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Pathways For A Green Transition To A Bio-Economy

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Abstract [i]

This paper explores the potential for a transition toward a bio-economy. It aims to answer how places and governments might maintain prosperity and well-being while supporting the development of a bio-economy. The bio-economy will utilize renewable natural resources with advanced technologies, life science, digitization, artificial intelligence, and prevision systems to produce food and fiber and recycle and reduce waste. This paper discusses the bioeconomy in a historical context. It addresses the techno-economic and political challenges in the transition to the bio-economy. By analyzing case studies from diverse regions such as Denmark, Israel, and Japan, this paper provides insights into how local communities can leverage their unique capabilities to build a bio-economy. Analytically, this paper 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, this paper suggests integrating the case studies by identifying categories of developments required for the transition to bio-economy and innovative approaches in institutional arrangements and development collaborations.

Authors

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The bio-economy 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 is an aspiration, a goal for new path toward sustainability and growth. A modern bio-economy should be distinguished from the epochs of traditional agriculture and is characterized by sophisticated life science tools and digital applications.[ii] The green transition, an element of the story, is the path to an economy that substitutes plant-based materials and renewable energy sources for depletable materials and fossil fuels. The transition is system shift, and hence, will require systems' thinking. The challenge, technical and political, is how to accomplish that green transition and open into a full-scale BioEconomy.[iii] The question we must ask is how places and governments might maintain prosperity and wellbeing while supporting the development of a BioEconomy. Can we turn the notion of a BioEconomy from a goal into tool that can frame growth strategies.

As we convert this essay into an operational research design, we will consider several specific regions, one of which will be parts of inland California. For now, the objective of this note is to structure a conversation on how particular places can build equitable growth models that are facilitated by and advance this transition. That requires sketching aspects of the green transition toward a bioeconomy.

I. *What is the Bio-Economy?*

Let us set the bio-economy in a caricatured historical perspective.[iv] An extra-ordinary surge of wellbeing and wealth in the advanced countries began with the industrial revolution. A huge improvement in human well-being occurred in the century from about 1870 to 1970.[v] The industrial revolution was built by manipulation, 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 electricity generated by coal and oil.

The foundations of the bio-economy 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, 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 U.S., this increased from 39.4 in 1870 to 76.47 in 2000).[vivii]

A digital era, which has profoundly reframed our social and economic life, may 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 the products, of the physical industrial era. The products and

services of the digital economy may not have been physical, but the operations and processes they required make huge demands on our environment in the form of materials and energy. The current already immense and still rapidly growing energy requirement of Generative AI is a case in point.[viii] 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. Vantage bought an abandoned Ford plant in Bridgend UK to build an enormous data server farm. The energy requirements for Nvidia Chips to support Generative AI are extraordinary. The energy required for one such chip during a year is estimated at 1 ½ times the energy of a Tesla vehicle in a year.

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

Fortunately, new capabilities in the life sciences can provide the capacity to transition to the 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, establish a potential to build the bioeconomy. However, further development requires a new set of regulations, policies, and institutions.

A BioEconomy as an ultimate goal of the green transition might be framed as a goal for the next phase, building on, but correcting the damaging consequences and flaws of, the two proceeding epochs. A bioeconomy will utilize renewable natural resources with advanced technologies, life science, digitization, artificial intelligence, and precision systems to produce more than food and fiber–namely, chemicals, fuel, pharmaceuticals, and environmental services. It will also aim to recycle and reduce waste, circularity, again taking advantage of advanced science. A green transition to a bioeconomy, both to reduce, if not eliminate, the use of fossil fuels and other depletable resources, replacing them with renewable, often plant based alternatives, will be required for this to happen. 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 era have both drawn on depletable resources, generating carbon dioxide threatening the climate as well as spewing other pollutants that threaten the environment. Some aspects may be driven by markets in the immediate, such as the radical cost advantages that solar power represents, at least once appropriate infrastructure is in place. Other aspects will likely unfold slowly, with soft market signals. But we do not have time for a slowly evolving transition to green.

