Supporting Emerging Energy Technologies: Policy Portfolios, Risk, and Resilience

Daniel Matisoff, Ph.D. - Georgia Institute of Technology

Proposal for Environmental and Energy Policy and the Economy

Achieving deep reductions in greenhouse gas emissions requires the development and commercialization of technologies that remain expensive, risky, or technologically immature. Sustainable aviation fuels, clean hydrogen, carbon capture, direct air capture, advanced geothermal, long-duration energy storage, and advanced nuclear technologies are all at different stages of development, but each faces some version of the well-known "Valley of Death" between technological development and widespread commercial adoption. High costs, uncertain markets, technological risk, limited infrastructure, and unfamiliar supply chains can prevent promising technologies from gaining traction. Early adoptions can help overcome these barriers by building supply chains, creating information and learning, and reducing costs for subsequent adopters, creating a self-reinforcing process of market transformation (Blackburn, Flowers, Matisoff, and Moreno-Cruz, 2020).

Policymakers have a diverse set of tools to help emerging technologies cross this valley: R&D, demonstration projects, supportive infrastructure projects, capital grants and tax credits, loan guarantees, feedstock incentives, production subsidies, mandates, low-carbon standards, and procurement. These policies often operate simultaneously. Sustainable aviation fuel (SAF), for example, can receive support from federal R&D and loan programs, production and investment tax incentives, Renewable Identification Numbers (RINs), state low-carbon fuel standards and production or consumption incentives, and public or private offtake agreements.

Much of the policy discussion surrounding these programs focuses on understanding how large a subsidy is needed to make an emerging technology competitive? However, a dollar delivered through a capital grant is not equivalent to a dollar delivered through a production tax credit or loan guarantee. These policies address different barriers, allocate risks differently, benefit different stakeholders, and create different incentives for technological development. The architecture of policy support may be as important as its magnitude, and policy-makers need to be armed with better information about the tradeoffs across policy levers.

Consider a capital subsidy and a production tax credit. Both incentives improve project economics, but a capital grant provides public support before a project demonstrates successful operation. It reduces private capital at risk and may be particularly valuable for first-of-a-kind facilities; however, if the project fails, risk falls on taxpayers. In contrast, a production tax credit pays only when a facility successfully produces, leaving developers and investors bearing the construction and technological risks.

Production incentives introduce other types of risk. A facility may take several years to permit, finance, and construct and then be expected to operate for decades. If the policy that makes the facility economically viable expires or can be changed by a subsequent administration, the investor faces a mismatch between the life of the investment and the life of the policy. A production subsidy exposes taxpayers to relatively little project-failure risk while leaving investors exposed to substantial policy risk. Policies vary based not only on how much support a policy provides, but how risks are allocated across the innovation ecosystem.

The paper will compare major policy instruments supporting emerging clean-energy technologies, distinguishing traditional market failures from commercialization barriers. Table 1 illustrates the approach.

Table 1. Policy Instruments, Market Failures/Barriers, Risk Allocation and Technological Lock-In

Policy instrument	Market failure / barrier addressed	When support occurs	Private project risk	Direct public project risk	Technological diversity / lock-in implications
R&D funding	Market failure: knowledge spillovers	Earliest stage	Low	High	Supports competing pathways
Demonstration grants	MF: information/learning spillovers; barrier: FOAK/scale-up risk	Pre-commercial	Medium-low	High	Preserves less-mature options
Capital grants / ITCs	Barrier: upfront capital/financing constraints	Construction	Medium	High	Favors investment-ready pathways unless targeted
Loan guarantees	MF: information asymmetry; barrier: lender aversion to novel technology	Construction	Medium	Contingent	Enables less-proven, capital-intensive pathways
Feedstock incentives	Barrier: input availability/cost	Upstream	Medium-high	Medium	Develops supply chains for alternatives
Production tax credits	MF: environmental externality if performance-linked; barrier: incumbent cost gap	Production	High	Low if project fails	Favors scalable mature pathways; lock-in risk
Performance credits / LCFS	MF: environmental externality	Production/use	High	Low direct fiscal exposure	Reinforces mature low-cost pathways
Mandates	MF: environmental externality; barrier: insufficient/uncertain demand	Market formation	High	Low direct fiscal exposure	Broad: favors low-cost pathways; differentiated: preserves diversity
CfDs / long-term offtake	Barrier: revenue/price uncertainty; bankable demand	Operation	High completion risk	Contingent	Can support less-mature pathways

This framework builds on research on environmental and technology policy in the presence of multiple market failures (Jaffe, Newell, and Stavins 2005; Fischer and Newell 2008), technology-push and demand-pull policies, learning and technological change (Nemet 2009; Johnstone, Haščič, and Popp 2010), and policy mixes (Flanagan, Uyarra, and Laranja 2011; Rogge and Reichardt 2016). I focus specifically on how the composition of a policy portfolio allocates technological, financial, market, and political risks during commercialization.

Technology Neutrality and Technological Lock-In

Policy design also affects which technologies develop. Policymakers frequently favor “technology-neutral” policies that reward outcomes rather than particular pathways, allowing competition to reveal lower-cost approaches and reducing the need for government to pick winners.

