come.

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INTRODUCTION

The bioeconomy can be understood as both the successor to – and an antidote for – the industrial economy, as well as a complement to the digital economy. For now, it's an aspiration, a goal for a new path towards sustainability and growth. A modern bioeconomy should be distinguished from the epochs of traditional agriculture and is characterised by sophisticated life science tools and digital applications. The green transition, a piece of the puzzle, is the pathway to an economy that substitutes plant-based materials and renewable energy sources for depletable materials and fossil fuels. The transition is a system shift, and hence, will require systems' thinking. The challenge, both technical and political, is how to accomplish that green transition and open into a full-scale bioeconomy.

That's why what we must ask is how places and governments can maintain prosperity and wellbeing whilst supporting the development of a true bioeconomy. Can we turn the notion of a bioeconomy from an aspirational goal into a tool that can frame growth strategies?

This CEPS Explainer considers several specific regions, one being inland California. It aims to structure a conversation on how particular places – including in Europe – can build equitable growth models that are facilitated by, and advance, this transition. This requires sketching aspects of the green transition towards a bioeconomy.

WHAT IS THE BIOECONOMY?

Let us set the bioeconomy in a caricatured historical perspective. An extraordinary surge of wellbeing and wealth in the advanced countries began with the Industrial Revolution. A huge improvement in human wellbeing occurred in the century from about 1870 to 1970. The Industrial Revolution was built by manipulation (though some would say exploitation) of our physical environment. Manufacturing was an approach to shaping materials to our designs and purposes, at increasing scale. The energy supporting our economies and society in this era rested increasingly on coal, then oil and finally electricity generated by coal and oil.

The foundations of today's modern bioeconomy were laid down in the late 19th century. 1870-2000 was a period where science-based agriculture and medicines emerged. Taking advantage of Mendel's discoveries of genetic principles, Haber-Bosch's discovery of artificial nitrogen fixation, the Darwinian revolution, the discovery of vaccination, the theory of microbes, and the introduction of sanitation and hygiene, modern agricultural and medical practices have emerged. They led to increased global population from 1.5 billion in 1870 to 6.1 billion in 2000, and global average life expectancy increased from about 30 years in 1870 to 66.8 in 2000 (in the US, this increased from 39.4 in 1870 to 76.47 in 2000).

The digital era, which has profoundly reframed our social and economic life, can be dated from the introduction of the first micro-processor in 1971 and the innovations that followed in digital storage/memory and communications. The digital era built on the capabilities and products of

the physical industrial era. The products and services of the digital economy may not be physical but the operations and processes they require make huge demands on our environment in the form of raw materials and energy. The energy requirements for Nvidia Chips to support Generative AI are extraordinary. The energy required for one such chip over a year is estimated at 1.5 times the annual energy requirements of a Tesla vehicle. Indeed, sometimes, such as in the case of the server farm of Vantage Data Centers in Bridgend, UK, they are literally built on the ruins of an industrial era.

In parallel to – and interconnected with – the digital era was the emerging era of science-based agriculture. Science-based agriculture saw immense increases in population and life expectancy but also significant increases in agricultural land use, deforestation and the loss of biodiversity, groundwater contamination and agricultural greenhouse gas emissions. While the achievements of this period are impressive, they are not felt everywhere. Food security is a major problem in many parts of the world.

Furthermore, contemporary agricultural and resource management systems are not sustainable – they rely on non-renewable resources and deplete natural resources. There is thus a need to transition to a new sustainable mode of managing agriculture and natural resources that will enhance food security, contain climate change and preserve and enhance biodiversity.

Fortunately, new capabilities in the life sciences can provide the capacity for transitioning to the modern science-based bioeconomy. This transition could benefit from multiple scientific breakthroughs, including the discovery of DNA in 1955, the development of new approaches to study the microbiome in 2000, the capacity to sequence the genome, the ability to manipulate genetic material and the knowledge that can improve the input-use efficiency of agricultural and natural resource management. The enhanced capabilities of agriculture and life sciences, benefitting from the digital revolution, are the foundations for building the bioeconomy. However, further development requires a new set of regulations, policies and institutions.

