# Industrial policies for the twenty-first century

## Lessons from the United States

William B. Bonvillian

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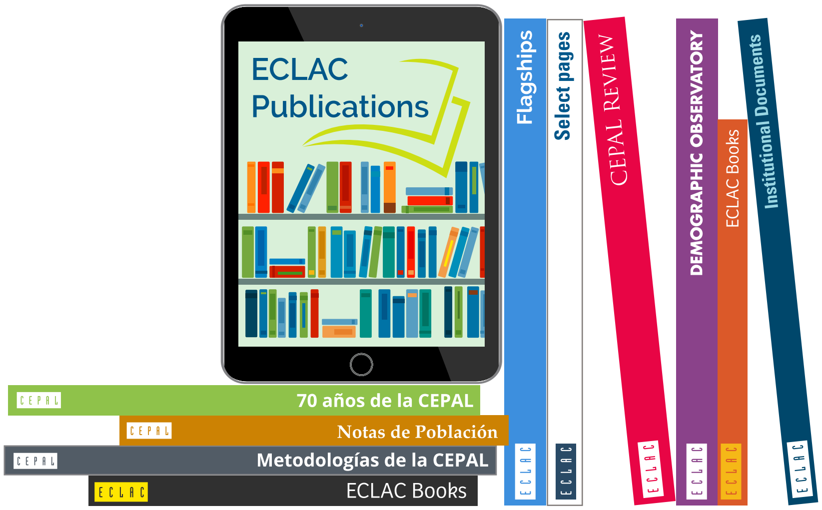

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# Contents

# List of Acronyms

| | |
|---|---|
| ARPA-E | Advanced Research Projects Agency-Energy |
| ATP | Advanced Technology Program |
| CCS | Combined Charging System |
| CDC | Center for Disease Control |
| CHIPS | Creating Helpful Incentives to Produce Semiconductors |
| CTAP | Coronavirus Treatment Acceleration Program |
| DARPA | Defense Advanced Research Projects Agency |
| DEI | Diversity equity and inclusion for minorities and women |
| DOD | Department of Defense |
| DOE | Department of Energy |
| EDA | Commerce Department’s Economic Development Administration |
| ESGC | DOE’s Energy Storage Grand Challenge |
| EU | European Union |
| EUA | Emergency Use Approval |
| EV | Electric vehicles |
| EXIM | Export Import |
| FCAB | Federal Consortium for Advanced Batteries |
| FDA | Food and Drug Administration |
| HDI | Human Development Index |
| HHS | Department of Health and Human Services |
| IMF | International Monetary Fund |
| MEP | Manufacturing Extension Partnership program |
| NASA | National Aeronautics and Space Administration |
| NIH | National Institutes of Health |
| NIST | National Institute of Standards and Technology |
| NSF | National Science Foundation |
| NSTC | National Science and Technology Council |
| OSTP | White House Office of Science and Technology Policy |
| OTA | Other Transactions Authority |
| OWS | Operation Warp Speed |
| PPP | Public private partnership |
| R&D | Research and Development |
| SBIR | Small Business Innovation and Research Program |
| STEM | Science, Technology, Engineering and Mathematics |
| TRL | Technology Readiness Levels |
| UN | United Nations |
| US | United States |

# Introduction

During the Covid-19 pandemic period of 2020-2022, the world witnessed a revival of activist state economic policies in many nations, through attempts to secure medical supplies and develop therapies, as well as to offset the economic drop caused by the pandemic.[1]

As the pandemic receded toward endemic status, many states pursued economic recovery strategies that continued interventionist policies used during the height of the pandemic and were based on industrial policies. These new approaches have moved beyond traditional rationales of seeking productivity and competitiveness gains to embrace development of capabilities in innovation-based growth.

These growth policies are based on deliberate governmental interventions in post-research stages of innovation. The policies rely on improving technological knowledge and capabilities to enable production systems to adopt new technologies and expand quality jobs, and to build resilience through supply chains to respond to future crises, as well as to meet sustainability demands. New forms of innovation organization are required and underway at substantial scale to manage the new programs. Collectively, because these policies are focused on fostering innovation, they can be termed "industrial innovation policies." Although different nations are attempting different approaches, an analysis of international practices can provide useful lessons for Latin American and Caribbean countries.

The paper therefore attempts to evaluate new industrial innovation policy approaches in the United States (U.S.). Historically, the U.S. has resisted such governmental interventions in its innovation system. But the U.S. in the 2020-2022 period has embarked on a set of major industrial innovation policy approaches to improve its technological innovation system, which are explored here.

The document is structured into eight sections in addition to this introduction, the rest of which addresses the importance of industrial policies for developing countries. The first section provides an historical overview of industrial policies in the United States. The second section examines the definitions

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[1] The views expressed in this paper are solely those of the author and not necessarily positions of his employer, MIT.

of industrial policy and the debate on its objectives and highlights the notion of industrial innovation policy. The third section presents the historical precedents for industrial innovation policies in the U.S. The fourth section describes the driving forces behind the resurgence of industrial policy in the country, in a quality and quantity never experienced before. The fifth section analyzes seven industrial innovation policy approaches underlying recent initiatives in the U.S. in the 2020-2022 period. Section six looks at the institutional infrastructure that needs to co-evolve with the new industrial innovation policy impetus for it to work. The seventh section summarizes these new policies and approaches, and then section eight discusses five main lessons for Latin American and Caribbean countries and concludes.

## A. Relevance of industrial policies to developing nations

Are such industrial innovation policies relevant to developing countries? The United Nations (UN) has defined developing countries as those with a relatively limited standard of living, an undeveloped industrial base, and a moderate to low ranking on the Human Development Index (HDI), developed by the UN in 1993 as a comparative measure of poverty, literacy, education, life expectancy, and related factors.

Industrial policy has long been a contentious idea in economics, arising in recent decades despite a backdrop of neoliberal economic views dating from the early 20th century but dominant starting in the 1960s and favoring free markets and trade, deregulation, globalization and a limited governmental role. A competing economics literature began emerging in the 1980s and 1990s in opposition to this mainstream neoliberalism.[2] UN studies have long examined industrial policy approaches for developing nations. For example, a 2016 UN Economic Commission for Africa (UNECA) study found that,

> The debate on industrial policy has arguably been the most ideological one in the history of economics. The best proof of the ideological nature of the industrial policy debate is shown by the debate on the 'economic miracles' in the East Asian countries, like Japan, (South) Korea, and Taiwan. It is hard to believe it today, but until the 1980s, many mainstream economists were denying the existence —not to speak of the efficacy— of industrial policy in those countries. Why did these economists do that, when a quick look through financial newspapers and magazines —not to speak a short visit to those countries— would have revealed how extensive and intrusive their industrial policies are? (UNECA, 2016).

A 2019 International Monetary Fund (IMF) report has summarized the basic point noted above. It looked at countries that achieved developed status after World War II (Cherif and Hasanov, 2019). Of the fourteen countries in that category, the IMF study found three types:

(i) Countries that used major natural resources —primarily oil— for economic growth. These were Middle Eastern nations.

(ii) Countries with smaller economies that were able to grow through integration into larger regional economies. Portugal, which integrated into the European Union (EU), provides an example.

(iii) Countries that applied industrial policies based on governmental economic interventions. This is the East Asian development model.

All the countries in this third category used industrial policies as the basis for their growth, including Japan (which had to rebuild after World War II), Korea (Rep. of), Taiwan, and Singapore. Clearly, industrial policy has been a major pathway toward economic development in these developing nations. China is the latest example of a developing nation in this third category. The IMF report, like the 2016 UNECA report, is part of a larger literature that, particularly after the economic crash of 2008

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[2] For the historical context see, for example, Oqubay, Cramer, Chang and Kozul-Wright (2020); Andreoni and Chang (2019); Chang (1994); Amsden (1989); Johnson, (1982).

when mainstream economics faced something of a comeuppance, suggests the potential relevance of studies of industrial policy approaches to developing nations.

An examination of a recent industrial policies in the U.S. therefore may present some approaches that may be relevant to developing countries in the Americas. After an in-depth exploration of these new policies, an attempt is made to draw lessons for developing economies. These include issues regarding regional innovation, the importance of manufacturing and adopting corresponding innovation in production, financing for production scale-up, workforce education and incorporating both "top down" and "bottom up" approaches.

# I. The United States historical context

The United States went through waves of shifting industrial policies as it evolved from an agrarian, developing country to developed status by the mid19th century.[3] These have followed a pattern of governmental action and reaction. After its Constitution formed a central government in 1789, the federal government adopted a series of industrial policy approaches including a central banking system and government-owned arsenals and shipyards for military production. At the state level, there was direct support for roads, canals, steamship routes, railroads and manufacturing. A political reaction in the 1830s ended the central bank and opposed state-awarded monopolies for transportation infrastructure in favor of *laissez faire* competition.

The American Civil War in 1861-1865 and the rise of the northern political dominance for most of the remainder of that century led to another round of interventionist policies for transcontinental railroads, land-grant universities and land distribution through homesteading. The subsequent rise of the corporation as the core organizational model for industry challenged the power of the state. In turn, this led to a "progressive" reaction, encompassing government regulation of railroads and antitrust laws.

During World War I, the federal government took control over much of the economy, including imposing widespread price controls. This was followed by a reaction against governmental interventions that lasted until the economic depression of the 1930s and the "New Deal" interventionist policies that accompanied it. During World War II, controls comparable to World War I's were implemented.

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[3] This paper draws from Bonvillian (2022).

## A. Post-World War II developments

On the innovation policy side of those wartime policies, Vannevar Bush —President Franklin Roosevelt's World War II science advisor— led the creation of a highly connected system for technology advance. His approach enabled the federally funded research university to be initiated at scale, and these universities were closely linked to industry, the military, and government agencies. Federally-funded research and development centers (later called FFRDCs) were created as well, and these elements led to critical wartime technology advances such as radar and atomic weapons. It was an intense system of industrial policy designed by Bush and other technology leaders that enabled the U.S. and allies to win the war. Immediately following the war, Bush led the dismantling of much of this extremely successful "connected" system. He recommended instead a focus on basic research within a disconnected system. The title of his policy tract advocating this approach, "Science, the Endless Frontier," was designed to appeal to the American sense that opportunity beckons at the frontier (Bush, 1945).

Why did he advocate this disconnected approach? With the war machine being dismantled in the expectation of world peace, Bush likely was trying to salvage some parts of the system. He saw the power of the federally funded research university and advocated federal support for basic research that could sustain that creation. Basic research is far cheaper than applied development, and he likely thought the government could still support that basic stage amid the postwar cutbacks. He also was concerned that science, had become too tied to government, with all its intense political and military power, and he wanted to shield it, reclaim its independence. Bush advocated what was later called the "pipeline model" for innovation, with early-stage research as the federal input into the pipeline, with the later pipeline inputs leading to technology development relying on industry. The model disconnected the actors in that innovation system.

One of the implications of Bush's disconnected approach was that the federal government failed to support innovation in manufacturing technologies and processes. That was industry's job. The U.S. was the first nation to adopt mass production at great scale, and by the end of World War II no nation was close to its industrial output through these mass production innovations. So there was no need for the government to focus on manufacturing, that leadership seemed assured. Yet production can be highly innovative in itself —designing a new technology or product for implementation is a highly creative step, involving extensive engineering and often new science to bring an idea to a market price with market resilience. Yet the U.S. innovation system missed this— it treated the research and development (R&D) stage as innovation and failed to grasp that production was an important aspect of innovation. Correspondingly, weakness in production innovation means erosion in the overall innovation system.[4] Too often it means that new products and technologies remain ideas and fail to enter the market or are scaled-up elsewhere, with corresponding economic loss.

## B. Position of United States mainstream economics

Bush's pipeline model also reflected the subsequent attitudes of mainstream U.S. neoclassical economists. Put simply, their view has been that governmental interventions in areas where there are not clear market failures distort markets and their efficiency. There are two underlying problems economists have noted with industrial policy. The first concerns information asymmetry: government does not know what to focus on so its market interventions will be inefficient. The second concerns regulatory capture: rent seekers in the private sector will use governmental support mechanisms to distort markets to limit their competition.

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[4] For a discussion of this problem see Bonvillian and Singer (2018).

Part of the reluctance of U.S. mainstream economists to countenance government intervention in not simply an economy but in its innovation system, comes from the limits of their toolset. These economists emphasize mathematical economic modeling of markets and their efficiency and have an inability to model and therefore understand innovation and the complex systems behind it. Innovation requires consideration of many complex elements outside of scientific advances that are not readily amenable to economic modeling, such as culture, traditions, vested political interests, change agents, governmental infrastructure, public expectations, collective action, and organizational management.[5] Many mainstream economists have treated innovation as exogenous —important to economic growth but beyond the reach of their toolsets to grapple with and model.

On the other hand, economist Dani Rodrik has noted that the case *for* industrial policy rests on two basic rationales: externalities and coordination failures (Rodrik, 2022; Rodrik, 2008). Externalities include costs or benefits that producers' actions create for society at large. Because the social benefit of investments in technology development exceeds the benefit to the firm itself, the firm will inevitably underinvest and much of the overall potential benefit will be underachieved. Coordination failures occur because firms will invest to advance technology where there is adequate infrastructure, R&D knowledge available, quality suppliers nearby, and a skilled workforce present. If these conditions do not exist, there has been a coordination failure in creating them, and government agencies have a role in improving the coordination. This has long been the theoretical basis for the pursuit of industrial policies in developing economies (Rodrik, 2004).

However, in the U.S., the above coordination conditions —infrastructure, R&D, suppliers, and workforce— have long been present in many regions. Therefore, mainstream neoclassical economists have opposed governmental industrial policy intervention as disruptive of market efficiencies. Despite this, the U.S. government has pursued industrial policy approaches in a series of *economic* areas, where market failures of various kinds prevail: health care, transportation and energy infrastructure, agriculture, and education.

On the innovation side, the government has provided strong support for scientific research, which has been justified as overcoming a market failure, since industry generally cannot bear the risk of long term research without clear applications. But the government, applying the Bush pipeline model, has generally followed mainstream economic doctrine and avoided governmental interventions in post-research innovation phases, apart from the defense sector. This has included, until recently, a lack of focus on innovation in manufacturing technologies and processes.

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[5] For a discussion of the dynamics of innovation, see Bonvillian and Weiss (2015).