For now, a BioEconomy is a goal, not an automatically unfolding techno-economic era, and the core question is how to support this transition and still maintain economic growth and social well-being. A new growth model – a basis for future growth – is essential. Otherwise, a radical reduction in well-being would generate social resistance and political opposition that would delay if not stop the transition. Exchanging electric vehicles for internal combustion cars is the tip of a pyramid of changes. The entire transportation system will be redefined from how electricity is generated and distributed, through the products and component design, the materials used for their manufacturing and how these are fabricated. Indeed, global supply systems will be reconceived and reconfigured. The consequences will be widespread. The socio-political, not only the technical and economic, needs to be addressed.

The vision of a prosperous and healthy society and economy, the bio-economy, must be developed so that a believable future can animate policy and firm strategies. The goal must be more than the essential objective: avoid climate harm. We need an understandable pathway, growth model, and an image of a better world. A world of electric vehicles from personal transport 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. What possibilities does the pursuit of a bio-economy open? How can advantage in existing activity and creation of new activity be generated?

The green transition, the entry into a bioeconomy, means, therefore, 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". That, one might say as an example of the profound system shifts ahead, requires, "Electrify everything, decarbonize electricity"[ix]. Easy phrases, but they involve not only new means of generating electricity, but a significant reconfiguration of the electrical grid. Certainly, for example, the price of solar electricity has dropped below that of coal, but to capture the benefits means widespread adoption by companies and consumers, for that to happen a new infrastructure will need to be put into place and the existing infrastructure orphaned in the transition must be offloaded. This is a significant physical and financial undertaking.

II. *Finding a path forward means addressing twin challenges:*

The transformation has twin fundamentals, techno-economic, and political, supporting and facilitating the transition. There are, certainly, technical challenges such as "electrifying everything and decarbonizing electricity. Clearly, finding a path forward requires developing, innovating, the needed technologies and technology systems, introducing throughout the economy renewable materials and energy as substitutes for depletable polluting materials and energy sources."

The technical challenge is entangled with the political challenges. Coalitions supporting the transformation will be required. Creating a path forward is both a matter of promoting the green transformation and addressing the concerns, containing, or channeling, the resistance and muting its consequences. So first a few words about

the political and how it intertwines with developing an economic/ technology path forward.

The winners of every techno-economic transformation are motivated by gains, material gain or in the pursuit of them – the positive externalities of market gains. Certainly, 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 consequences. The politics of resistance by those who are, or perceive themselves, to be losers will dampen the incentives, the opportunities, to move down the green path, if not directly block the required changes. Diverse groups are affected. Electrify everything, decarbonize electricity means significant changes in the automobile and the energy sectors. In the case of auto producers, it is not just a matter of changes in designs, models, and production processes that require corporate adjustment and obviate existing skills, but the entrance of new competitors from Tesla to BYD in China. It is not just fossil fuel corporations who gain from the current economic path, but , for example, the communities supported by the mining and drilling. The "Yellow Vests" (Gilets Jaunes) in France are an instance of resistance by consumers, small producers, hit by the policy goal of establishing carbon taxes. The list of potential opponents to the move to the bio-economy is long, and animated at times by a denial of, or indifference to, the real consequences of climate change.

Consider 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*, perhaps inspired by Hayek but ignoring the markets and their incentives are political creations, might argue, let the losers lose.[x] Ignore the Yellow Vests, which of course did not prove to be politically viable in France. *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. (Before the West becomes too complacent and self-righteous, one must note that the enclosures in England, as an example, were the use of political authority to force changes and reconstruct society and markets. We, skip past, in drawing the accounts, the history of the labor movement).

The next two solutions creating cushions for transition and generating a clear future. *Third*, compensating, buying off, the losers is a strategy commonly adopted by both 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 worker resistance to the industrial revolution required for German power. From the left, the social welfare systems in northern Europe, Germany and the Nordics, emerge 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, small towns, were subsidized, having their concerns addressed, all the while that the signals from the market place were being reinforced and long-term modernization of agriculture and industrial development proceeded. General de Gaulle, pointing to the threat from the Communists to the left entrapped much of the otherwise resistant right in his political movement. Labor was the political loser during this era.[xi]

There is a *fourth* strategy. Creating a path forward for displaced groups, a path in which there is a vision of an attractive future, one in which their participation in the bioeconomy provides for broad swathes of society attractive positions in community and economy, where groups fit in their conception of themselves, of their sense of their place in society. This is essential to the political economic strategies they may accept or actively support. Whatever the economics, if the social role and place in community is undermined by economic transitions, there will be resistance. The displaced unionized factory worker who was the economic support for the family may find it difficult to accept the role of check-out clerk at a food store.