A modern science-based bioeconomy as the green transition's ultimate goal might be framed as a goal for the next phase, building on (and correcting the damaging consequences and flaws of) the two proceeding epochs. A bioeconomy will use renewable natural resources with advanced technologies, life science, digitisation, AI and precision systems to produce more than just food and fibre – namely, chemicals, fuel, pharmaceuticals and environmental services. It will also aim to recycle, reduce waste and prioritise circularity.

A green transition to a bioeconomy that reduces – if not eliminates – the use of fossil fuels and other depletable resources will need to replace them with renewable, often plant-based alternatives. A goal of this transition would also be to enhance a region's human capital by providing good quality jobs and upskilling the workforce to take advantage of new economic opportunities.

Together, the purely physical and digital eras have both drawn on depletable resources, generating carbon dioxide that's threatening the climate as well as spewing out other pollutants that threaten the natural environment. Some developments may be initially driven by markets, such as solar power's radical cost advantages – at least once appropriate infrastructure is in place. Other aspects will likely unfold slowly, with soft market signals. If there were time, the market might drive this transition. But we simply don't have the time for a slowly evolving transition.

For now, a bioeconomy is a goal and the core question is how to support this transition while maintaining economic growth and social wellbeing. A new growth model is essential, otherwise a radical reduction in wellbeing would generate social resistance and political opposition that would delay the transition, if not stopping it in its tracks entirely.

Exchanging electric vehicles for internal combustion cars is the tip of a pyramid of changes. The entire transport system will be redefined from how electricity is generated and distributed, through the products used and component design, the materials utilised for their manufacturing and how these are fabricated. Indeed, global supply systems will be reconceived and reconfigured, with widespread consequences. The socio-political, not just the technical and economic, must be addressed.

For a prosperous and healthy society and economy, the bioeconomy must be developed so that a viable future can animate policy and firm strategies. The goal must be more than the essential objective – namely to avoid climate harm. We need an understandable pathway, growth model and a vision of a better world. A world of electric vehicles to large scale construction equipment, without smog and pollutants, is compelling. It requires not just vehicle product innovation but also charging and storage technologies, a network of charging stations and a complete overhaul of the electricity production system; we must have 'Lego' blocks made from renewable plant-based materials as well as biomanufacturing for an array of goods. The vision of a bioeconomy must be translated into growth and innovation strategies that can be implemented and believed.

So, what possibilities does the pursuit of a bioeconomy open? How can advantages in existing activities and the creation of new activities be generated?

The green transition, the entryway into a true bioeconomy, thus means a fundamental system transformation. In the case of energy, one framing can be the move from a 'high carbon/low efficiency system to a low carbon/high efficiency system'. An example of the profound system shifts ahead of us is the notion of '*electrify everything, decarbonise electricity*[1]'.

[1] The authors adapted this phrasing from the COP15 discussion in Copenhagen in 2009. The recent work of the California Energy Commission suggests that this vision is tending towards reality in California.

Easy phrases, but they involve not only new means of generating electricity but a significant reconfiguration of the electrical grid. Certainly, for example, solar electricity is now cheaper than coal but capturing the benefits means widespread adoption by companies and consumers. For that to happen, we'll need a completely new infrastructure put in place and the existing infrastructure orphaned through the transition must be offloaded. Make no mistake about it, this is a significant physical and financial undertaking.

FINDING A PATH FORWARD MEANS ADDRESSING TWIN CHALLENGES

The transformation has twin fundamentals (techno-economic and political) supporting and facilitating the transition. Clearly, finding a path forward requires developing the needed technologies and technology systems, and introducing renewable materials and energy substitutes for depletable polluting materials throughout the economy.

The technical challenge is entangled with the political challenges. We'll need coalitions supporting the transformation. Creating a path forward is both a matter of promoting the green transformation and addressing concerns, containing/channelling resistance and muting its consequences.