# II. Defining industrial policy

## A. The debate over social goals for industrial policy

A preliminary question concerns defining industrial policy. In 2013, a British economist broadly defined it as "any type of intervention or government policy that attempts to improve the business environment or to alter the structure of economic activity toward sectors, technologies or tasks that are expected to offer better prospects for economic growth or societal welfare than would occur in the absence of such intervention" (Warwick, 2013; UNCTAD, 2016; Page and Tarp, 2017). More recently, another analyst defined industrial policy as "a set of policies and programs explicitly designed to support specific targeted industries and technologies" (Atkinson, 2021). In this sense, there can be multiple industrial policies, for a variety of goals —including U.S. international competitiveness, especially in advanced technology sectors.[6]

Others have taken the term "industrial policy" and tried to apply it to goals that are more about social policy, taking up the "societal welfare" element to advocate for "mission-based innovation" (Mazzucato, Kattel and Ryan-Collins, 2020; Mazzucato, 2020). This approach seeks to apply technological innovation not only to technological challenges but to societal missions such as reducing economic inequality and building sustainable development —and puts forth the Apollo Moonshot project as an organizational model for how to get there.

Such advocacy for an industrial policy that addresses societal welfare poses the question of industrial policy's purpose.[7] A report from an American liberal think tank provides a good example; it

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[6] A 2022 report from the Center for Strategic and International Studies explores some of the more traditional definitions of industrial policy; see, DiPippo, Kennedy, Mazzocco and Goodman (2022).

[7] See Atkinson (2020); Weller, Farooque, Sullivan Govni, and Kaplan, (2020), seek an industrial policy that will yield "hybrid learning tools and pedagogies to broaden access to high-quality education [and] energy technologies that align with communities' values and priorities, and [technology for] neglected and hazardous infrastructure" to advance American ideals of equality, justice, and opportunity". Roberston and Hamilton (2020) argue that industrial policy should be reframed around economic interventions that benefit workers, prioritizing "child care, elder care, health care, and housing".

advocates industrial policy that would be aimed at the services sector because it is where the employability of women and Afro descendants is predominant (Tucker, 2019). Yet services sectors are also the home of the nation's lowest-wage, lowest-quality jobs, so why not focus instead on *technology* sectors that offer quality jobs and work to expand desperately needed workforce education so minorities can better access those quality jobs?

Political economist Suzanne Berger argues that such advocacy reaches too far (Berger, 2021). Technology programs such as the Apollo mission or the Manhattan project were organized around technology goals, not broad societal goals —rocketing to the moon or creating atomic weapons, not solving economic inequality or other societal goals. Putting societal goals ahead of technology development goals for industrial policy risks political disarray and is simply impractical.

What Berger is saying is that the term "industrial policy" has to emphasize *industrial*. Going beyond that adds a major political dimension that requires widespread public consensus for long-term, sustained political change. Making social goals (economic equality, etc.) the aim of industrial policy requires broad political consensus that is difficult to achieve in the U.S. as well as in most other nations. Pursuit of more direct technological goals is more politically manageable, although they may have societal goals embedded in them.

Growth economics has long established that technological and related innovation is the largest factor in economic growth —which, in turn, is a major enabler of societal economic well-being. But some specific societal goals are more in range of a technology strategy than are others —like developing energy technology that addresses climate change or implementing advanced manufacturing technologies to make the manufacturing sector more competitive and retain manufacturing jobs.

Often driven by external crises, the federal government has periodically and actively sponsored industrial policy approaches. Societal welfare has typically not been the stated goal, but can be a byproduct; rather, the goals are typically narrower sectoral or technology targets, or economic goals, such as improving economic competitiveness. That said, no one who has spent time in the American industrial Midwest, with its swath of closed auto, steel and other factories and the corresponding social nightmares to which such closings can lead can argue that an industrial policy based on restored competitiveness is without societal justification.

## B. Industrial economic policy versus industrial innovation policy

Historically, the United States has pursued many industrial *economic* policy-type approaches in areas such as transportation and energy infrastructure; healthcare delivery through medical benefit programs; and agriculture infrastructure and price supports, with government involvement through subsidies, contracting, regulatory, and tax policies that, in turn, affect technology deployment. These industrial policy interventions have been in particular economic sectors and involve deploying available technologies to further governmental policies.

Industrial *innovation* policy is somewhat different. It focuses on the government role in fostering innovation approaches within the broader industrial *economic* policy context —such as support for advanced manufacturing technologies and processes. Industrial innovation policy includes a governmental role not only in research but also in later-stage development and implementation of technology innovations.

Industrial innovation policy plays out within the well-known stages through which a technology must advance: research, development, technology prototyping, testing, demonstration, product development, production financing, market entry, and expanded market creation. It entails government intervention in one or more of these stages in order to further a technological advance. This is the working definition applied in this paper. The U.S. science and technology organization of

World War II, for example, which knitted government, industry, and universities together with interventions at all these economic stages, was clear industrial innovation policy to meet wartime technology needs.

Industrial innovation policy goes beyond the "moonshot" approach some call for, which follows a relatively straightforward government-contract model —the government issues contracts to firms and organizations for the technology to get us to, say, the moon. Many industrial policy approaches, however, also require that new technologies be developed, adopted, and embedded in the far larger private sector, a much more complex technology organization and system effort that requires major public-private collaboration. Energy and related climate challenges, for example, fall into this category. We also need to keep in mind that industrial policy, as discussed below, can involve a range of implementation approaches.

# III. Prior United States industrial innovation policies

## A. Four periods of industrial innovation policies

Despite the reluctance of its mainstream economists, the federal government has since the end of World War II nonetheless moved through four somewhat discernable periods that can be considered as precedents for industrial innovation policy approaches. In each one, it has tried to reconnect —at least partially— the different actors in the U.S. innovation system in industrial stages beyond research (Bonvillian, 2014).

These four periods began with a *first period* during the Cold War that firmly established defense industrial innovation policy but did not do the same for civilian industry. Beginning around 1950, the military worked to integrate key innovation actors —industry, university, and government— in service of the defense mission, which ultimately led to the creation of the National Aeronautics and Space Administration (NASA) and the Defense Advanced Research Projects Agency, both in 1958.[8] The scope of the Cold War threat forced its Department of Defense (DOD) to return to the connected approach of World War II briefly described above.

The *second period* was the era of manufacturing competition with Japan in the 1970s and 1980s, when Japan's economy advanced in leaps with the modernization of its industrial production process, the total quality management revolution— and the United States found its industry comparatively disadvantaged by a lack of government coordination of innovative activities and actors. U.S. industry was forced to play catch-up as it climbed the steep learning curve to embrace total quality production. This was the period of novel policy attempts to try to help small innovative firms and start-ups at the cutting edge of technological innovation grow and compete in global markets.

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[8] See, for example, Fong (1986).

These programs included streamlining technology transfer with the *Bayh-Dole Act* in 1980, which gave universities ownership rights to patents that resulted from federally funded R&D, and the *Stevenson-Wydler Act* also in 1980, which introduced similar incentives for federal laboratories. They also included the *Manufacturing Extension Partnership* to bring new manufacturing processes to small manufacturers and the *Small Business Innovation Research* program to support small firms and startups in developing technologies from their research. Other policy initiatives sought to support companies seeking to gain a competitive edge via innovation. The programs included the *Advanced Technology Program* to support technology development at companies, *Sematech, t*o restore U.S. semiconductor leadership through manufacturing quality and efficiency improvements, and the *R&D tax credit* to encourage companies to invest in research and development.

The *third period* began around 2001 with policy efforts to mitigate climate change through energy innovation at the Department of Energy. The new policies translated into new offices and tasks added to the department rather than modifying its existing functions. The new elements included the Advanced Research Projects Agency-Energy (ARPA-E), expanded renewable energy programs, advanced manufacturing institutes, a Loan Programs Office for financing new energy technology projects, Energy Frontier Research Centers to support basic research in new technology areas, and energy Hubs to promote applied R&D in key technology fields. Regulatory programs were also expanded to drive technology shifts.

*A fourth period* has evolved in recent years around advanced manufacturing. When U.S. manufacturing employment shrank by one-third between 2000 and 2010, 60,000 factories closed as production shifted to China and other countries ready both to operate at a fraction of the labor cost and to introduce new efficiencies. The problems of the disconnect made in U.S. policies between innovation and manufacturing noted in section I became acute in this time period. Accelerating manufacturing productivity by applying U.S. innovation capability seemed the best answer. In response, after 2012, the federal government created its network of manufacturing innovation institutes (there are currently 16) called Manufacturing USA, supported by the departments of Defense, Energy, and Commerce (through its National Institute of Standards and Technology (NIST) (Bonvillian and Singer, 2018). Each institute was organized around a particular advanced manufacturing technology, ranging from 3D printing to photonics, digital production, and robotics. While past manufacturing policy focused on trade or tax incentives, the institutes aimed to accelerate introduction of productivity-enhancing manufacturing technologies to enable the United States to better compete in a collaborative model to bring together industry and universities, with support from three federal agencies and from state and local governments. However, the institute program is still operating at a limited scale.

## B. Remaining challenges in energy and manufacturing

The success of industrial innovation policies over these four periods has been mixed, with many successes on the defense side but a mediocre record for demonstration projects motivated by energy policies (Weiss and Bonvillian, 2009). Energy and manufacturing initiatives are ongoing so require particular attention. Several past energy projects faced massive cost overruns or were otherwise unsuccessful; among the most visible setbacks was when the Department of Energy (DOE) made a $535 million loan guarantee to a solar firm, Solyndra, in 2011 to scale advanced thin film solar technology. Solyndra could not compete with low-cost, lower-tech subsidized panels put into the U.S. market by Chinese firms, and the firm went bankrupt (Lott, 2011; Lazonick, 2011). This highly publicized episode was embarrassing for those advocating industrial policy approaches and problems like Solyndra remain a warning light for future federal industrial policy attempts. As discussed below, a new infrastructure is needed for not only testing and demonstration of new energy technologies but scale up and financing of these technologies.

In the manufacturing space in the U.S., a series of updates to the new manufacturing institutes programs is required to improve their effectiveness (Adler and Bonvillian, 2023; Bonvillian, 2021; Bonvillian and Singer, 2018). Because manufacturing policies play a significant role in the programs developed in 2020-2022 and discussed below, issues in the Manufacturing USA program requires elaboration here.

- *The term limit problem*: The institutes have never had the budget or long-term commitment that a manufacturing technology transformation requires. At the outset of the program, the institutes were placed on term limits, with federal support set to end after five years. This was a political decision but was never realistic: the structural problems in manufacturing the institutes were designed to tackle cannot be solved in five years, they represent long term challenges. The term limits forced the institutes to organize around the needs of large companies —the only source that could sustain them over time when the government pulled out— which meant they had to neglect the smaller firms that were furthest behind in adopting new technologies and limit their workforce education investments. For the program to improve its effectiveness, the term limits should be ended with institutes subject to rigorous review at the end of their terms; if they are successful they should be extended with comparable funding. The Department of Commerce's NIST has taken this approach with a renewed federal cost share continuing prior funding levels. The Department of Defense has begun to evaluate and renew its institutes but at a lower cost share. The Department of Energy as of 2023 is still considering this approach. The institutes require both a renewal process and substantial funding.

- *A network of Institutes is missing* - In addition, institute efforts need to be networked across the institutes. Companies do not want to adopt advanced manufacturing one technology at a time just because they were developed at separate, stove-piped institutes. Instead, institutes need to offer packages of their technology advances to firms. For example, firms do not want to adopt just robots, they want robotics integrated with digital production technologies, and with other technologies such as 3D printing or advanced composites. The program needs an institute network function to pull together advances from across institutes and package them for easier adoption.

- *Improved collaboration with state and local governments is needed*. Although the institutes must have a national mission, manufacturing is highly regional, and the states and local governments play the leading roles there in economic development and workforce education. Collaborations between them and the institutes are ongoing but deepening them will be key to institute success. New manufacturing technologies need to be available for national adoption but tested and piloted regionally, which means institutes must operate at both national and regional levels.

- *Gap in connections to the R&D agencies*. The federal basic research agencies work at what DOD and NASA have characterized as "Technology Readiness Levels" (TRL) 1 through 3, meaning they support early stage research up to proof of concept experimentation. Since industry typically devotes most of its resources to the scale-up and initial production stages —TRL levels 7 through 9— there a is major gap (the "valley of death") in between. The manufacturing institutes are designed for these in-between levels, from development and prototyping to technology demonstration (TRL levels 4-7). But if the institutes focus at these post-research stages, over time they will need new input from earlier stage research. The federal R&D agencies have historically not focused on research on manufacturing technologies and processes —that has been viewed as industry's purview, although industry emphasizes later stage development not research. However, manufacturing needs to be seen as a system, with connections throughout, from research to production. These

> connections need to be built, and a cross agency agenda between these agencies and the manufacturing institutes is needed. Otherwise, development work at the institutes may become stranded.

In addition, programs for scale-up financing and improved manufacturing workforce education (discussed in sections VI and VIII, below) are required outside of the manufacturing institutes to supplement their efforts.

## C. Overall points

The United States, to summarize, has engaged in a series of industrial innovation policy approaches since the end of World War II. By far the most significant has been through its defense system, where it built innovation agencies and linked them to follow-on defense procurement investments. While the investments were made for national security reasons, many of the technologies were "dual use," creating new economic sectors, including space, nuclear power, computing, and the Internet. Most of the post-war innovation waves have come out of this connected system.

The efforts outside defense were smaller in scope and scale, but still have been noteworthy. These include various programs enumerated above, in response to competitiveness pressures from Japan, new energy technology efforts to address climate change, and, lately, an effort to create public-private consortia to develop advanced manufacturing technologies. Both the energy demonstration efforts and the advanced manufacturing institute program face challenges and require improvements. But all generally fit within the industrial innovation policy definition of governmental policy interventions that alter economic activity in post research phases of innovation. In general, these interventions into sectors, technologies, or tasks aim to improve economic prospects for innovation in ways non-interventionist market forces cannot. All have tended to share three general characteristics concerning coordination of the conditions of innovation: they build on strong U.S. R&D capacity, they support particular technology advances and sectors, and they take advantage (if available) of federal follow-on procurement funding or financing.

# IV. The driving forces behind the United States new policies

A number of new industrial policy efforts took shape between 2020 and 2022 that were dramatically different in size and scope from what has been previously attempted in the United States.[9] This was enabled in part by a major shift in government fiscal policy approaches in response to the Covid pandemic that created a rather abrupt outpouring of billions for industrial innovation policy as part of a general stimulus policy.[10] There were three drivers of new policy in this period.

## A. The pandemic

The first was the Covid-19 pandemic, which killed more than a million Americans and over six million worldwide between 2000 and the end of 2022 and drove U.S. industrial innovation policies for the development and deployment of new vaccines.