Consider an earlier example. In the 19th century faced with inexpensive American grain, German landlords could not 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 still is central to the politics of the country. The German landlords instead, doubled down on the control of the peasanty, defending their social position with tariff walls against the inexpensive American grain, moving their economy and society toward war-like closed-economy path.[xii]

The goal, when combining the strategies of markets andcompensation, while generating a compelling vision of the future, requires the development of political coalitions that support the creation of the green transition and progress toward a fully bioeconomy society.[xiii] An instance of this approach is the effort made by now secretary of energy Jenifer Granholm when she was a faculty member at Berkeley following her work as Governor of Michigan. Anticipating a ruling from EPA, had the democrats won in 2016, that would have closed down coal plant, she developed a team to propose state by state strategies to energy adaptation that would generate jobs and tax increases. The insight was that if Governors had a strategy at hand that could generate benefit, they would be less inclined to fight the new regulations, or at least modulate their opposition. In this spirt the approach to strategy sketched later is intended to help generate the political support, the coalitional base, required to implement the emergence of a bioeconomy.

Concerns over economic displacement are longstanding – even before the emergence of climate change 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 aging workforce in need of upskilling, and Denmark for a coordinated response to changing economic conditions, the so-called "Triple Helix approach). As part of the project, from which this paper emerges, we consider whether the experiences of these three countries could help provide a roadmap to as California moves towards its own version of an inclusive bioeconomy and addresses its pressing economic and environmental issues.

III. *The Transition to a bio-economy is a system change.*

Moving from the industrial and digital epochs to a BioEconomy era is a system change. It is not simply that the final products and their process of their production will be different. Importantly, entire new supply chains will be reformed and the eco-systems supporting them redeveloped.

There are two approaches to a system change. In a **first,** which demands long-time horizons, one innovation provokes demand in another, and the innovations cumulate later into change in system. In the same way, the story goes, we moved from horse and buggy to auto society, we will move from gas stations to electric charging stations. As the demand for buggies drops, the demand for windshield wipers and mechanics rises. Prices shift, products, production and 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 that Semiconductor Industry Association, "Roadmap."[xiv] In this case longer term objectives, such as timing for introduction of particular technology objectives such as line widths on a chip, provided goals. The SIA roadmap program amounts to a collective action moving an entire supply chain forward. The complexity of production means that quite diverse tool sets are required, and without a clear target market, the development of each tool will be slowed waiting for potential demand to express itself. Not only were tool makers given clarity, but producers that would use such chips in their products could plan. Discussions amongst producers about the timing of the diverse tooling sped the advance of the semiconductors. This required joint action of a trade association in the form of shared information rather than financial subsidy, and at times government action through DARPA. An earlier instance would be the policy of the British government to encourage the move from wood to coal in order to preserve wood for ship building.[xv] Again, that involved dramatic restructuring of supply networks; in this case the development of rail system being part of the system change. These cases represent a form of collective action led in one case by a public actor and in the other by private 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 the economy and society generated by the move to coal and the emergence of a digital era, was not, in itself, the goal.

It is 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 all the more challenging. The breadth of a system change requires specifying elements in the transition. Considering how they interrelate is crucial. 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 is a general question. For those developing strategy for a place, the task is what emphasis will provide leverage for change.

To simply suggest how complex and difficult the system shift will be, let us note that there are, at least, four interconnected domains that will be reshuffled. Each represents both opportunities that can be seized by entrepreneurs and firms and dislocations that must be recognized 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 slow adaptation.

- Products and services innovated specifically for the needs of a bio-economy and existing products that are altered.

- Production processes will be altered for existing and newly envisioned products. The emergence of biomanufacturing expresses the shift from physical materials to plant and biomaterials.[xvi] Even supposedly straightforward simple changes, such as Lego to make its products from plant-based materials, means 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 decentralized grid will substitute for a centralized grid.