The winners of every techno-economic transformation are motivated by material gains. Transformations create opportunities but they also create losers by driving displacements and dislocations that induce opposition and resistance to the changes. The politics of transformation involves, therefore, addressing the disruptions and their consequences. The politics of resistance by those who are, or perceive themselves to be, losers will dampen the incentives and opportunities to move down the green path, if not directly block the required changes.

Diverse groups are affected. '*Electrify everything, decarbonise electricity*' means significant changes in the automobile and the energy sectors. In the case of auto manufacturers, it's not just a matter of changes in designs, models and production processes but the entry of new competitors, from Tesla to China's BYD. It's not just fossil fuel corporations who gain from the current economic trajectory, but, for example, those communities supported by mining and drilling. The *gilets jaunes* in France are a good example of organised resistance by consumers and small producers, hit by the policy goal of establishing carbon taxes. The list of potential opponents to the bioeconomy is long and animated at times by a denial of – or indifference to – the real consequences of climate change.

There are *four* classic approaches to address the dislocated and displaced by economic growth and transformation. The first two solutions, viewed now as extremes, involve ignoring the costs or at least imposing them on the perceived losers. *First*, market purists might argue that we should simply 'let the losers lose'. *Second*, in the 20th century, political authorities in the Soviet Union and China, faced with resistance from the peasants, used direct force to recraft the society and economy.

The next two solutions aim to create cushions for transition and to generate a clear future. The *third* is compensating (i.e. buying off) the losers, a strategy commonly adopted by both the right and left. From the right, Bismarck, the 19th century German chancellor, implemented the early aspects of what we now call the welfare system to help contain workers' resistance to the Industrial Revolution required for building German power. From the left, the social welfare systems in northern Europe, Germany and the Nordics emerged from Social Democratic strategies of containing the communists to their left. French postwar growth combined all three of these strategies – markets, political force and compensation. Small farmers and towns were subsidised, having their concerns addressed, all while the signals from the marketplace were being reinforced and the long-term modernisation of agriculture and industrial development proceeded. Labour was the political loser during this era.

The *fourth* strategy is to create a path forward for displaced groups, a path where there is a vision for an attractive future, one where their participation in the bioeconomy provides attractive positions for broad swathes of society, in the community and economy. This is essential to the political and economic strategies they may accept or actively support. Whatever the economics, if social roles and place in the community are undermined by economic transitions, there will be resistance. In short, the displaced unionised factory worker who was the family's main breadwinner may find it difficult to accept the role of cashier at a supermarket.

Consider an earlier example. In the 19th century, faced with inexpensive American grain, German landlords simply couldn't envision the strategy the Danes adopted. The Danes fed cheap grain to cows and pigs, which were then processed and exported back at high profits, transiting the Danish economy to agrotech-based growth and creating a new social contract that is still, to this day, central to Danish politics. The German landlords instead doubled down on controlling the peasanty, defending their social position with tariff walls against the inexpensive American grain, moving their economy and society down a more war-like closed-economy path.

The goal, when combining the strategies of markets and compensation, while generating a compelling vision of the future, requires the development of political coalitions that support the creation of the green transition and progress towards a true bioeconomy society. Concerns over economic displacement are longstanding – even before climate change emerged as an added stress to the system.

However, three countries – Japan, Israel and Denmark – have adopted policies designed to assist their rural regions adapt to changing economic and environmental conditions. Each has addressed a slice of the larger pie (Israel for water, Japan for an ageing workforce in need of upskilling and Denmark for a coordinated response to changing economic conditions, the so-called Triple Helix approach). As a part of the 'The Inland California and the BioEconomy' project that inspired this CEPS Explainer, we consider whether the experiences of these three

countries could help provide a roadmap as California moves towards its own version of an inclusive bioeconomy and addresses its pressing economic and environmental issues. At the same time, exploring the California experience may provide some compelling insights for others – including in Europe.