The implications of Covid-19 for future industrial policy lie in what the future holds. Going into Covid-19, the United States had the reputation as the world's best-prepared nation for such outbreaks —a reputation that, except in vaccine development, was shredded during the pandemic (The Covid Crisis Group, 2023). The operating assumption of the American public by the end of what appeared to be the most acute phase of the pandemic in 2022 was that it would be a once-in-a-lifetime development, comparable to the 1918–1919 influenza pandemic. Most felt they would be good for another century —a view contradicted by the new realities of global connectedness that drove the pandemic's spread.[11] An ongoing threat of global infectious disease outbreaks could, therefore, become a continuing driver for industrial policy efforts.

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[9] See generally, Maher (2021).

[10] These events are detailed in, Tooze (2021).

[11] See, Mandavilli (2022). These new realities include massive international travel, growing animal-human transmission, and widespread resistance to masking, vaccines, and other public health measures. Public health experts predict that infectious outbreaks will grow in frequency, exacerbated by chronic underfunding of public health systems, divided public health responsibilities between states, localities, and federal agencies, obsolete data collection systems, and a lack of urgency in making corrections.

## B. Climate change

Climate change is a second policy driver. The risks have become increasingly apparent through the increasing intensity of disruptive events such as wildfires, droughts, and hurricanes. While political resistance to recognizing climate change persists in the United States, which has precluded national political action on economy-wide carbon pricing and cap-and-trade legislation, there has been a shift toward grudging political support for a technology policy approach to climate. This led in 2021 and 2022 to major legislation incentivizing the entry of new energy technologies. This technology policy approach has been an alternative to the problems of getting agreement on a carbon pricing policy approach (Bonvillian, 2016; Weiss and Bonvillian, 2009).

## C. China's technological advance

Finally, there is the challenge of China's technological advance —the third driver. That this became a driver is linked not only to major spending to mitigate Covid-19 and its economic impacts, but also the Trump administration's spending ways more broadly —including major tax cuts passed without spending reduction offsets. This signaled that at least part of the Republican Party had temporarily abandoned its longstanding fiscal conservatism. Other areas of federal spending were also opened up in the 2020-2022 period in the name of economic recovery. This included industrial policies thought to be required for competition with China, which became the leading nation in manufacturing output in 2011and has been spending massively on its own industrial policy efforts.[12]

China's entry into the World Trade Organization in 1999 sparked a major expansion in an era of global economic integration, but since 2008 that trend has been reversed.[13] A new international system is emerging based more on global clusters, with major consequences for innovation policy. The Covid-19 pandemic provided lessons about the dangers of depending on global supply chains, providing a corresponding impetus for domestication of supply chains and national supplier systems; these widely perceived Covid lessons were heightened by growing international conflict led by Russia's invasion of Ukraine in February 2022. Today, older ideas on organizing industry, like just-in time inventory and abandoning non-essential elements in favor of an emphasis on core competencies, are being replaced by concerns about resiliency and more vertical integration.

The fading post-Cold War consensus about world economic integration has underscored views in the United States about the need to reestablish domestic supply chains and manufacturing leadership. There is an increasing understanding that technology leadership drives national security leadership. Manufacturing is increasingly understood in the U.S. as the crossroads between national security and economic security and the three are increasingly seen as interdependent. China's new ascendancy —including its major new applied technology programs that exceed U.S. funding levels in semiconductors, artificial intelligence, and advanced manufacturing— has led to a perceived technology challenge in the United States, motivating industrial policy approaches.

These three policy drivers, which are likely to endure, have led to a set of new approaches to industrial innovation policy that have emerged in the United States in recent years. The magnitude of the efforts associated with these approaches is far above anything previously attempted outside the defense sector. Combined, fully implemented beyond the examples discussed below, and adequately funded, they could signal a major policy turning point and constitute a fifth period of industrial innovation policy, in addition to the four discussed above —and a more systematic one.

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[12] See, for example, Naughton (2021); DiPippo, Mazzococo, Kennedy and Goodman (2022).

[13] See, for example, Kroenig (2020); Bateman(2022); Kuttner (2022).

# V. United States industrial innovation policies in the 2020-2022 period and their underlying approaches

The U.S. between 2020 and 2022 put into effect six major new industrial innovation programs: Operation Warp Speed (for rapid vaccine development), the CHIPS[14] Act (for rebuilding U.S. technology capability in semiconductor manufacturing), the Infrastructure Act of 2021 (which included major energy technology demonstrations), an executive branch initiative on Building Resilient Supply Chains (for improving supply chains in four critical technology areas), the Inflation Reduction Act (which included $378 billion for implementing climate-related energy technologies), and the science portions of the CHIPS and Science Act (which established new applied programs at NSF).[15] Total approved funding for these programs was over a half trillion dollars.

Below is a summary of the underlying approaches to industrial innovation policy these six major new initiatives exemplify. Seven approaches have been identified and each represent a series of identifiable support steps for industrial innovation policy.

## A. Top-down approach

Nearly all of the historical industrial policy approaches from 1957 through 2019 described above in section III were driven by crises. So, too, was the effort beginning in early 2020 to develop a vaccine for Covid-19 known as Operation Warp Speed (OWS); it was a massive crisis that emerged suddenly. OWS involved the implementation of a new *top-down* approach to industrial innovation policy that is almost universally acknowledged as a major accomplishment, thereby showing the potential of the top-down

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[14] Acronym for Creating Helpful Incentives to Produce Semiconductors.

[15] Details on these programs are set out in Bonvillian (2022).

approach that drove the effort. It offers important lessons for other industrial policy efforts, and the wide-ranging toolset of OWS is potentially relevant to other industrial innovation efforts.

Organizationally, OWS was a wholly governmental, cross-agency partnership involving multiple departments and agencies, including the Defense Department, the Department of Health and Human Services (HHS), the Food and Drug Administration (FDA), the Center for Disease Control (CDC), and the National Institutes of Health (NIH). It gathered a *team* of first-rate, dedicated officials assembled from across the government, led by a former senior pharmaceutical executive and an Army logistics general. This group operated as a change agent at rapid speed to respond to the national crisis, cutting across bureaucratic lines and taking advantage of diverse agency expertise and legal authorities. It was, as Dr. Matthew Hepburn, the OWS lead for vaccine development, put it, "inspired by DARPA but with a focus on scaling and implementation. OWS was DARPA at scale."[16]

OWS took a page from DARPA and decided on a *portfolio approach*, building on prior research on mRNA and other vaccine approaches. The portfolio approach allowed for managing the technology risk and electing a range of technologies and firms (Slaoui and Hepburn, 2020). After reviewing more than 100 pending vaccine projects, three vaccine technology platforms were selected and then two leading companies were picked to support each of them. OWS was picking winners: it made these selections based on which companies it found were furthest along and most able to develop the different types of vaccines.

The effort was not a public-private *partnership*,[17] but rather was *directed at* and included *collaboration with companies* in the private sector. This is a distinction worth noting. A public private partnership (PPP) involves an organizational entity where the governance is shared between public and private sector participants. The advanced manufacturing institutes described above in section III, for example, exemplify more of a PPP with industry as well as universities and governments participating in and helping govern the institutes. Because OWS was selecting vaccine candidates among industry competitors and then playing a role in their regulation, involving firms in governance would create potential conflicts of interest. So OWS apparently elected instead a collaboration approach with industry, keeping governance in the hands of government officials and appointees. That is not to say that PPPs cannot manage potential conflicts, for example through fencing off directly affected participants from certain decisions. But OWS faced potential conflicts throughout its processes and elected for collaboration not a PPP. This may be more of an issue for top down type approaches. The OWS collaboration was successful, however, in significant part because the collaborating companies were committed to the mission—especially with committed leadership at companies such as Moderna, Pfizer and BioNTech.[18] This company mission commitment can be a key success factor in both PPPs and collaborations.

These components —the portfolio of winners "picked" by the government, the particular team that was built, and the way the private sector was involved— are what define this approach as "top-down" in this discussion. This OWS effort employed a set of tools that is relevant for other such efforts, which included:

- Guaranteed contracts
- Flexible contracting mechanisms
- Technology certifications
- Mapped supply chains

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[16] Quoted in Adler (2021). This source was drawn on for information in this section.

[17] For a definition and description of public private partnerships, as well as conflicts and other issues with PPPs, see, for example, Investopedia (2022).

[18] See, for example, Lo (2020); Bourla (2022); Vardi(2020); Miller (2022); Gelles (2020).

- Diverse talent from across skills and fields
- Federal officials working collaboratively with companies on regulation and product development and introduction
- Cross-agency collaboration
- Accelerated distribution systems.

*Contracting* was a critical OWS tool: both *guaranteed contracts* and *flexible contracting mechanisms*. The selected firms received guaranteed contracts to purchase substantial volumes of their vaccines despite that they were not yet fully developed or approved by the FDA. This allowed for further development and clinical trials and assured doses would be ready as quickly as possible. The government guarantee to purchase the vaccine at scale enabled purchasing supplies, developing production facilities, and scaling up production and distribution as soon as they were approved. The government's guarantee that it would purchase the vaccine at scale enabled the firms to take the risk of ordering supplies and developing production facilities and was vital to scaling up rapid production. This ability to provide contracts to assure an initial market and therefore reduce the risk of scale-up is a mechanism with potential applicability to other health challenges, as well as to other technology development fields.

OWS also made extensive use of *flexible contracting mechanisms*. The Defense Production Act was employed because it allows the federal government in national emergencies to require suppliers to supersede serving their existing customers in order to meet security needs. OWS also intervened directly when necessary under the Act to help in production, by building or refurbishing production plants, purchasing and fitting out equipment, hiring staff, enabling raw material supplies and purchasing vials, syringes, and needles in bulk (Adler, 2021). This decidedly top-down element of the OWS approach was key to lining up supplies and resources for vaccine makers to avoid production delays. The ability to intervene to assure secure supply chains is also relevant to other technology development projects to further industrial innovation policies.

Other Transactions Authority (OTA), first developed by DARPA and used by DOD agencies, offered a way around the extraordinarily slow-moving process of normal federal procurements that could have sunk the OWS efforts, reducing the time to a contract agreement to days and allowing greater involvement of biotechs and smaller suppliers that do not typically work with complex federal contracting. Again, this authority is broadly applicable in other technology areas.

*Technology Certification* was also an important element. The FDA's Emergency Use Approval (EUA) enabled it to do just that —to meet emergency needs like the pandemic, without the usual full approval process that can take years. This FDA step was critical, amounting to a technology certification and validation of the technology, ensuring instant market acceptance. Because FDA approval is the most respected approval agency for medical products worldwide, most of the American public immediately accepted the FDA-approved vaccines for Covid-19 as soon as they were available. There is no technology certification at all equivalent to FDA's for medical products in other areas, which amounts to a gap in the innovation system. But the federal government could use its strong lab network to undertake technology certifications to help ensure earlier market acceptance in a range of technology areas.

The Defense Production Act enabled OWS to intervene into supply chains, but key to that was an in depth understanding of every facet of relevant supply chains. *Mapping Supply Chains* was another important task. DOD's logistics experts, fluent with emergency logistics crises, understood supply chain reliability and how to map these chains. It greatly helped the vaccine companies with the intense supply issues they faced in vaccine production. The techniques for supply chain mapping could be systematized and used to create resilience in a host of technology development efforts.

OWS also set up *close linkages between federal personnel and companies* to help then with the complex regulatory approval processes and to assist with project management and supply access. The FDA traditionally keeps companies and research organizations at a distant "arms length" to assure regulatory independence. But FDA's Coronavirus Treatment Acceleration Program (CTAP) was an "all hands on deck" effort in "a public–private approach" to speed the introduction of treatments. It "deployed medical and regulatory staff to serve on review teams dedicated to COVID-19 therapies, streamlined processes and operations for developers and scientists to send inquiries and requests and provided resources to health care providers and researchers to help them submit emergency requests to use investigational products" (FDA, 2020). The FDA made it easy for the industry to set up advisory meetings with the agency during the development process for pandemic-related products. And it provided detailed guidance explaining the FDA's priorities and recommendations for clinical trials of potential treatments to speed trials (The Commonwealth Fund, 2020). While Pfizer, as a large company, could manage its own clinical trials, the NIH managed the clinical trials for smaller companies like Moderna.

In addition, the Army Corps of Engineers oversaw construction to expand company production facilities (Adler, 2021). This kind of direct assistance was particularly vital to the smaller biotechs participating in the project. As an OWS leader put it, "We told the smaller biotech companies, we will help you grow. We will put people in your manufacturing plant. We will help you with project management. We can assist with your regulatory strategy" (Adler, 2021). The linkage with government personnel did not at all compromise the regulatory process but it cut bureaucratic barriers and accelerated processing. This is an approach, with appropriate conflict of interest safeguards, that could be more widely employed to speed critical technology development.

Finally, concerning *Distribution Systems*, OWS took on the task of getting vaccine doses shipped to states, setting shipment priorities based on a state population-based formula. The two mRNA vaccines from Pfizer/BioNTech and Moderna predominated and were particularly difficult to ship because they had to remain frozen and required special complex handling. Only a tiny amount of vaccine ended up spoiled in shipment. While the military helped boost distribution at occasional crisis points, OWS relied on efficient private sector shippers for delivery. Actual administration of the shots was left to states and their public health officials at their insistence. While in many states this was problematic and actual vaccinations lagged well behind deliveries, over time this was straightened out. In the end, the United States led vaccine development and distribution, starting vaccinations two weeks ahead of its EU developed nation counterparts. The lessons from OWS on distribution organization and efficiency can also be more widely employed in technology development efforts.

OWS was not about science research; that work was largely completed by the time OWS began. But it did set a new standard for rapidly scaling up a technology into final development, manufacturing and widespread use. OWS removed the R&D risk and the regulatory risk and its guaranteed financing and demand regardless of final regulatory outcome removed implementation risk. While the Defense Department often undertakes this kind of effort, OWS was largely unique for non-defense areas. As Matthew Hepburn, the OWS vaccine director, has pointed out, it was like a DARPA for scale up. It revived interest in the United States in industrial policy, lifting it out of its long-dormant status as the bane of mainstream economists. It represented a strong and remarkably successful industrial policy approach. To reiterate, each of the major tools OWS employed has the potential for application for industrial innovation programs.

Unfortunately, the Biden Administration shut down OWS when it came into office, although some of its tools were still needed for pandemic management and its approach —including industry collaborations— could have been applied other major medical needs. Keeping it going would have offered further proof of this top-down approach as one model for the range of capabilities that can be deployed. The Biden Administration has since attempted to revive OWS as "Project Next Gen" although it lacks the impetus and funding that led to OWS (Diamond, 2023).

## B. Bottom-up approach

Government support for businesses is one of the most politically contentious issues in American policy debates. Opponents on all sides of the political spectrum argue that it can give an unfair advantage to one or a few companies, skew competition, and, generally, that government has never been good at picking winners. The Solyndra example above speaks to the problems: the company received Department of Energy (DOE) loans for its production and then failed during the early years of the Obama administration, which triggered a sharp political attack on the government's lending.