The tool set of a bioeconomy will have to evolve, and not always smoothly. AI and Generative AI both will influence the development of products and processes. However, and it is a very large however, the energy required to drive the AI systems will involve a significant jump in energy demand. Indeed, in the transition to a full bioeconomy it is estimated that the world would need up to twenty times more minerals to be mined. Starting from copper and nickel, to lithium, and the rare earths minerals. At current technology and mineral production system, not only it is questionable that such massive output increase is possible, but it is clear that the environmental damage from it would be unsustainable. A current example is the growing uses of leaching to get nickel for EV batteries, which has already been devesting large swaps of Indonesia's islands and release massive pollution to 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.

IV. *The opportunity of places to prosper in in this systemic shift*

For those who want to use the shift toward the bioeconomy to ensure their communities sustained prosperity, the transition is a generational opportunity. The reason being periods in which old models of behavior and organization are in transit, are the perfect times in which 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 to be, think about how innovating within the bioeconomy transition would allow them to reach that goal, and then go on to experiment and contextualize their growth models to the specific position in the global system that they think best fits their vision, will achieve prosperity.

Dan Breznitz[xvii] proposes that a place must identify where it fits, not only in global markets as such, but in the process of imaging, developing, and producing goods and services. This approach recognizes 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 stage of the innovation process. He notes four stages:

1. Novelty
2. Design, Prototype Development and Production Engineering
3. Stage Three: Scale-Up and Market Formation
4. Cost-Cutting and Relocation

The bioeconomy transition will generate opportunities as well as dislocations. Accordingly, in each phase, we must consider, by looking at particular places, how they

can benefit by creating, growth maintained, innovation generated local-eco-systems as the transition unfolds and a bioeconomy emerges.

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 behavior 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 up in a changed (preferably positive) behavior of their firms and entrepreneurs. It is crucial to remember that such policy's goals are to: i) equip the companies and individuals with the capacities they need in order to excel; ii) develop, support, and sustain the economic ecosystem that innovators need in order to thrive; and iii) find the most effective ways to stimulate those agents to innovate and grow their businesses, while staying locally embedded.

As places plan, implement and revise their policies, they need to constantly focus on four fundamentals.[xviii] The first being the local *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 institutionalize modes of ensuring constant bi-directional flows of these three critical components. That means institutionalizing the modes in which the local interacts with the global and the global interacts with the local. The second fundamental is *the supply and creation of public and semi-public goods*. A systemic transition is inherently a collective endeavor that requires an array of public and semi-public goods. From the supply of specialized skills, to shared assets, to collaborative–public spaces, the socio-economic places where an industry moves from sharing knowledge to becoming a community.[xix] Those first two leads us to the third fundamental, 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 specialization.[xx] The last, but not least, fundamental is the c*o-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 space. This is a perfect example of inflexibility, a textbook failure to change policy instruments in tandem with the environment. During time of systemic transition, even more than in any other times, those who do not change, become extinct.

V. *What then is to be done:*

The goal of the "Pathways to Green", for which this essay represents a starting formulation, is to contribute to the development of an approach, analytic 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, the processes of production, and the bio-based materials that feed into the processes. That will mean a reorchestration that some would call circular, as biogas processes feed into electricity generation or a reuse of the biogas outputs in other processes.

The challenge for nations and places will be determining which capacities need to be assured and developed. In which aspects of the transformation, which phases from invention to scaling, can a community, 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." We consider this 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 effort is on rural communities. Regional analyses have not focused on this crucial transition, focusing rather on industrial, service, or energy adjustments.

- Developing a General Purpose Framework and Approach for community development and policy discussion.

Analytically we will generate a frame built both from our existing work on innovation and economic development and by current work with particular places. That 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 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 case study can provide unique insights about developing a bioeconomy in California and globally. Denmark has a diverse experience working with innovation and the development of circular bioeconomy systems. We will analyze the lessons of this experience and identify how it can be applied to California. The Danish experience in the development of cooperatives, high-value bioeconomy products, and in particular, 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, digitalized irrigation, and desalinization is very useful as California is challenged to address water scarcity and quality problems. The Japanese experience in developing high-quality products directed to niche markets, especially in new technologies, 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.