THE TRANSITION TO A BIOECONOMY IS A SYSTEM CHANGE

Moving from the industrial and digital epochs to a bioeconomy era is a system change. It's not simply that the final products and their production processes will be different. Importantly, entirely new supply chains will be reformed and the ecosystems supporting them redeveloped.

There are two approaches to a system change. In the *first*, which demands long-time horizons, one innovation provokes demand for another and the innovations accumulate into widespread system change. In the same way, as the story goes, that we moved from the horse and buggy to an 'auto society', we'll move from petrol stations to electric charging stations. As the demand for horse-drawn buggies drops, the demand for windshield wipers and mechanics rises. Prices, products, production, and the demand for skills shifts. This may be prodded by policy, direct subsidies or taxes.

The *second* approach specifies a clear-cut objective, considers all the elements, and then proposes and implements a strategy to go from one phase to the next. One example is the Semiconductor Industry Association's (SIA) 'Roadmap', which began in the early 1990s. In this case, longer-term objectives, such as the finding the right timing for introducing particular technology objectives, provided clearcut goals for associated components and products. The SIA Roadmap programme amounts to collective action moving an entire supply chain forward. The complexity of production means that quite diverse toolsets are required, and without a clear target market, the development of each tool will be slowed due to having to wait for potential demand to express itself. Not only were toolmakers given clarity but producers using such chips in their products could also forward plan.

Discussions amongst producers over the timing of particular developments sped the advance of the semiconductor sector. The roadmap was a private joint action led by a trade association in the form of shared information rather than a governmental financial subsidy – though at times there was significant government action through DARPA. An earlier instance would be the British government's policy to encourage the move from wood to coal to preserve wood for shipbuilding. Again, this involved the dramatic restructuring of supply networks, with the development of rail being part of the system change.

These examples represent a form of collective action led in one case by a private actor and in the other by public action. Both cases represent a single targeted element, each of which – the move to coal for fuel and the acceleration of semi-conductor development – produced a dramatic socio-economic shift. But the broader system shift in society and the economy

generated by the move to coal and the emergence of a digital era, was not, in itself, the end goal.

It will be a daunting challenge to make the shift to a bioeconomy with its own ecosystems and supply systems. Making the shift in a hurry, because of the imperatives and dangers of climate change, is more challenging. The breadth of a system change requires specifying elements in the transition – considering how they interrelate is crucial. In short, no networks of charging stations, no electric vehicles. Renewables and increased electricity demand require expanding and reconfiguring the electricity system, both production and distribution. For analysis, that's a general question. But for those developing strategy for a place, the task is to decide *what* policy emphasis will provide the best leverage for change.

To simply suggest how complex and difficult the system shift will be, let us note that there are, at least, three interconnected domains that will be reshuffled. Each domain represents both opportunities that can be seized by entrepreneurs and firms, as well as dislocations that must be recognised and attended to. Just listing them suggests the breadth of the changes involved. The interrelationships of products and processes, as well as the tools for both, mean that there will be bottlenecks and a slow level of adaptation:

- Products and services innovated specifically for the needs of a bioeconomy and existing products that are altered.
- Production processes that will be altered for existing and newly envisioned products. The emergence of biomanufacturing expresses the shift from physical materials to plants and biomaterials. Even supposedly straightforward simple changes, such as Lego shifting to make its products from plant-based materials, if appropriate materials can be found, would mean significant shifts in production processes.
- Energy from renewables is not just a shift in how electricity is generated but how it is stored and distributed. At the very least a decentralised grid will substitute for a centralised grid.

The bioeconomy's toolset will have to evolve, and not always smoothly. AI and Generative AI will both influence the development of products and processes. However – and it's a very large however – the energy required to drive the AI systems will itself involve a significant jump in energy demand.

With the current technology and mineral production system, not only is it questionable that such a massive output increase is possible but it's clear that the resulting environmental damage from such an expansion would be unsustainable. A current example is the growing uses of leaching to mine nickel for EV batteries, which has already devastated large swathes of Indonesia's islands and has released massive pollution into the environment in the name of 'green EV transportation.' Together chips, servers, and batteries will represent pressures on a bioeconomy and generate opposition to many of the adaptations needed.