The Department's loan program continued, though, and in 2022 was significantly expanded through the Inflation Reduction Act (discussed below). Tesla, the first major electric vehicle maker, had been a major beneficiary of the program; it received a major DOE loan —critically important to the company— that was approved in 2009 and available through 2013. By the end of 2021, Tesla had reached a market value above the combined value its five largest competitors (although its value has declined somewhat since then) (Macrotrends, 2022; Boudette, 2022) By 2022, it was producing close to two million electric vehicles a year (Kane, 2022).

In fact, Tesla is a good example of how a company —and a sector of the economy— can benefit from government support (Vance, 2015), in this case part of a *bottom-up* industrial innovation policy approach undertaken for a climate change mission of promoting electric vehicles (EV)**.** Unlike with Operation Warp Speed, the government role in supporting EVs was not *top down*; it did not select a portfolio of winners to receive support in a series of key technology areas. Rather, the strategy was more *bottom-up*; it created a menu of incentives and then relied on firms to come to the table and take advantage of them. In the specific case of Tesla, government did not drive the creation of the company, but government incentives, loans, and regulatory elements were employed by Tesla, systematically, to help the company overcome barriers and assume leadership in electric vehicle production. These mechanisms were more or less direct.

The direct category includes *lending*, as noted above, in the form of the $465.5 million DOE guaranteed loan, authorized in 2009 as part of the Advanced Technology Vehicles Manufacturing program to build out its factory in California.[19] This loan, which Tesla paid back in 2013, helped rescue the company from near bankruptcy.[20]

It also includes *subsidies*. Tesla has received about $2.4 billion in subsidies, largely from U.S. states (and not including the repaid loan or the electric vehicle credits described below), including as just two examples about $1.3 billion in benefits for its Nevada Gigafactory for battery production, and $750 million for its New York solar panel factory (Tesla integrates its vehicles with solar and storage technologies). Tesla laboratories have received about $3.6 million in subsidies and loan guarantees, and the company has also obtained governmental support from nations other than the United States where it produces vehicles, including China and Germany.

Other government support has come in the form of federal programs that have aided Tesla indirectly, but also substantially. For instance, *tax incentives to consumers for purchase of electric vehicles* have clearly helped spur Tesla's sales (Rezvanit, 2022).[21] In fact, the first federal tax subsidies to help boost

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[19] Tesla's loan from the Department of Energy was approved in 2009 and was available in January 2010; Tesla repaid the loan in 2013, ahead of schedule. See DOE, Loan Programs Office; Higgins (2022). Also, communication to the author from Matt Hopkins, senior researcher, Academic-Industry Research Network, May 23, 2022.

[20] Federal contracts from NASA beginning in 2008 enabled survival of Musk's SpaceX company, which assisted his overall financial position in managing Tesla. See Majeed (2021). Also, communication to the author from William Lazonick, professor of economics, University of Massachusetts Lowell, May 23, 2022.

[21] The EV tax credit, initially created in the Energy Improvement and Extension Act of 2008 and later the American Clean Energy and Security Act of 2009, was $7500 for consumer purchases of electric vehicles limited to the first 200,000 cars produced by a firm. The 2022 Inflation Reduction Act provided a credit of $7500 for vehicles assembled in the United States, without the limit.

EV sales of $7500 per vehicle, initiated in 2008 and 2009, reduced the cost of the first 200,000 Tesla vehicles by a whopping $1.5 billion. This consumer tax credit was renewed without the 200,000 car limit in 2022 for EVs built in the United States. In addition, the federal government provided (and the Inflation Reduction Act of 2022 extended) a tax credit of up to $1000 for EV charging hardware (totaling $1.7 billion) for consumers and $30,000 for commercial installations. And 2022 infrastructure legislation contained $7.5 billion for the deployment of half a million charging stations nationwide. Tesla, as the leading U.S. producer of EVs, will be a major beneficiary of this *infrastructure support*, which expands its existing network of charging stations.[22] Each of these tools are potentially applicable outside the energy sector to other technology development projects.

To these federal programs must be added *state regulations and incentives* —particularly in California, where clean air regulations and incentives have supported over time substantial subsidies for EVs, of particular benefit to Tesla. For instance, California's *electric vehicle mandate and offset payments*, a state program for credits for EVs paid by other automakers not making these cars resulted in payments to Tesla of nearly $4 billion from 2019 to 2021 —a substantial part of the company's profits.[23] These payments have been important to its ability to scale up production. In addition, California has, since 2016, offered *rebates* to consumers who purchase EVs, up to $7000 for EVs, based on income eligibility.[24] An earlier version of the rebate program amounted to $2500 per Tesla vehicle, helping to build its customer base (Hirsh, 2015). The Tesla experience indicates the potential value to technology development efforts of state regulatory programs that parallel federal goals.

The less-direct category —meaning the government support was not directed specifically *to* or *at* Tesla —includes *early-stage R&D support* by DOE for the development of improved lithium ion battery technology— along with a number of new programs for applied research and development for EV batteries since 2020. As in so many industries (pharmaceuticals being a key example), private companies can benefit tremendously from such programs. Because batteries are an EV's engine and by far its largest cost element, this support is potentially critical to EV makers, including Tesla.

DOE has funded a range of R&D projects, including for advancements in batteries for electric vehicles, in light-weight materials, and in new mobility systems. Tesla could be a beneficiary of R&D advances that may emerge from DOE's Energy Storage Grand Challenge (ESGC), announced in January 2020. It was the department's first comprehensive strategy based on what it calls "Innovate Here, Make Here, Deploy Everywhere." Performance targets include cost reductions (from 2020 costs) of 90 percent for stationary applications and 44 percent for battery packs in EVs.

Tesla and other companies could also be significant beneficiaries of what comes out of the Federal Consortium for Advanced Batteries (FCAB), a consortium of federal agencies for cross-government cooperation. In 2021, FCAB released a National Blueprint for Lithium Batteries 2021–2030 that laid out five critical goals that cover the entire spectrum of R&D and innovation, including developing a strong domestic lithium processing sector, enabling end-of-life reuse and recycling, and advancing U.S. leadership in battery technology by supporting R&D and Science, Technology, Engineering and Mathematics (STEM) education.

As with these examples, Tesla and the broader EV industry could also benefit from *Li Bridge*, a government-business sector partnership to close gaps in the domestic lithium supply chain. DOE coordinated its formation in 2021 through its Argonne National Laboratory and has provided $209 million

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[22] To access 2021 federal infrastructure funding, Tesla had to agree in 2021 to give up its proprietary changing system and shift to the Combined Charging System (CCS), the common standard for charging electric vehicles. See Lambert (2021). Also, communication to the author from Matt Hopkins, senior researcher, Academic-Industry Research Network, May 23, 2022.

[23] See Boudette (2022). Regulatory credits from other automakers to Tesla totaled $1.5 billion in 2021, making up 27 percent of its $5.5 billion in profits that year.

[24] California Clean Vehicle Rebate Project, Eligibility and Requirements, https://cleanvehiclerebate.org/en/eligibility-guidelines.

in funding for 26 EV battery projects on the "cost and size of next-generation battery technology, fast charging EV infrastructure advancements, potential grid impacts of EV charging, and cooperative vehicle-to-vehicle communications and controls that reduce energy use and emissions" (DOE , 2021). And there is the $3 billion in support for battery development and production for vehicles and storage as part of the $1.3 trillion federal infrastructure package enacted by Congress in 2021 (DOE, 2022).

In summary, in the context of an industrial innovation policy (even if not explicitly identified as such) aimed at supporting expanded use of EVs to mitigate climate change, the government took bottom-up steps that supported (both directly and indirectly) a key company in that sector —even rescuing it from bankruptcy. This support enabled it to build key production facilities, subsidized consumers to purchase its products, supported a massive build-out of charging station infrastructure, and supported advances in EV battery technology. Thus, government (primarily federal, but also state) has been an important supporting partner at every stage. These mechanisms are relevant to technology efforts outside the energy field.

The mix of incentives at the federal level provided in this bottom up approach were not consciously designed as a coordinated mix. The R&D support for battery technologies evolved out of a long history of federal energy R&D support. The loan program began as a support mechanism for nuclear power which was extended to clean energy technologies including electric vehicles. The consumer tax benefits evolved through separate tax legislation. All the federal elements, however, were grounded in a motivation to support electric vehicles. The state programs, particularly California's were rooted in that state's long-established concerns about air quality. The state support for battery plants was an aspect of state economic development efforts. These state efforts emerged from state concerns uncoordinated with the federal programs. So this mix of initiatives was not coordinated in a specific policy thrust and developed at separate times but in the end resulted in an effective, multifaced approach. The R&D efforts scaled into production through the loan program, and demand was encouraged by consumer subsidies —each addressed core industrial policy elements of development, production and demand. The state programs added icing to the federal cake with further production and demand incentives.

This mix of development, production and demand support was not designed up front, and was uncoordinated once put into place, but nonetheless proved quite effective. These governmental efforts amounted to a menu —opportunities were offered but it was up to companies to select from the menu. However, each element effectively reinforced each other. This specifically benefited Tesla, but including development, production and demand elements shows how to help ensure this positive interaction in other bottom-up efforts.

The investments have had major consequences. Putting aside the persistent controversy that has surrounded Tesla's co-founder Elon Musk, the company has successfully demonstrated to the American and world public that electric vehicles work. Tesla has also almost single-handedly driven all the world's major auto producers to commit to a future of battery-driven electric vehicles, displacing more than a century of fossil-fueled internal combustion engines. That supports the government mission explicated earlier.

From a policy perspective, this example demonstrates that a *variety* of approaches to industrial innovation policy exist. While support for Operation Warp Speed was "top down," involving government picking a portfolio of winning companies that offered a range of vaccine technologies, support for EV development was more "bottom up," with government creating incentives and supportive research programs and leaving it up to private sector —with Tesla the leading company— to drive economic development.

The year 2022 provided another major example of the bottom-up approach. In August 2022, Congress passed a massive energy and climate program within the Inflation Reduction Act. The bill's climate-related provisions will cost more than $375 billion in the form of tax and consumer incentives for electrification from clean energy technologies, electrification of surface transportation, and decarbonizing buildings and manufacturing. Among these provisions, the bill greatly expanded the Department of Energy's loan authority, by some $40 billion, through its Loan Programs Office, for energy technology firms, providing support for energy technologies, including manufacturing initiatives and greenhouse gas emissions reduction projects at industrial facilities (Hansen, 2022; Congressional Progressive Caucus Center, 2022).[25]

This maze of incentives and funding was projected to reduce U.S. carbon emissions significantly, bringing it closer to the 2030 goal of a 50-percent reduction from 2005 emission levels (Jenkins, et al., 2022). The key industrial innovation features of the legislation, then, were the tax and consumer incentives and production incentives to industry, at very substantial scale, to drive the introduction of new technologies. In addition, the lending authority could be key to scaling up energy technologies. The legislation clearly amounts to a bottom-up type approach to industrial innovation policy at a level not previously seen.

## C. Demonstration project approach

The demonstration phase for technology development, which follows directly from developing a working prototype, is critical to industrial innovation policy. Only after a technology has been successfully tested and demonstrated can it be moved to the pilot production phase and ultimately scaled up to full production —firms cannot otherwise take the risk.

The Department of Defense has long understood this, and so ensures demonstration phases for its emerging technologies —which has created deep experience with administering this phase along with needed testbeds. The Department of Energy, though, has not created an ongoing capability to manage demonstrations (especially where the commercial sector lacks the incentives to carry these out on its own) —but it will need to do so.

The massive 2021 infrastructure bill passed by Congress places a strong emphasis on the demonstration stage of technology implementation and provides $21.5 billion in funding for these projects through a new DOE Office of Clean Energy. These include *carbon management projects* such as direct air capture hubs and carbon capture demonstrations; *clean hydrogen programs*; *renewable energy programs*; nuclear energy programs for *advanced nuclear* reactor demonstrations; and demonstrations for *critical minerals* and rare earths (Service, 2021; AIP, 2021).

Past problems with government demonstration projects provide three important lessons for adopting this approach to industrial innovation policy:[26]

(i) Incentives (production payments, tax credits, loans or loan guarantees, and guaranteed purchases) for demonstrating the possibilities of new technology deployment to the private sector have important advantages over standalone, government-dominated demonstrations not well connected to potential users;

(ii) Because large demonstration projects with large cash outlays attract congressional interference (such as senior members directing projects to their own districts), creating a quasi-public corporation to manage the demonstration is a way to provide insulation against congressional intervention;[27]

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[25] See, H.R. 5376.

[26] This discussion is drawn from Weiss and Bonvillian (2009); that discussion draws on Deutch (2005).

[27] For a detailed discussion of government corporations, see Froomkin (1995).

(iii) It is important to build flexibility and resilience into the economic model for demonstrations (as is often done effectively in the private sector), so that the executors of the project can react to changing market conditions and design the demonstration to avoid the assumption that current economics will always continue —a mistake that has plagued so many past projects.

Managing a commercial demonstration requires project management expertise that the private sector has and the government largely lacks. A public corporation could be a means to recruit people that do possess such expertise. A public corporation could also operate outside the limits of government procurement systems in an environment more comparable to that of a commercial firm. This private-sector expertise —in both major project financing and commercial-scale engineering— could be backed by the kinds of financial incentives described earlier, as well as by access to a sufficient multiyear stream of assured funding to permit the efficient execution of a demonstration project. Cost sharing with industry can provide a further incentive to cost control and commercial discipline.

Technology demonstrations constitute significant industrial policy. They will not work unless the government builds the management capacity to handle them.

## D. Direct production support approach

Sometimes it is not enough to promote scale up through guaranteed contracts, tax incentives, or technology demonstrations; *direct support of production facilities* —a step rarely taken by the federal government outside the defense sector— is needed. We find an example in semiconductors, an industry that undertakes the most advanced manufacturing at what are by far the most expensive plants in the world. Policymakers found that for the United States to retain even a modest level of advanced semiconductor production capability, a governmental intervention to support production was needed.

The importance of having this approach in the industrial innovation policy toolset becomes clearer with a bit of background on semiconductors themselves, which are a foundational technology on which all software operates and data are processed. They are essential for defense technologies and systems and for upcoming generations of advanced technologies, particularly artificial intelligence and quantum computing which also have significant national security dimensions.[28] And, of course, they are core to a host of societal services, such as computing, the Internet, and broadband, upon which the daily economies and functioning of societies are based. U.S. technology leadership is essential for all these reasons (Slater, 2021).