In particular, the integration of the case studies with the California experience will help in:

- Identifying categories of developments required for the transition. We will attempt an inventory of developments that can be adapted to different locations to take advantage of their unique positions in global markets.
- Imagining innovative institutional arrangements. We will consider a variety of solutions, but two arrangements that we wish to consider include:
    - Innovation agencies that allow imaginative exploration both in terms of possible investments and the coalitions to support them.
    - Industry University Cooperative research and development collaborations aim to:

- To be a source of investment and capacity-building which provides a competitive edge and new employment and income opportunities appropriate to the region.
- A second is to shape a broad vision to form technological, financial, and institutional innovation that will enable a transition to the bioeconomy.

[i] This essay is an early product of "The Inland California and the BioEconomy" . "The Inland California Project" is an effort of four University of California campuses (Berkeley, Davis, Merced and Riverside) under the auspices of Labor and Automation in California Agriculture (LACA). It has the support of the Public Policy Institute of California, Carnegie California as well as regional economic development organizations in the San Francisco Bay Area and Sacramento.

ii Let us use David Zilberman's conception and words. "The traditional bioeconomy .... has been the dominant sector of traditional economies for nearly as far back as we can trace food markets, historically utilizing domestic animals for transportation and power. Agriculture and forestry are major elements of the bioeconomy. The traditional bioeconomy used fermentation to produce cheeses and kimchi, preserve meats, and produce bread. Beer, wine, and other alcoholic beverages are also major products of the traditional bioeconomy."

[iii] Part of the transition, for some analysts, and in some places, will be a circular economy, a concept that has varied specifications. *Perplexity* says: involves reducing waste and pollution, circulate products and materials, regenerate nature. *Claude* says reduce, reuse, recycle. Our approach to allow a targeted discussion emphasizes as an outcome: renewable plant based materials and renewable energy sources. Certainly circularity can be an important tool where there is broad agreement on that approach.

[iv] Apologies to Alexander Gerschenkron, whose book, Economic Backwardness in Historical Perspective, Cambridge: Massachusetts, 1962, is relevant to our discussion here.

[v] See Robert J.Gordon, The Rise and Fall of American Growth, Princeton: New Jersey, 2017. And Daron Acemoglu and Simon Johnson's Power and Progress: Our Thousand-Year Struggle Over Technology and Prosperity, New York: New York, 2023.

[vi] https://www.statista.com/statistics/1040079/life-expectancy-united-states-all-time/

[vii] https://www.statista.com/statistics/1040079/life-expectancy-united-states-all-time/

[viii] On the topic of the energy industry and AI chips in the United Kingdom, see Gooding. 2024. " Vantage Buys Former Ford Engine Plant in Wales for Data Center Campus." https://www.datacenterdynamics.com/en/news/vantage-buys-former-ford-engine-plant-in-wales-for-data-center-campus/ (Accessed August 15, 2024)

[ix] I adopted that phrasing from the discussions around COP 15 in Copenhagen in 2009. Then it was a bit of a flip statement of vision. The recent work of the California Energy Commission led by David Hochschild suggests that the vision is tending toward reality in California.

[x] See F.A. Hayek, The Road to Serfdom, Chicago: Illinois, 2007.

[xi] I argue this in Governments Markets and Growth: Financial Systems and the Politics of industrial Change. New York: Cornell, 1983.

[xii] See Alexander Gerschenkron's essay, "Social Attitudes, Entrepreneurship, and Economic Development" in Economic Backwardness in Historical Perspective, Cambridge: M Economic Backwardness in Historical Perspective, Cambridge: Massachusetts, 1962.

[xiii] Concerns over economic displacement are longstanding – even before the emergence of climate change 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 aging workforce in need of upskilling, and Denmark for a coordinated response to changing economic conditions, the so-called "Triple Helix approach). As part of the project, from which this paper emerges, we consider whether the experiences of these three countries could help provide a

roadmap to as California moves towards its own version of an inclusive bioeconomy and addresses its pressing economic and environmental issues.

[xiv] The SIA roadmap project began in the early 1990s. References to it can be found online looking for SIA Roadmap. For the 2007 edition of the SIA Roadmap, see "International Technology Roadmap for Semiconductors, 2007 Edition." https://www.semiconductors.org/wp-content/uploads/2018/08/20071_Executive-Summary-.pdf (Accessed August 15, 2024).