PLACES CAN PROSPER IN THIS SYSTEMIC SHIFT

For those who want to use the shift towards the bioeconomy to ensure their communities' continued prosperity, the transition is a generational opportunity. Periods where old models of behaviour and organisation are shifting are the perfect times to differentiate and disrupt, and for communities to believe in themselves and their abilities to devise their own unique way forward. Those that develop a vision of the society they want, who think about how innovating within the bioeconomy transition would allow them to reach that goal and then go on to experiment and contextualise their growth models to their specific position in the global system that best fits their vision, will achieve prosperity.

Dan Breznitz proposes that a place must identify where it fits in, not only in global markets as such, but in the process of imagining, developing and producing goods and services. This approach recognises the fragmented nature of global production and innovation and offers a more realistic path to prosperity. He argues that communities should identify which stage aligns with their existing strengths and capabilities and focus on developing the necessary ecosystems and policies to excel in that particular stage of the innovation process. He notes four stages: novelty; design, prototype development and production engineering; scale-up and market formation; and cost-cutting and relocation.

Borrowing from Breznitz, we should also recall that as places think about those options and develop a way forward, they must remember that the only economic actors that innovate and create growth in the economy are individuals and firms. Therefore, the policy focus should be on changing the behaviour of – and the environment for – those actors. Thus, before investing billions in complimentary assets and actors, places must be very clear how that investment would end in their firms and entrepreneurs' changed (preferably positive) behaviour. It's crucial to remember that such a policy's goals are to equip the companies and individuals with the capacities they need to excel; develop, support and sustain the economic ecosystem that innovators need to thrive; and find the most effective ways to stimulate those agents to innovate and grow their businesses, all while staying locally embedded.

As places plan, implement and revise their policies, they need to constantly focus on four fundamentals:

1) Flows of local–global knowledge, demand, and inputs – since we live in a world of fragmented production, continuous success requires that a region establishes and institutionalises modes of ensuring constant bidirectional flows of these three critical components. That means institutionalising the modes in which the local interacts with the global and the global interacts with the local.
2) The supply and creation of public and semi-public goods – a systemic transition is inherently a collective endeavour that requires an array of public and semi-public goods. From supplying specialised skills, to shared assets, to collaborative–public

spaces, the socio-economic places where an industry grows moves from simply sharing knowledge to becoming a true community.

3) Building a local ecosystem that reinforces the firm-level benefits of the previous two fundamentals and allows access to critical resources, such as finance or legal services, that fit the business models and the local stage of innovation specialisation.
4) The co-evolution of the previous three fundamentals and the role of public policy as the locale grows and excels. One of the classic mistakes of policymaking is the assumption that what works in one time and one place will always work across time and in other places. This is a perfect example of inflexibility, a textbook failure to change policy instruments in tandem with the environment. During a period of systemic transition, even more than in any other period, those who do not adapt are doomed to become extinct.

What then is to be done?

The goal of the 'Pathways to Green' is to contribute to the development of an approach – analytical and practical – to support the transition to, and the adaptation of, communities to the bioeconomy.

Commitments to this broader transformation will only be made if countries and places within them can envision a productive future. The 'pathways' must involve transformations of energy generation and distribution – renewable energy sources, infrastructures from communications through transport, production processes and the bio-based materials that feed into said processes. That means a reorchestration that some would call circular, as biogas processes feed into electricity generation or biogas outputs will be reused in other processes.

The challenge for nations and places will be determining which capacities need to be guaranteed and developed. Or, to put into other words, in which aspects of the transformation, which phases from invention to scaling, can a community or a place generate distinctive global leadership and defensible market positions. This project will need to review the existing debate on formulations, both to understand how pathways are being understood and to situate this effort in a manner that it can make new and distinctive contributions.