The U.S. government is now undertaking its second intervention into the sector; the first was in the late 1980s, when the U.S. semiconductor chip industry was falling behind Japan's leading firms, Nikon and Cannon, which were working closely with Japan's industrial policy program through its Ministry of International Trade and Industry.[29] The Reagan administration was convinced to back a public-private partnership, Sematech (a consortium of 14 semiconductor companies cost-shared with $500 million of DARPA funding), in an effort to restore U.S. technology leadership (Browning and Shetler, 2000).

Sematech is generally acknowledged to have played an important role in the return of technology leadership in semiconductors to the United States. It focused on chip manufacturing, and was a major joint effort to improve the speed and quality of chip production systems.

By 2020, though, after having offshored much of its electronics production, the United States again faced a loss in chip leadership, to Taiwan, which faces a continuing threat of invasion from China, and Republic of Korea, which faces threats from Democratic People's Republic of Korea. Companies in these nations were producing the most advanced semiconductors. The world has become largely

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[28] See, for example, S.W Huang, et al (2020).

[29] See, generally, Johnson (1982).

dependent on one semiconductor maker: Taiwan Semiconductor Manufacturing Company which makes 90 percent of the most advanced semiconductors only a hundred miles from mainland China (Jie, Yang and Fitch, 2021; Miller, 2022). The loss of U.S. leadership in chipmaking happened despite the fact that in 2019 semiconductors were still the largest U.S. electronic product export and the fifth-largest export product, amounting to some $42 billion, and that American companies —including those with production abroad— held 45 percent of the global semiconductor market (Semiconductor Industry Association, 2019).

Meanwhile, China has been making massive investments in semiconductor technology since the early 2000s, essentially starting from zero, in a systematic effort to dominate the sector. While China does not have technology leadership, it now has a major presence in lower-end chip production and its investment level dwarfs that of the United States (Triolo, 2021; Strub, 2019; Ernst, 2016).

While U.S. R&D and design capabilities are still solid, the United States is failing to translate them into production leadership in semiconductors, a problem it has in so many other production areas —which is what elevates this discussion to the level of another approach to industrial innovation policy. In this particular case, production needs to be seen as part of innovation and is deeply tied to it (as discussed in section I); production erosion leads to innovation erosion. In the semiconductor example, this is exacerbated by the fact that venture capital for semiconductor startups in the United States has been available at the seed stage, but it is foreign capital that has dominated at the scale-up stage, when start-ups need to bring technologies into production and implementation (Griffith and Goguichvili, 2021). On top of that, there is the question of where the trained talent is going to come from if the United States is to restore its leadership in semiconductor technology. That is a *workforce* challenge with implications for educational programs that will be needed at both the electrical engineering and technician levels.

Alert to the security and geopolitical implications of these developments, Congress passed the bipartisan CHIPS Act in 2020, a major piece of legislation designed to restore U.S. semiconductor technology leadership that authorized $52 billion for government interventions into the sector.[30] This was supplemented by a 25-percent investment tax credit and a $75 billion loan guarantee program. It was fully funded in 2022 (as part of the CHIPS and Science Act discussed below), with strong bipartisan support. While the funding level will not make the U.S. the dominant production leader it once was, it should halt the erosion of its share of world semiconductor production (Hunt, 2022). The reality is that semiconductors are a globalized product and that will continue, but the U.S. in implementing the act may be able to assure onshore production of a reasonable volume of advanced chips (needed for national security reasons), and grow somewhat its share overall of semiconductor manufacturing. The legislation marked a major and direct government intervention into the sector at an unprecedented funding level.

The key provisions of the legislation are a roadmap to how this approach to industrial innovation policy fits other sectors where the same sort of governmental intervention might be needed. They include:

- *Direct manufacturing support* of $39 billion in the form of grants to construct, expand, or modernize domestic facilities and equipment for semiconductor fabrication, assembly, testing, advanced packaging, or research and development;
- An *investment tax credit* and *loan guarantee* program for advanced production facilities;
- A major $11 billion investment in *research and development*, including the establishment of several public-private partnerships and government-industry-university centers and

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[30] CHIPS for America Act, S.3933; see also, Sen. Mark Warner (2020).

programs in new semiconductor technologies and packaging to strengthen U.S. capabilities across the sector;

- Creation of up to three new *manufacturing* institutes with a production innovation focus;
- *Workforce education* focused on both the engineering and technical level;
- A focus on *international supply chains* through efforts centered in both the State and Commerce departments of the federal government.

The direct competitive grant support for production facilities is the most significant departure in the legislation from prior policy.

It is notable that the legislation engages at a series of technology development stages, consistent with the industrial innovation policy definition above: at the R&D stage, to attempt to secure semiconductor technology leadership; at the supply chain level, with an assessment of supply vulnerabilities and international coordination; at the production financing level, to assure location of fabs for producing advanced chips in the United States; in the development of advanced manufacturing technologies for both chips and related packaging areas; and with a coordination element to attempt to secure Asian and European cooperation in the face of massive Chinese subsidies of its semiconductor sector as well as cross-agency coordination. While the direct production support was the new feature, the legislation was more than that: it placed this production support within a *comprehensive* industrial innovation policy approach.

## E. Supply chain approach

In June 2021, the Biden White House, after 100 days in office, issued a major report in response to a prior presidential executive order on "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Foster Broad-Based Growth" (White House, 2021). The Departments of Commerce, Energy, Defense and Health and Human Services all cooperated in the report's development.

This was a planning project to be implemented in subsequent years. The report examined domestic supply chain gaps in four areas and made a long series of recommendations for bolstering supply chains in each one of them.

This effort underscores the government's involvement in industrial innovation policy. Some of the specifics for each of the four areas addresses —pharmaceuticals and ingredients, advanced batteries, critical minerals, and semiconductors— offer a look at the generalizability of this approach.

In *pharmaceuticals and pharmaceutical ingredients*, the United States experienced serious supply problems for personal protective equipment and other needed medical supplies during the coronavirus pandemic, which led to a new awareness of supply chain issues in the medical sector. The report found that the United States had offshored much of its production capability for pharmaceutical goods and argued that more resilient supply chains, including improving supply transparency, building emergency capacity, and investing in domestic production, were all required. Policy recommendations included using the Defense Production Act to set up a consortium for on-shoring of essential medicines and supplies.

With respect to *advanced batteries*, which are integral to technologies needed for a clean energy transition as well as national security capabilities, the report found that the nation's reliance on imports for the elements required for fabricated advanced battery packs exposed the nation to supply chain vulnerabilities that threatened to disrupt the availability and cost of the technologies that rely on them. It stated that investment in scaling up a secure, diversified supply chain is required and recommended that DOE develop a National Blueprint for Lithium Batteries and a ten-year plan for lithium battery supply chains, which it has since done (DOE, 2021), and that DOE should develop a major lending program for domestic battery supply chains and launch a number of pilot battery storage projects at federal sites.

The report found that even if the United States diversified its sources of *critical minerals* or increased domestic extraction, it would still be reliant on China, which has captured large portions of the relevant value and accounts for an outsized share of the world's refining capacity. The report recommended that the United States work with allies to diversify supply chains, and also invest in sustainable domestic production, refining, and recycling capacity. There were recommendations to provide incentives for production and processing in the form of loans, grants, and federal purchase agreements, and to expand international investments in needed projects to ensure access.

Finally, there were recommendations regarding *semiconductors*. The report supported the steps taken by the CHIPS Act, described above.

The report also made clear that this was not to be the only supply chain effort, and the Biden administration subsequently established a Supply Chain Disruptions Task Force across agencies to address near-term supply chain challenges to the 2021–2022 economic recovery, with a focus on areas where supply/demand issues had become an economic problem in 2021: homebuilding and construction, semiconductors, transportation, and agriculture and food. This expanded the reach of the supply chain approach to industrial innovation policy. In February 2022, the White House issued a follow-on report with industrial base reports from seven different agencies charged with tasks under the initial 2021 report (White House, 2022a).

These planning efforts and the multi-agency projects that grew out of them to build more resilient supply chains are a signal of a new level of government industrial policy involvement through supply chain mapping and interventions.

The Biden Administration's executive order and the activities that followed from it were focused on four specific areas, pharmaceuticals and pharmaceutical ingredients, advanced batteries, critical minerals, and semiconductors, as noted. These were not the only supply chain efforts; supply chain-related provisions were contained in parts of the recent legislation, as well. The Infrastructure Act in 2021 made a major investment in U.S. transportation and electric grid infrastructure as well as in energy technology demonstration projects. It also included broad domestic content standards, strengthening existing "Buy America" requirements to support more resilient supply chains in these construction fields. The CHIPS Act (funded as part of the CHIPS and Science Act in 2022) aimed to reduce the sharp decline in domestic U.S. semiconductor production and the reality that the most advanced semiconductor production had shifted abroad, as noted above, through direct support of production facilities. It therefore attempted to address growing concerns about the resilience of the U.S. semiconductor supply. The Inflation Reduction Act of 2022 was largely aimed at climate decarbonization policies and provided, as noted, a collection of consumer tax incentives and subsidies for clean energy technologies, and accompanying provisions favoring domestically-produced content.

Overall, assuring resilient supply chains and corresponding domestic production have become a major thrust of U.S. industrial innovation policies.

## F. Coupling basic and applied research approach

An underlying goal of what became the CHIPS and Science Act was to bring basic research into proximity with applied research to take advantage of linkages between the two. It marks a shift from the longstanding U.S. basic research emphasis advocated by Vannevar Bush in 1945 (see section II) to include more applied research (Atkinson, 2021).

The legislation went on a roller coaster ride to get enacted. First introduced in May 2020 as the "Endless Frontier Act" (an homage to Bush), it aimed "to solidify the United States' leadership in scientific and technological innovation through increased investments in the discovery, creation, and commercialization of technology fields of the future," in the face of advanced technology competition from China (S.3832; Sen. Todd Young, 2020). It was revised the following April and added full funding for the previously authorized CHIPS Act (as discussed above), with a focus on new applied programs at the National Science Foundation (NSF) and the Department of Commerce, passing with bipartisan support in June 2021.

Meanwhile, the House Committee on Science, Space and Technology passed somewhat comparable bipartisan legislation that placed less emphasis on technological competitiveness and more on societal goals (HR 2225; House Committee on Science, Space and Technology, 2021). In a way, the two different bills presented aspects of the debate on "industrial policy for what?" discussed above (section II).

After a multi-month conference, the final compromise legislation —largely merging the two approaches— passed in August 2022. It included both the CHIPS Act funding and major science provisions and was renamed the "CHIPS and Science Act" (HR 4346 (bill text and summary); COSSA, 2022). Its science provisions were authorizations, not actual funding appropriations, but it nonetheless spelled out a set of new industrial innovation policy thrusts. Given the bipartisan support, there was a reasonable expectation that over time some implementation funding would follow.

The bill's many provisions, some of which are spelled out below, help explain why this is a new approach to industrial innovation policy. With respect to NSF, the legislation's key science-related provisions included a new agency focus (COSSA, 2022):

- Creation of a new *Directorate for Technology, Innovation and Partnerships* at NSF, representing a break from NSF's historic basic research focus to emphasize translational research that strengthens U.S. competitiveness by accelerating the development of key technologies into science and engineering innovations.
- The directorate was required to address "Societal, National and Geostrategic" challenges ranging from national security and manufacturing to workforce development, climate change, and inequitable access to education and opportunity; and to support *ten critical technology areas* (subject to being periodically updated in coordination with other federal agencies): artificial intelligence, high-performance computing, advanced manufacturing, quantum information technology, cybersecurity, advanced communications technology, biotechnology, advanced energy technologies, disaster prevention, and advanced materials. This major step of adding an applied focus to NSF included two other elements.
- Establishment by the new NSF directorate of *Translation Accelerators* with universities and industry to further the R&D and commercialization of the critical technologies.
- Creation by NSF of *Test Beds* to advance the development, demonstration, and deployment of new technologies.

Prior to the legislation's enactment, NSF had already embarked on an ambitious effort to form *Regional Innovation Engines.* These were to bring an innovation economy to geographic regions left outside the nation's technological advance in an effort to create more geographic parity. Although NSF had little experience with fostering regional innovation, the new law codified NSF's regional effort.

To fill a long-standing U.S. innovation system gap, there was also a new technology strategy effort which could also better link basic and applied programs:

- Development of a comprehensive, four-year *national science and technology strategy* by the White House Office of Science and Technology Policy (OSTP), which has the government's cross-agency coordination role, and its submission to Congress. It was to reach across basic and applied lines, with a primary focus on economic security.
- Periodic development and updating by OSTP of a national security-focused science and technology strategy in support of the nation's existing National Security Strategy.
- A quadrennial review by OSTP of the nation's overall science and technology enterprise.

The provisions could all be important to U.S. competitiveness. In addition, there were social goals: the legislation created and expanded NSF programs for broadening participation in science, for STEM education, and for a major expansion of a research set-aside program for research at less-established research universities. And there was funding aimed at satisfying NSF's university basic research constituency (Senate Committee on Commerce, Section-by-Section and Division B Summary). In the area of "DEI" —diversity equity and inclusion for minorities and women— provisions called for NSF to support DEI research in science, created a Chief Diversity Officer at NSF, supported expansion of opportunities for women and minorities in science studies and careers, expanded university opportunities for women and minorities including training for university administrators in recruitment and evaluation of women and minority candidates, and expansion of pilot programs for improving the diversity of institutions competing for NSF grants (Senate Committee on Commerce, Sections 10326-10330. 16-17). DEI is also a policy aim in the regional innovation efforts discussed in the next section.

The Act also gave significant new responsibilities to the Commerce Department's NIST and Economic Development Administration (EDA) (Senate Committee on Commerce, Section-by-Section and Division B Summary):

- Creation of *Regional Technology Hubs* to focus on technology development and improving regional innovation capacity. These were in addition to NSF's regional efforts noted above.
- Development of a *Recompete Pilot Program* to support persistently distressed communities with economic development activities.
- Expansion, in the form of tripled funding, for NIST's *Manufacturing Extension Partnership* (MEP) program. MEP is cost shared with states and assists small manufacturers in every state with improving manufacturing processes and technologies, including on cybersecurity, workforce training and supply chain resiliency.
- Creation of new competitively awarded industry-university *Manufacturing USA Institutes*, with responsibility for production technology development and expanded capacity for education and workforce development.

In addition, the Act also authorized additional funding for Department of Energy science programs, both basic and applied.

The importance of this legislation, with its overall aim of putting the United States in a position to compete with major ongoing applied technology initiatives in China and despite having been watered down from its original conception, is considerable (Lopez, 2021; Hammond, 2021). It concentrates attention in large part on NSF, America's one major, broadly focused basic R&D agency not tied to a specific, and narrower, mission such as health, energy, or defense.[31] While technology development has not been NSF's job, the Act establishes a technology-focused subunit within the agency —the new Technology Innovation

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[31] Discussion here draws from Bonvillian Testimony (2021).

and Partnership Directorate, and aims to connect the basic and applied research sides. Therein lies the reason this rises to the level of a new approach to industrial innovation policy. And optimally, the Technology Directorate could form part of a larger system. The strategic planning requirements in the legislation could also help with basic and applied links.