[xv] Perhaps one forgotten but dramatic instance is British policy on wood. See Steinmueller, W. Edward. 2013. "The Pre-Industrial Energy Crisis and Resource Scarcity as a Source of Transition." Research Policy Volume 42 (Issue 10), 1739-1748. https://www.sciencedirect.com/science/article/abs/pii/S0048733313001522. Here is Steinmueller's recent discussion on this issue:

> " A word of caution. My view that timber scarcity was not an adequate explanation of energy transition in several sectors needs a bit more nuance for ships. This is because of the need for main sail poles and long timbers for the keel. These pieces of timber require more than one human lifespan to cultivate and hence something more than individual entrepreneurial effort. I do note a story once told to me by my late friend, Paul David. An elderly Oxford college bursar receives a young manager who reports the high table has wood worms. This appears to be a problem due to the massive size of the table. The bursar pulls up a library chair ladder and retrieves a large tome from an upper shelf. Dusting it off he opens the book and after a few moments' murmurs, 'yes, here it is, an entry from 1758. An oak was today planted on college land to replace the high table which will eventually succumb to wood worm. Here are the coordinates. I will contact the college forester to set about harvesting it and making preparations a the sawmill. The moral is institutional memory and commitment can transcend individual lives."

[xvi] From Wikipedia: https://en.wikipedia.org/wiki/Biomanufacturing

Biomanufacturing is a type of manufacturing or biotechnology that utilizes biological systems to produce commercially important biomaterials and biomolecules for use in medicines, food and beverage processing, and industrial applications. Biomanufacturing products are recovered from natural sources, such as blood, or from cultures of microbes, animal cells, or plant cells grown in specialized equipment. The cells used during the production may have been naturally occurring or derived using genetic engineering techniques.

[xvii] Breznitz several books and articles on this topic. The most relevant to this discussion is Dan Breznitz, Innovation in Real Places: Strategies for Prosperity in an Unforgiving World, Oxford: England, 2021.

[xviii] Breznitz, Dan. 2021 Innovation in Real Places: Strategies for Prosperity in an Unforgiving World. New York: Oxford University Press.

[xix] Dan Breznitz and Michael Murphree, Run of the Red Queen: Government, Innovation, Globalization, and Economic Growth in China. New Haven: Connecticut, 2012.

[xx] Where then do firms fit in this systemic shift? Evidently, capabilities of firms in a place – region, city, or country – are part of the local eco-system and part of the foundation for any transition strategy. The capabilities of firms in a place – region, city, or country – are part of the eco-system and part of the foundation for any transition strategy. Firms will need to adjust, adapt to new requirements, and their adjustments, or failure to adjust, structure a region's possibilities. Consequently, a "place" must ask three additional questions: 1) what assets its firms capabilities represent; 2) what challenges those firms will face in adapting; 3) and what resources might be developed.

Evidently, Firms are organizations that embed skills and capabilities. The capacities were developed to address today's problems and entirely new skills are likely needed for tomorrow's. It is not simply the seemingly dramatic shift from knowledge about fossil fuels to knowledge about electricity and electric, which requires changes in recruitment and hiring. That is hard and often slow. Nor is it simply a matter of effectively reorganizing the deploy the new talent toward the firm's objectives.

Often it is a matter of perhaps even more difficult shifts in decision making. Consider three real cases from earlier years. First, should a manager promoted by skills in steelmaking be placed in charge of a semi-conductor facility?[xx] Both involve steel making and semi-conductors involve, or seem to involve, process production, but they are radically different processes and industries. Success in one is likely irrelevant to the other. Second, is success with fossil fuel cars a good guide to proper strategy and investment in the move to EVs, both how and when, and at what level of investment. Third, often the difficulty in judgment and decision making is more subtle. Is a semiconductor firm selling "chips" to be built into systems company or systems on a chip. Those are very different businesses, and in at least one case we observed a firm found it difficult to shift direction, or rather its leadership found it difficult. The general matter is that those leaders who position rests on one set of skills are not going to easily, let along automatically, cede power of decision to others.

The evident question is how a "place" might support the transition of its firms, Resistance to change may slow dislocations, but will not create advantage.