The concerns and arguments are general. Here, we intend to focus on developing strategies for diverse 'places.' This is crucial because while national policy may set frameworks and market rules, the adjustments will always be local and particular. The initial empirical focus of our efforts is on rural communities. Regional analyses have not focused on this crucial transition, focusing rather on industrial, service or energy adjustments.

The challenge is to develop a general-purpose framework approach, for diverse communities to imagine their own futures in a bioeconomy. With this in mind, we will generate a framework built both from our existing work on innovation and economic development and by current work with particular places. This will lead to developing methodologies to identify the

appropriate strategies to develop a bioeconomy in specific locations, taking advantage of their unique capabilities and resources. This effort will set a discussion about the available pathways to a green bioeconomy, what pathways may be developed and how, and what will be required of policy and communities in the transition. This in turn will suggest the nature of the investment that must be pursued in terms of infrastructure, workforce development and industrial resources.

Each country case can provide unique insights about developing a bioeconomy in California and globally. California already has a strong foundation for a bioeconomy based on academic research as well as the presence of major companies that deploy biotechnology for pharmaceutical, energy and agriculture. It also has an extensive agricultural sector that provides fresh fruits and vegetables to much of the US, as well as overseas. Yet it's also a centre of rural poverty amongst an aging farmworker population and is grappling with serious problems of water research management and land-use. California's agriculture is unsustainable, generating vast amounts of greenhouse gases and other pollutants. The cases of Denmark, Israel and Japan provide us insights, as we would hope to provide insights to others, including in Europe.

Denmark has diverse experience working with innovation and the development of circular bioeconomy systems. The Danish experience in the development of cooperatives, high-value bioeconomy products, and recycling animal waste to produce energy and other valuable products can provide avenues to be pursued in California. The Israeli experience in the management of water conservation technologies, digitalised irrigation and desalinisation is very useful as California has a pressing need to address water scarcity and quality problems.

The Japanese experience in developing high-quality products directed to niche markets, especially in new technologies, and to augment the capacities of older and physically limited individuals, can provide avenues to address the challenge of an aging population and value-added generation from agricultural resources. This may prove even more important over the next few years as current national policies in the US are likely to drive labour shortages. We will analyse the lessons learnt from these experiences and identify how they can be applied to California. We'll also consider what implications the California experience could have for others in its agricultural regions and in its innovation and technology development.

In particular, the integration of the case studies with the California experience will help in identifying development categories required for the transition. We will attempt to craft an inventory of developments that can be adapted to different locations to take advantage of their unique positions in global markets.

Doing this will also help us to imagine innovative institutional arrangements. We'll be considering a variety of solutions but two arrangements that we wish to consider include:

- Innovation agencies that allow for imaginative exploration both in terms of possible investments and the coalitions to support them.
- Industry-University Cooperative research and development collaborations aim to:
    - Be a source of investment and capacity-building which provides a competitive edge and new employment and income opportunities appropriate to the region.
    - Shape a broad vision to form technological, financial, and institutional innovation that will enable a transition to the bioeconomy.

CONCLUSIONS

Transitioning to a bioeconomy represents both an immense opportunity and a formidable challenge. It demands a systemic shift in how societies produce, consume, and innovate, requiring technological advancements, new institutional frameworks and political coalitions that support equitable growth. While the industrial and digital revolutions reshaped economies through resource-intensive models, the bioeconomy aims to reverse environmental degradation while fostering economic prosperity. This shift, however, cannot be achieved passively – it requires deliberate strategy, investment and policies that address both the opportunities and the dislocations inherent in systemic change.

By analysing case studies from California, Denmark, Israel and Japan, we gain insights into how local communities can leverage their strengths to build a sustainable bioeconomy. And these issues are as central to Europe as they are to California. Success will depend on creating a vision for the future that balances technological progress with social wellbeing, ensuring that displaced industries and workers have a clear path forward.

Ultimately, the bioeconomy must not only be a goal but a practical framework for sustainable development. By fostering innovation, collaboration and inclusive growth strategies, we can ensure that the green transition leads to long-term prosperity and environmental resilience.

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