Getting to new technology, as opposed to new science, requires moving through a series of post-research stages, as noted earlier: development, prototype, testing, demonstration, scale-up/piloting, initial markets, and full production. Non-defense legislation that recognizes the need for an innovation *system* is a significant new step, and this legislation attempts to create organizational elements aimed to match each stage of a systemic process. The challenge now is to link these new organizational elements and pull them into a new system.

If the NSF can drive applied and translational technology as well as basic science —which may be a challenge given its basic research culture— and if it can create working technology accelerators and test beds despite its lack of experience with these approaches, there will be important lessons provided about moving this approach forward.

## G. Regional implementation approach

The Regional Technology Hubs called for in the CHIPS and Science bill (as noted above), to be funded and set up through the Commerce Department's Economic Development Administration (EDA) and NIST programs, as well as the Regional Innovation Engines under NSF, are new programmatic elements that could be a way to encourage regional innovation —another approach to industrial innovation policy. Regional entities offer a way to move the flow of research from basic and applied stages into implementation, since innovation tends to scale up in regional innovation ecosystems, not at the national level.

As discussed in more detail in section VIII, below, regional ecosystems are generally needed for successful innovation (Atkinson, Muro and Whiton, 2019; Gruber and Johnson, 2019), but there is no uniform approach to supporting and forming these and often these efforts fail. Typically, a regional innovation ecosystem includes a university-level education and research institution that serves as an anchor for technology research and talent. Success also seems to require an organized public sector working with the private sector —including committed companies and area business groups— all pursuing a joint strategy. Larger firms with supply chains of smaller firms are another ingredient. Regions need to build on their existing regional strengths— not every area is going to be a biotech hub. Workforce education systems to form a pool of skilled workers and innovators is another element. Ongoing success also seems to require a range of technology capabilities and several economic sectors —if a region has a single technology focus and that erodes the ecosystem cannot be enduring.

Can NSF and the Department of Commerce create successful regional innovation centers that both enable technology implementation and assist in regional economic equality? This is a particularly difficult challenge, although the menu listed above provides guidance on policies that have helped some U.S. regions. More detail on effective policies is offered in section VIII. Some of these experiments will likely work, and others may not. The Department of Commerce's EDA has had many decades of work experience with many regions in promoting new infrastructure and development. However, NSF historically is a science agency and has little past experience in spurring regional innovation. Neither EDA's (with NIST) Regional Technology Hubs nor NSF's Innovation Engines are fully funded and securing adequate funding will be a challenge for both programs with the 2023 shift in party control of the House of Representatives. NSF does have funding for initial awards, and an initial competition is underway, focused on regions that lack strong innovation economies (Mervis, 2023). Thirty-four regional teams are currently competing for the first five NSF awards, each for $15 million for two years to be awarded in the fall of 2023, with the expectation of more over a decade if additional funding comes through. EDA received an initial $500 million in funding for its tech hubs and issued a funding opportunity notice for regions to apply in May 2023 (EDA, 2023). If funding evolves for the NSF and EDA/NIST regional programs, there should be important lessons learned from the effort.

## H. Summing up

While the Defense Department has long operated an industrial policy system with economic interventions at many stages of the innovation process, this is largely a new road for the U.S. government in the civilian economy. There are, of course, historical precedents, as discussed in section III, above. These include the programs developed to respond to Japan's development of quality production technologies and processes in the 1980s, development of energy technologies in the 2000s, and the effort to create advanced manufacturing institutes after 2012. But the plethora of new industrial innovation policies proposed between 2020 and 2022, with underlying approaches (seven in total) summarized in this section, is unprecedented.

Some may not go into full effect because of funding issues. Others could amount to a new and larger-scale period of industrial innovation policy approaches beyond the examples offered.

In discussing these new approaches, one thing that becomes clear is that there are key operational mechanisms that will be required to organize them so they are fruitful. In effect, what is needed is a new supporting infrastructure. The United States will need to adopt a "systems of innovation" approach and revise the old linear pipeline model. It will need to approach innovation in a dynamic way in terms of its interdependent components, flows, organization and underlying policies. It will need to look at barriers and bottlenecks to these needed flows, with collaborating agencies brokering solutions. A scattered agency approach will not be enough. It will need scale up support.

Industrial innovation policy is a complex process with many actors, and it requires a careful plan, strong foundational programs, and a spirit of enterprise. It requires a new, sustaining infrastructure. As the Pentagon discovered long ago, you cannot just build the pieces; you must also build the system.

# VI. The new infrastructure required for United States industrial innovation policies

All of the seven new industrial innovation policy approaches discussed above face a challenge of continuing public support. There is another critical challenge, as well. Programs like these that operate at various innovation stages are not enough. For an industrial innovation policy program to work, it will require a larger framework, applying a number of guiding organizational principles —in effect, new operating mechanisms that amount to, as suggested above, a new kind of infrastructure.

When attempted in the past, U.S. industrial policy approaches outside the defense arena, particularly energy technology demonstrations, have, as noted, sometimes failed. Getting these new programs to deliver on their promise means strengthening the innovation system through a series of new operational mechanisms. This is an unstable area, where the U.S. has not yet built the foundations to form strong projects or the talent base that will understand how to implement them. Examining our menu of seven industrial innovation policy approaches, a range of critical operational mechanisms and guiding organizational principles are delineated below that should be applied to these programs. They amount to infrastructure prerequisites for industrial policy programs to work. Efforts are needed in three overall areas: steps to improve the *organizational infrastructure* for the needed innovation, the *scale-up infrastructure* of the new technology or process, and the *evaluation infrastructure* of the policy's performance. These efforts and their main elements are discussed below.

## A. Organizational infrastructure

### 1. Cross agency coordination

Let us start with one example. Multiple agencies are already involved in semiconductor R&D. While the CHIPS Act gave major responsibility to the Commerce Department's NIST to administer much of the act's $52 billion for new facilities and R&D, the Defense Department has in the past led government efforts in semiconductors. These range from DOD's early role in creating the initial markets for integrated circuits to DARPA's role in coordinating semiconductor design and its support for Sematech, which rescued the U.S. industry in the early 1990s. In recent years, DOD backed the creation of a "trusted foundry program" and a proposed "quantifiable assurance" for producing chips for defense systems in secure U.S. production facilities,[32] a Microelectronics Commons of semiconductor prototyping and innovation hubs (DOD, 2023a), and DARPA's major Electronics Resurgence Initiative begun in 2017 for restoring technology leadership in microelectronics and semiconductors, which is ongoing (DARPA, 2022). Other agencies, including NSF and the Department of Energy, are involved as well. NSF funds its own research portfolio in the area through its computer science directorate and is required under the CHIPS Act to initiate a major semiconductor R&D and workforce education effort. DOE has long led in government supercomputing technology development.

The Office of Science and Technology Policy (OSTP) in the White House has the R&D coordination role among agencies and can form committees around technology issues through the cabinet level National Science and Technology Council (NSTC)[33] that it administers. But OSTP does not have a direct role in setting the budgets of science agencies so lacks a key tool to ensure connections across these agencies. In addition, the agencies report back to the numerous separate mission agencies and Congressional appropriations subcommittees that fund them, and funding cannot flow from one agency to another —the appropriations committees will not tolerate it. So collaboration is not easy in the decentralized American science system —someone once defined interagency coordination in American governance as a contradiction in terms. Although such coordination is vital in the area of industrial innovation policy, the U.S. has only limited tools to ensure it.

However, Operation Warp Speed offers an example of how to effectively get around this problem. There, two respected leaders were brought in to lead an independent, multi-agency task force effort, one for vaccine development, who had extensive industry experience in this field, and one for distribution logistics, an Army general who was a logistics expert. The task force was organized around a specific mission —vaccine development— and was composed of agency officials with relevant expertise from the Department of Health and Human Services, the Center for Disease Control, the Food and Drug Administration, the National Institutes of Health and the Defense Department. They reported to the new leadership team but kept their agency ties so they could coordinate input from their agencies. Above the task force was a panel of cabinet secretaries responsible for aspects of the mission and led by the Secretary for Health and Human Services. The task force had its own budget within that department. The agency participants on the task force could each apply their agency's available policy and program authorities to support the task force vaccine development mission.

Using a similar independent, mission-based task force-type organization, as opposed to a looser committee structure, could work in other industrial innovation policy areas where agency coordination is needed.

### 2. Linking applied to basic research efforts

The various industrial innovation policies described above call for applied work, but if the initiatives are to be longer term and lasting, they need to be linked to earlier stage research at R&D agencies. Without ongoing research inputs into applied projects, they will get stranded and less productive over time. The CHIPS Act, for example, attempts to make these links by supporting both an effort to build new, advanced semiconductor fabs along with a major R&D program in the foundational technologies needed for the next stages of advances. Industrial innovation policy is not only about application, it must

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[32] See, for example, Defense Microelectronics Activity (2022); DOD, Microelectronics Quantifiable Assurance (2023); Lapedus (2018); Ortiz (2016).

[33] National Science and Technology Council (NSTC).

also integrate with earlier stage research. Ensuring "connected research" will be critical to ongoing and longer term applied efforts.

### 3. Integration between agencies, industry, and universities

All the innovation efforts reviewed here require implementation in the private sector. None are about Manhattan or Apollo technology projects conducted solely for the government to perform a mission. Therefore, they will all need to be fully integrated with industry efforts. This is the connection pathway that semiconductors, Endless Frontier/CHIPS and Science Act critical technologies, DOE demonstration projects, and secure domestic technology supply chain programs must follow. OWS provides a good example of the government closely integrating with private sector vaccine makers to the point where government personnel were located in a number of the involved firms to build understanding to speed regulatory reviews. It is important for implementation success that industry partners be actively engaged and committed —if they are not, the projects will inevitably fail. Industry leadership is thus a significant aspect of successful industry engagement.

In programs that will move technologies from research through implementation, such as with semiconductor advances and the new technologies called for in the CHIPS and Science Act, integration between university research, government agencies, and industry will be required. These collaborations are complex and close integration between the three main actors —industry, universities and government— will be vital. Operation Warp Speed, as discussed, provides examples.

### 4. Training change agents skilled in project management not just research

Because innovation does not just happen, change agents are critical to complex innovation.[34] Even if the elements of an innovation system are assembled, a catalyst or group of catalysts is needed to force the changes and connections required, just as a conductor is required for an orchestra. The team creating and leading Operation Warp Speed discussed above provides a good example of this change-agent role. Some of the characteristics of successful DARPA program managers apply. They need to be "empowered" with the authority to pursue their mission; they need "visioning" ability, ready to see a new innovation territory; they need to be highly entrepreneurial; they need to have "religion," to be dedicated to their innovation task; and they need to be effective collaborators working with and leading teams of fellow innovators.[35] Clearly, change agents and the leadership they can bring will be needed for industrial policy projects.

There are other parts of the talent team that must be built as well. Although talented researchers are needed, since industrial innovation policy stretches beyond research, a series of other skill sets belong in the talent team. As discussed in the section on Energy Department demonstration projects, project management, project engineering and project finance expertise will also be required. And those with bureaucratic know-how and understanding of the legal and contracting authorities could also prove vital, as Operation Warp Speed demonstrated. Understanding of regional innovation could also be key as projects called for in the CHIPS and Science Act illustrate. The point is that a new set of skill sets is going to be required by these kinds of projects—not simply R&D skills, but a panoply of tech development, tech scale-up, tech financing, and tech production skills. Sticking traditionally trained scientists and engineers into leadership positions will not work; new education efforts will be required to create the needed change agents. We do not have this talent base in place outside the defense department, and it must promptly be built.

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[34] The role of change agents in innovation is discussed in Bonvillian and Weiss (2015).

[35] See generally, Bonvillian, VanAtta and Windham (2020).

## 5. Workforce education for the technical workforce

The American workforce education system for its technical workforce is largely broken.[36] Yet without a workforce trained in the skills required for new technologies they cannot be implemented. The overall problems include: **a disconnect** between the education system and the workplace; **a history until** recently of disinvestment by government and employers in workforce education; Labor Department training programs that do not reach **higher technical skills or incumbent** workers that need to upskill; Education Department programs that are focused on college not workforce needs and not linked to the Labor Department programs; vocational education in secondary schools programs that have been largely dismantled; underfunded community colleges that lack the resources to provide advanced training in new fields and have too low completion rates; colleges and universities that are disconnected from workforce education; no system for lifelong learning; underfunded advanced technical education programs (at NSF and at advanced manufacturing institutes); and a broken labor market information system. These problems are compounded by the reality that the existing actors are in a "legacy" sector —the long-established education sector is hard to change.

Yet new policies are needed and new tools are available to help spur this change. The reforms could include:

- Adopting new education technologies such as online education, virtual and augmented reality, computer gaming, and over time, digital tutoring, to help scale-up workforce programs.
- Forming short courses adopted to scheduling needs of incumbent workers and those with families, at community colleges and in training programs. These should connect to community college certificates and degrees.
- Creating community college programs not just for community college students, but also for incumbent workers and secondary school students.
- Creating Apprenticeships or "Apprenticeships Light" to break down the work/learn barriers, at both the secondary school and community college age levels.
- Mechanisms for industry, educators and state and local governments to coordinate to build regional workforce programs.
- Turning around low community college completion rates through state tuition supplement programs and integrating remedial and career-oriented courses.
- Creating new Technical and Comprehensive secondary schools at the state and local levels.
- Expanding the employer role in workforce development through industry consortia to support apprenticeships and development of employer-led training and standards.
- Developing new curriculum for advanced fields through university, industry and community college consortia.
- Developing an online labor market Information system using data from federal agencies.

These are clearly ambitious steps, but no single effort will sufficiently change the system, and an overall systems approach is needed. Workforce education elements reflecting a systems' approach also need to be embedded in each new industrial innovation program.

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[36] Workforce education problems and solutions discussed in Bonvillian and Sarma (2021).

### 6. Technology certification and validation

While the health sciences sector has a technology certification process, its FDA approval process, which is fully accepted and recognized, no other sector has a similar mechanism. It amounts to a widely-accepted technology validation system. FDA approval guarantees immediate market acceptance, making it a very powerful innovation tool because it can command prompt markets. The FDA's preliminary step to full approval, Emergency Use Approval (EUA), was a technology certification that proved vital to the success of Operation Warp Speed in limiting the effect of the pandemic, helping the adult population quickly reach an over 70 percent full vaccination rate. There are safety certifications in a several areas, such as in aviation by the Federal Aviation Administration, energy efficiency standards from the Energy Department, and electrical safety certifications for various electrical products. But these are limited to specific areas and are not broad technology "workability" certifications. No equivalent certification is available outside the health sector, but its utility suggests that comparable technology certification or validation mechanisms should be considered as the government pursues industrial innovation policy approaches. The network of strong federal laboratories, for example, in cooperation with industry, might be able to play a role in this area comparable to the role the Fraunhoffer labs (Bonvillian and Singer, 2018, 133-134) play for German industry in technology validation.

## B. Scale-up infrastructure

### 1. Adoption of advanced manufacturing

A weakness of a number of the industrial innovation policy-type programs cataloged above is that they lack a strong manufacturing element for scaling-up new technologies. Any industrial policy is going to be dependent on a strong manufacturing system; unless this system is strengthened and moved toward the efficiencies possible with advanced manufacturing technologies, initiatives will tend to fail. As noted in the section discussing recent manufacturing initiatives, U.S. manufacturing productivity has fallen to historically low levels over the last 15 years, with investment in capital plant and equipment declining in parallel. These declines indicate that U.S. adoption of advanced manufacturing technologies and processes is lagging behind its major competitors, which are doing better on productivity.

Manufacturing needs to be seen as part of the innovation process, a step the United States has not taken, although its leading industrial competitors have. Many of the six initiatives previously discussed focus on implementing advanced technologies, yet the U.S. has run, as noted, a massive and growing $244 billion deficit in advanced technology goods in 2022 (Census Bureau, 2023). This is an indicator that a number of these pending advanced technology industrial policy programs will simply not achieve their aims. It is a signal that renewed focus on advanced manufacturing as a foundation for these programs will be critical if they are to work, although these programs, such as the advanced manufacturing institute program, have received limited attention from the Trump and Biden administrations; steps to improve the reach of this program are detailed above in section III. Manufacturing capability is a critical gap that must be filled. Strengthening the manufacturing sector in general and implementing advanced manufacturing technologies and processes will be a critical foundation for industrial innovation policy programs; without this strengthened foundation, they will not work.

### 2. Technology testing and demonstration

While many prototypes often evolve, only some will ultimately work well. Testing and demonstration are therefore critical innovation stages, key to scale-up. DOD, which has long followed industrial policy approaches, builds them into virtually all its technology development programs, but they are often missed in civilian agency efforts. Testing and demonstration are also crucial to commercialization —firms and users will not be interested in a technology unless it is tested and proven. This is why developing testing and demonstration capability at DOE is so critical if new battery, advanced-nuclear, and renewable technologies and processes for industrial decarbonization are to be developed and adopted (Hart, 2021). This is the rationale for the new DOE demonstration program called for in the 2021 Infrastructure Act. It will also be key, and so is built into, the Endless Frontier/CHIPS and Science Act for the new technologies it will support.

### 3. Scale-up financing

Initiatives for industrial innovation policy may grind to a halt unless financing is available for the technology projects required. There are a variety of financing types that may be appropriate for scaling-up particular projects, including lending, guaranteed contracts, and tax incentives. Guaranteed contracts were crucial to OWS's ability to rapidly scale-up vaccine production, for example. The DOE demonstration program relies on authority from DOE's Loan Programs Office, as do the critical materials and minerals-development efforts called for in the initiative to secure critical domestic technologies and materials. The semiconductor initiative uses investment tax credits as well as loan guarantees as a financing tool to enable domestic fab and foundry creation. If advanced manufacturing is to be spurred as a foundational element for industrial policy initiatives, financing for new advanced manufacturing equipment, particularly at small and mid-sized manufacturers, will be needed. Recognizing this gap, Senate legislation was introduced in 2021 to create an Industrial Financing Corporation to invest in innovative manufacturing (Sen. Chris Coons, 2021). Another alternative is that the Export Import (EXIM) Bank, a government owned financing bank to promote exports with some $80 billion in lending authority, develop a domestic lending capability to meet domestic manufacturing requirements. This option was supported by the White House in 2022 to help secure critical supply chains (White House, 2022b). All these points underscore the importance of financing as a cornerstone of successful industrial innovation policy initiatives.

### 4. Procurement

Most of the above mechanisms for implementing industrial innovation policy efforts operate on the supply side in promoting technology development. What about the demand side? Government has an additional tool, its large procurement programs which can be applied for innovative new products and technologies.[37] If government can act not simply as a technology development supporter but as an initial market creator, as it frequently does with new defense technologies, it can help assure scaling and acceptance of new technologies and systems. Federal procurement and programs play a massive role in defense-related and health sectors —the accelerated vaccine procurement effort behind OWS discussed above is a good example. The character of demand also shapes the new industrial production processes, and the federal government can use its leverage over demand. For example, while defense production accounts for only a modest portion of total manufacturing output, a surprisingly sizeable proportion of manufacturers rely on some defense contracts. Defense procurement therefore can leverage significant advances in production processes through requirements for its contractor base to adopt advanced manufacturing technologies. Effective use of federal procurement can play a significant role in creating initial markets for new technologies, helping shape the demand that will be key for new technologies to scale.

### 5. Mapping supply chains and filling the gaps

In building an innovation system through industrial policy approaches, there cannot be gaps in the system; strong connections are required throughout the system for scaling-up new technologies. The exercise of mapping supply chains can be vital to an operational system. This supply chain mapping, and corresponding efforts to fill in gaps, was crucial to OWS. It is proving central to the effort to secure

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[37] See for example, Robyn (2022).

domestic supply chains for critical technologies and materials, and clearly will be required in semiconductors, DOE technology demonstrations, the climate provisions in the Inflation Adjustment Act, and for the technologies called for in the Endless Frontier/CHIPS and Science Act.

All of these elements need to be introduced if an effective effort to scale-up new technologies into production and implementation is to be undertaken.

## C. Evaluation infrastructure

After mustering the organizational and scale-up elements needed for effective industrial innovation policies one task remains. Infrastructure must be put into place to continually evaluate, assess and improve these infrastructure elements to assure the programs are working well. Industrial innovation policy is far more complex than running an R&D project —it involves many more actors from a range of different sectors and requires extensive coordination across these boundaries. These innovation program challenges mean there inevitably will be failures, but it is important to translate these failures into learning experiences that enable corrections and improvements to be put into place. An ongoing evaluation process that creates "lessons learned" will be key to the success of industrial innovation policies.

Three U.S. programs provide examples for how a quality evaluation process could work. The Advanced Technology Program (ATP) located within NIST ran from 1991 to 2007 and a successor program ran until 2011. It supported early stage research by companies developing new technologies and its evaluation system was particularly noteworthy. It attempted to both measure the impacts of the technology development projects it funded and to understand the underlying relationships between technological change and economic impact and to provide "lessons learned" to the program to increase its social benefits (Ruegg, 2008; Ruegg and Feller 2003). ATP's evaluation tools ranged from developing models to conducting surveys, compiling databases, conducting micro- and macro-economic case studies, and performing statistical and econometric analyses. The program metrics it applied included private rates of return, social rates of return, and public rates of return to arrive at the social-rate-of-return component attributable to the program. It also looked at technology spillover pathways, benefits and costs of collaboration, technology financing issues, and new models for assessment. A National Academies of Sciences (2001) study of ATP was a further attempt to evaluate its programs and to provide feedback. The study reviewed the results of fifty ATP awards, undertook detailed assessments of ATP's major joint ventures and described its project selection process. ATP's evaluation approaches and the National Academies study provide models for the industrial policy programs.

ARPA-E, the Energy Department program for breakthrough energy technology development, also has undertaken detailed evaluations of the performance of its programs, with three volumes of studies of its impacts (ARPA-E, 2018; 2017). ARPA-E also produces detailed technical reports on its research results.[38] The National Academies also undertook an operational and technical assessment of ARPA-E's programs and awards (National Academies of Sciences, 2017). The National Academies also evaluated, in a long series of reports, the performance of the Small Business Innovation and Research Program (SBIR) as administered by the leading R&D agencies.[39] SBIR supports technology R&D projects at small firms and start-ups and the National Academies has served as their program evaluator.

The new industrial innovation policies are now just underway and it is too soon to evaluate them. But the ATP, ARPA-E and SBIR programs each undertook detailed performance evaluations of their efforts and provide models for how the new policies could undertake that process. This could help ensure that "lessons learned" can be recycled to improve the programs on an ongoing basis.

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[38] See studies listed in, ARPA-E, News and Media. Publications.

[39] See, for example, National Academies of Sciences (2023); National Academies of Sciences (2022); National Academies of Sciences (2020).

# VII. Summary of the new United States industrial innovation policies

Between 2020 and 2022 the United States formed a series of new industrial innovation policies funded by over half a trillion dollars, marking a major commitment to industrial policy type approaches much larger in scale than anything attempted previously outside of its Defense Department programs. These intervened not simply in the R&D of technology development but in the subsequent technology implementation stages. As noted, the new effort included six major new industrial innovation programs: Operation Warp Speed for rapid Covid-19 vaccine development; the CHIPS Act for rebuilding U.S. technology capability in semiconductor manufacturing and research; the Infrastructure Act of 2021 which included major energy technology demonstrations; an executive branch initiative on "Building Resilient Supply Chains" for improving supply chains in four critical technology areas, the Inflation Reduction Act which included $378 billion for implementing climate-related energy technologies; and the science portions of the CHIPS and Science Act which established new applied technology and regional innovation programs at NSF.

Together, these new programs included seven basic approaches to industrial innovation policy. First, a *top-down approach* was adopted in Operation Warp Speed in its effort to rapidly develop vaccines for the pandemic. The federal government picked the winners. It selected two leading companies in three vaccine platform areas, including the two companies that were able to rapidly develop and produce the mRNA vaccines so critical to saving millions of lives in the pandemic. Second, a *bottom-up approach* to provide a network of incentives for development and adoption of new technologies. Rather than picking winners, the government offered a general package of incentives that companies might or might not adopt. Development of electric vehicles was supported by this approach, and it is the basic approach behind the new energy technology incentives in the Inflation Reduction Act of 2022.

A third approach was for the federal government to *support demonstration projects.* Department of Energy projects in the past often broke down on the pathway to implementation because testing and demonstration projects for new technologies were either inadequate or not well organized. Recognizing this problem, the Infrastructure Act of 2021 called for a series of technology demonstration programs at large scale for a range of new energy technologies and created a new Technology Demonstration Office within the Department of Energy to administer them. A fourth approach created *direct production support.* The CHIPS Act, passed in 2020 and fully funded in 2022, created support through grants, tax incentives, and loan guarantees to subsidize the creation of semiconductor production plants and facilities in the U.S.

The fifth approach involved *supply chain support*. Here the Executive Branch analyzed supply chains in four critical technology areas (pharmaceutical and pharmaceutical ingredients, advanced batteries, critical minerals, and semiconductors). The program designed interventions into the supply chains for each to help assure U.S. production. The sixth approach involved *combining basic and applied research*. Here, the science portions of the CHIPS and Science Act of 2022 supported a new applied technology agency within the basic-research-oriented National Science Foundation. This new technology directorate is to support applied R&D in ten critical technology areas, drawing on NSF's reservoir of basic research and moving it to implementation. A seventh approach, also called for in that act, called for *regional innovation support* efforts particularly for areas outside the current major innovation hubs. Both NSF and the Department of Commerce were authorized to form new regional innovation centers based on regional proposals.

These seven approaches to industrial innovation policy, however, also require creation of *a new innovation infrastructure* to support them. While the Department of Defense has long had an infrastructure to enable its industrial policy efforts, this infrastructure is largely missing in non-defense science and technology programs, which have been oriented to research and not the follow-on innovation stages. A new infrastructure needs to be formed in three areas: *organizational, scale-up and evaluation*.

Concerning *organizational infrastructure*, cross-agency collaboration mechanisms needed to be created, a training system for agency change agents skilled in project management is needed, applied and basic research programs need to be linked, better mechanisms for integration of agencies, industry and universities are required, a system for technology certifications needs adoption, and a new system for workforce education particularly for the technical workforce, is necessary.

Concerning *scale-up infrastructure*, many steps need further work to smooth the pathway toward technology implementation. The infrastructure elements needed include: a new focus on advanced manufacturing capacity, testing and demonstration capability, financing for technology scale-up, mapping supply chains and filling gaps in the chain, and using federal procurement to implement the new technologies.

Concerning *evaluation infrastructure*, a system is needed for ongoing assessment of new industrial innovation programs so that lessons learned can be applied to improve these programs.

Overall, the U.S. is developing a series of approaches to industrial innovation policy which could greatly extend its innovation capability. However, unless it establishes or improves the appropriate innovation infrastructure mechanisms for organization, scale-up and evaluation, there will challenges in the implementation of these approaches.

# VIII. The top-five: lessons from United States approaches to industrial innovation policy potentially relevant to Latin American and Caribbean nations

If one key lesson from the nations that have moved from developing to developed status in recent decades, as noted in the introduction, is that industrial policy approaches have played a key role for most, the question then becomes what are the most relevant approaches?

Returning to the points noted in section I from economist Dani Rodrik, innovation requires certain *underlying conditions*, such as adequate transport and other physical infrastructure, available R&D knowledge, quality suppliers, and a skilled workforce. A role of government is to assure adequate *coordination* among innovation system actors —industry, universities, and government— for these underlying conditions to be met. A point of this paper is that the traditional conditions cited above for building economic growth and corresponding innovation capacity are not adequate to account for innovation-based growth and reaching developed nation status. Arguably, a richer mix of mechanisms is required. These would include industrial innovation policies and the approaches to it described in this study. The U.S. is now experimenting with a mix of these approaches.

## A. The five most relevant approaches

The most relevant lessons from the U.S. for Latin American and Caribbean nations may be some of the U.S. industrial Innovation policy approaches themselves. As discussed above, many approaches and infrastructure elements could support industrial innovation policy, but five that appear particularly significant are highlighted below. Every nation faces different circumstances, so many other aspects of emerging U.S. approaches may be relevant. The discussion above amounts to a menu of options as well as providing more details about each of the five noted below. The top five strategies include:

## 1. Spur regional innovation

The U.S effort to establish regional innovation has a checkered history, as noted in section V, section G, but there are some relevant lessons.

How could regional innovation approaches work? This issue has been studied for years; Michael Porter's work on innovation clusters dates back over two decades (Porter, 1998).[40] There has been much regional experimentation; the U.S. has had many regional kitchens trying many ingredients, and there is no single recipe. Different regions can make different recipes work (Chatterji, Glaeser, and Kerr, 2014; Saxenian, 2007; Feldman, 2007). Imposing innovation tasks on struggling regions, however, often does not work – there is a long history of regional innovation failures. Yet, there are some examples of places that have become hubs of innovation activity not simply by accident but through concerted effort, including Pittsburg and San Diego. To summarize a large literature in a few words, most analysts believe we need regional ecosystems for innovation to thrive.[41] Typically, such an ecosystem includes an area university —an education and research institution— as an anchor for technology research and talent. Ecosystems also seem to need an organized public sector deeply engaged with the private sector —including committed companies and area business groups— all pursuing a joint strategy (Armstrong, 2019). Solid larger firms linked to solid supply chains of smaller firms are another ingredient. Regions need to build on their existing regional strengths —not every area is going to be a biotech hub.

Workforce education has become an increasingly significant component of a working regional ecosystem, as discussed in more detail below, so a number of regions are now encouraging companies and start-ups to come to their areas because they offer a trained and skilled workforce that is tied to employer needs. This means strong workforce programs for new skills at area community or technical colleges are also a component.

As noted in section V, a feature of the recent CHIPS and Science legislation is grants to communities to help them build strategies for their regional assets. To summarize a few key points, there needs to be a broad engagement in innovation —a big tent— not a narrow single-innovation focus; strong locally-based firms need to be engaged as "anchor tenants;" a connection is needed to the talent pipeline —state university and skills education programs, for example— which will be key to companies; and state and local governments need to strongly support the effort (Armstrong, 2021).

Innovation scale-up, then, needs to locate in regional ecosystems that can pull together existing assets such as those listed above. To effectively compete to build on these assets, regions will need to involve firms committed to implementing new technologies, and to pull in their other regional actors help implement them and the assets will need to be connected. Regional efforts, however, must go beyond simply assembling and connecting assets; an industry-government-educator alliance will need to support development through prototyping stages. In turn, more than prototyping is needed for successful innovation: additional efforts are needed to move from research to prototyping stages for work on the scale-up of new technologies. Not only government-university-industry collaborations are needed; also important are regional industry associations, with both small and larger firms and their supply chains, workforce training through community or technical colleges, and support from area government and economic development organizations. Regional innovation centers built on these collaborations and consciously organized for these tasks, could be mechanisms to bring this additional combination of actors and efforts together.

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[40] For a summary of limitations in the theory, see, for example, Motoyama (2008).

[41] See, for example, Atkinson, Muro and Whiton (2019); Gruber and Johnson (2019).

## 2. Offer scale-up financing

The issue of scale up financing is noted in section VI and remains a key to expanding innovative industries. The mechanisms include lending, guaranteed contracts, and tax incentives. How can these programs be administered? The U.S. Department of Energy has had a Loan Programs Office since 2005 to support development of clean energy technologies. Since its creation, it has issued more than $30 billion in loans, and received over $13 billion in repaid principal and earned $4 billion in interest (Murphy, 2022). The Office supports technologies that have not yet been implemented at scale or are seeking commercial markets. It aims to enable them to reach commercials viability. What is different about the office from traditional lending is that it has teams for each loan recipient that advise and support the firm's business development efforts and helps it keep on track to meet set goals and repay the loans.

The Office states that the projects it has supported have created 37,000 jobs, lowered carbon dioxide emissions by 40 million tons, and eliminated the need for 19.2 billion gallons of gasoline (Murphy, 2022). While it has had a noted failure, the thin film solar company Solyndra mentioned above, it has also had important successes, such as its loan to Tesla in 2009 for $465 million (repaid in 2013) that enabled Tesla, as previously discussed, to avoid bankruptcy and significantly grow its production, and pushed the auto sector toward electric vehicles.

This office is one of the few U.S programs that offers scale up financing. Tax incentives are a more widely used U.S. tool, but these tend to benefit firms that have the revenue to pay taxes, which leaves out many start-ups and entrepreneurial firms. Other countries use other mechanisms for scale up financing.

China, for example, has industrial guidance funds, which are government-sponsored, public-private, venture capital funds with two tasks: to support industrial policy goals while providing investment returns (Adler, 2022). They channel government funding to private firms, providing competition to state-owned enterprises that receive direct subsidies. The fundraising target for these funds, which now number some sixty, is up to $1.6 trillion, combining a market mechanism with national technology strategy. The amount raised to date is estimated at around $1 trillion. The guidance funds typically have a general partner from the private sector who manages the fund and limited partners who are the fund investors. Funds are sponsored by a national, provincial or local government which provides the initial funding, with additional funding coming from the limited partners. Although state-sponsored, the funds take equity positions in companies and are private sector-managed. The funds are precluded from investing in real estate, secondary market stocks, derivatives or futures —they are for scale-up support. The aim is to bring a venture-like, profit-oriented, private sector investment outlook into state-sponsored industrial policy, attempting to avoid the inefficiencies that can arise with government-run entities. The funds are designed to offer patient capital, recognizing that a revenue stream may be years away —where the government funding share helps enable this longer-term orientation. Although there have been concerns about inefficiencies and corruption around the funds, they represent a different, hybrid approach to scale-up financing.

These are only some of a wide range of models for scale-up financing, but they suggest different approaches to traditional lending. Overall, as discussed above, some mechanism for scale-up financing appears to fill a key gap in industrial innovation policy.

## 3. Promote advanced manufacturing

Developed economies ultimately rely on trade in complex goods, not commodities or services, for solid growth. As discussed above, advanced manufacturing will be central to the future of manufacturing; nations that do not take advantage of the emerging manufacturing technologies and processes will face a decline in manufacturing capability. As noted in section I and other parts, erosion in manufacturing can lead to erosion in overall innovation capability. As discussed in section III, the sixteen advanced manufacturing institutes created in the U.S. provide a potential model. As noted, these are loosely based on the successful Fraunhofer institutes in Germany. The concept behind the institutes is to bring together the critical actors that must be involved in improving manufacturing: industry, universities with strong engineering programs and government, including state, local and federal agencies. Federal seed funding, matched with industry and state support, enables development and prototyping of new manufacturing technologies that could be introduced. Each institute is organized around a particular strand of new manufacturing technology, from robotics to 3D printing, advanced composites, photonics, etc. Accompanying workforce education programs aim to assure that workers have the skills to master the new technologies.

Many of the countries in the Latin American region are now seeking to reverse the deindustrialization that their economies have suffered against the background of an acceleration of international competition and technological change. The U.S.'s advanced manufacturing institutes provide one model but efforts should be made to incorporate the lessons it is learning from its institutes, as reviewed in detail in section III. These include: (i) avoiding limiting the terms of the institutes, although periodically evaluating their performance; (ii) assuring a networking across the institutes so that they can package combinations of the new technologies that better enable industry to implement them; (iii) creating portfolios of manufacturing technology research at R&D agencies roadmapped to manufacturing institute technology implementation efforts; (iv) assuring that institutes have strong connections to small and mid-sized manufacturing firms so their technologies reach these firms as well as larger ones; and (v) promoting regional efforts with state and local regional agencies to implement the new manufacturing technologies and advanced manufacturing workforce education. Scale-up financing, as described above, is an important complementary program for implementing advanced manufacturing, as is workforce education discussed below.

### 4. Support workforce education

Workforce education remains a major challenge in the U.S. While its respected university system has created a strong group of engineering and scientific professionals to staff those parts of its innovation system, it faces major gaps in educating its technical workforce with the skills needed for an innovating economy. This is a problem in many other nations, as well. Efforts are underway to improve workforce education in the U.S. as discussed in section VI; some of the best practices common to the most successful programs for workplace education include:[42]

- *Form Apprenticeships with supporting education programs.* The disconnect in between work and learning is a major problem in preparing students for meaningful careers and quality work. Schools have become too distant from the workplace and workforce skills. Apprenticeships that are shared between employers and education institutions, as well as other forms of linkage programs such as paid internships, youth apprenticeships that start in secondary schools and cooperative programs are needed to get students into the workplace, earning money while they build skills. This also encourages them to pursue education: they can see a direct connection between the competencies they must learn and greater job opportunities.
- *Develop online education.* Workers will need skills in new technology areas like computing, but the existing education system is not geared to the new needs. Online education modules for advanced skills can be critical if workforce education is going to scale up to meet needs. Online cannot replace effective instructors or hands-on work with actual equipment,

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[42] Recommendations drawn from, Bonvillian and Sarma (2018); Bonvillian and Sarma (2021).

but it can convey and assess the foundational information behind the skills. And workers with basic skill sets can use online to add new advanced skills on top of that base.

- *Offer short programs at education institutions*. Those who have been in the workforce typically will not be able to take off time for two and four-year degrees; they have families to support and ongoing obligations to meet. They need short programs of 10 to 15 weeks with focused programs for technical skills.
- *Use certificates and credentials.* Apart from degrees for multiyear programs, we need certificates and credentials for shorter, more skill-focused workforce programs. Certificates can be issued for completion of a group of short, skill-related courses, for example, and be based on demonstrated competencies. Certificates should also be stacked toward college degrees and credits, which remain the most broadly recognized credentials.
- *Support competency-based education*. Today's education is usually based on an agricultural calendar and completion is based on time schedules. Instead, workforce education should be organized around demonstrated skills broken down into particular competencies. If students can show the skill competency, they should get the certificate, regardless of how long they have spent in the program. This can cut time in school, student costs and reward practical experience.
- *Embed industry-recognized credentials into educational programs*. Many employers want the assurance of skill knowledge that an industry-approved and accepted credential provides. It creates an additional and parallel pathway to help students toward employment. It also ensures that academic programs are relevant to actual industry needs. Industry credentials should be incorporated into certificate course offerings.
- *Improve completion rates*. A significant part of the workforce education problem is that most students do not complete programs they enroll in at community and technical colleges. A major cause is that most students must complete remedial courses before they can take work-related college-level courses. Frustration with the required remedial prep courses leads many students to drop out. One demonstrated solution is to integrate the supportive course work into students' study program for career skills so they can clearly see how the remedial work is relevant to their career opportunities.

These, of course are not the only steps required to improve workforce education. Improving funding for technical and community colleges, creating curricula in new fields, and developing better information systems so employers know what skills applicants have and workers know the skills employers want are all part of this story. But a skilled workforce is a critical input into productivity improvement and therefore workforce education should be a key element in industrial innovation policy.

### 5. Consider "top down" and "bottom up" approaches

As discussed in section V, the U.S. government in recent years has employed both "bottom up and "top down" approaches to industrial innovation policy; each has yielded strong results.

Operation Warp Speed (OWS), the successful effort to rapidly develop and deploy a vaccine for the Covid 19 pandemic, is a recent example of the "top down" approach, as detailed in section V. The OWS task force reviewed more than 100 pending vaccine projects and selected three different vaccine technology platforms (including mRNA) to pursue. It then picked two companies that were leading in efforts to develop vaccines in each platform area. OWS, in effect, was picking winners: it made these selections based on which companies it found were furthest along and most able to develop the different types of vaccines. It then partnered with the selected companies to support late stage development and clinical trials. In parallel, it issued guaranteed contracts to purchase the vaccines from the companies as the clinical trials were proceeding. This guaranteed the selected companies a market and enabled them to go ahead with production with the government offsetting the risk, and greatly reduced the timetable of vaccine introduction to a record 8 months. OWS pursued a number of other mechanisms as well, but this top down approach, of picking a portfolio of leading companies and partnering with them to pursue a technology, with government absorbing some of the development and production risk amounts to a top down approach that can be replicated in other fields and other countries.

U.S. government support for Tesla and the development of electric vehicles (EVs) provides an example of a "bottom up" approach. As detailed in section V, unlike with Operation Warp Speed, the government role in supporting EVs was not top down; it did not select a portfolio of winners to receive support in a series of key technology areas. Rather, the strategy was more bottom-up; it created a menu of incentives and then relied on firms to come to the table and take advantage of them. In the case of Tesla, government did not drive the creation of the company, but government incentives, loans, and regulatory elements were employed by Tesla to help it overcome barriers to entry and production scale-up and assume leadership in electric vehicle production. This approach where government in effect plants a field of incentives and relies on companies to come forward and harvest them is less direct than top down, but has the advantage of relying more on companies and less on government to undertake the challenging development process.

Other nations may want to pursue these approaches. Top down is most relevant when there is a cadre of firms well along in the development process; bottom up may be more applicable in encouraging innovative firms to emerge. Both may have a place in national industrial innovation policies.

To conclude, this paper has attempted to summarize in detail the steps the U.S. is taking in pursuit of new industrial policies, offering a specific menu of the seven approaches that have been followed. The U.S. is an advanced economy heavily reliant on technological innovation; its models have limits, therefore, in their application to developing economies. However, there may be some applicable, relevant lessons. Approaches to regional innovation, scale-up financing, advanced manufacturing, workforce education and to "top down" and "bottom up" innovation may have particular relevance.

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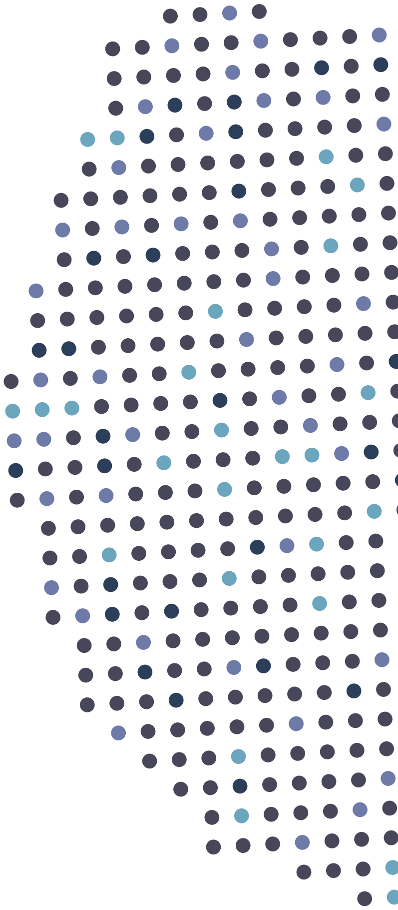
Amid the backdrop of advanced technology competition from China, climate change and a global pandemic, the United States —traditionally averse to industrial policy— embraced major industrial policy programmes between 2020 and 2022. These programmes focused on fostering technology innovation and are prime examples of industrial innovation policy. The scale of these initiatives and their focus on non-defence sectors are unprecedented. This study reviews six major examples of new United States industrial innovation policies involving federal government interventions in post-research phases of innovation, from development to prototyping, testing, demonstration and production.

These policies reflect different approaches, for example top-down strategies, whereby the government selects and supports specific companies, and bottom-up strategies, through which the government offers incentives for companies to meet government technology goals. However, gaps remain in areas such as scale-up financing, advanced manufacturing support and cross-agency coordination, although some efforts are under way to address them. While the United States has a highly developed economy, it has been experimenting with industrial policy models that may be relevant to developing nations in their efforts to meet the challenges of the twenty-first century.



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