Yet output neutrality does not necessarily produce technological neutrality. Technologies enter markets at different points on their learning curves. If one pathway is already cheaper or more mature, an output-based subsidy will disproportionately encourage deployment of that pathway. Deployment creates additional learning-by-doing, specialized suppliers, infrastructure, financing expertise, regulatory familiarity, and political constituencies furthering the technology's advantage. Policy support can produce the same self-reinforcing process that makes market transformation possible, while simultaneously creating risks for technological lock-in (Arthur 1989; Unruh 2002; Haelg, Waelchli, and Schmidt, 2018).

SAF provides a useful illustration. Hydroprocessed esters and fatty acids (HEFA) currently represent the most commercially mature SAF pathway. Alcohol-to-jet (ATJ), Fischer-Tropsch (FT), and power-to-liquid fuels rely on different technologies, capital requirements, and feedstocks and are at different stages of

commercialization. A subsidy paid for producing low-carbon aviation fuel may appear technology-neutral but nevertheless direct most near-term investment toward the pathway already closest to commercial competitiveness. Conversely, upstream feedstock support, demonstration funding, or targeted capital support may preserve technological pathways that are more expensive today but have greater opportunities for future cost reductions. This creates a tension between static and dynamic efficiency: the policy producing the cheapest low-carbon fuel today may not produce the technological portfolio that minimizes decarbonization costs over time.

From Policy Mixes to Policy Thickness

Emerging technologies rarely encounter a single policy; policies accumulate at different stages of development, along the value chain, and across levels of government. Policy makers need to consider how a portfolio of policies creates incentives and allocates risks across the technological development system. I propose extending the idea of policy mixes from a description of policy complexity to a theory of policy portfolio resilience. A thick policy environment may contain R&D funding, demonstration programs, capital support, production incentives, environmental performance standards, infrastructure investments, and demand-side policies. These policies provide different types of insurance against the risks faced by an emerging technological system (Rosenow, Kerna, and Rogge 2017; Li and Taeihagh 2020; Borozan 2022; Castrejon-Campos, Aye, and Hui 2020).

A policy mix functions similarly to portfolio diversification. Two technologies could receive the same expected dollar value of support while facing very different risks and allocating policy benefits across the supply chain. A technology dependent on a single federal production tax credit is highly exposed to that policy's future. Another receiving R&D support, a DOE loan guarantee, state low-carbon fuel credits, federal production incentives, feedstock support, and long-term procurement has a more diversified policy portfolio.

Nevertheless, simply counting policies is insufficient. Six federal tax credits that expire simultaneously and depend on the same political coalition provides little diversification. Policies embedded in different statutes, agencies, levels of government, and policy mechanisms have different risk attributes. Policy thickness depends not simply on the number of policies but on instrument diversity, location along the value chain, institutional origins, duration, and beneficiary constituencies.

Distributional politics provides another source of resilience. Feedstock, capital, production, and demand-side policies benefit different actors and create different constituencies. Distributing benefits across actors and regions may generate a broader, more durable coalition supporting technological development (Schneider and Ingram 1993; Breetz, Mildenberger, and Stokes 2018; Stokes 2020).

Thicker policy portfolios may have costs as well. Additional policies impose administrative and compliance costs, can create contradictory incentives, obscure the true magnitude of public support, encourage rent seeking, and make ineffective policies difficult to eliminate. Multiple overlapping subsidies can also overcompensate producers or reinforce precisely the technological lock-in that policy diversity might otherwise help prevent.

This paper seeks to develop an understanding of the tradeoffs of policy mixes and how policy portfolios can be designed to address multiple barriers and withstand technological, market, and political shocks without creating unnecessary complexity and rents. The completed paper will use SAF as a running case, with comparisons to other emerging energy technologies. Its central argument is that policymakers should evaluate not only the level of support but its architecture: where policies intervene, which risks they transfer, which pathways they encourage, who benefits, and how independently components are likely to survive. Designing

resilient policy portfolios may be as or more important than simply pumping more subsidies into a technological innovation system.

Disclosures:

Financial support for this research has been provided by the UPS Foundation.

References

Arthur, W. B. 1989. “Competing Technologies, Increasing Returns, and Lock-In by Historical Events.” Economic Journal 99(394): 116–131.

Blackburn, C., M. E. Flowers, D. C. Matisoff, and J. Moreno-Cruz. 2020. “Do Pilot and Demonstration Projects Work? Evidence from a Green Building Program.” Journal of Policy Analysis and Management 39 (4): 1100–1132.

Breetz, H., M. Mildenberger, and L. C. Stokes. 2018. “The Political Logics of Clean Energy Transitions.” Business and Politics 20(4): 492–522.

Castrejon-Campos, O., L. Aye, F. K. Peng Hui, P. Vaz-Serra, and M. Akbarzadeh. 2020. “Making Policy Mixes More Robust: An Integrative and Interdisciplinary Approach for Clean Energy Transitions.” Energy Research & Social Science 64: 101425.

Fischer, C., and R. G. Newell. 2008. “Environmental and Technology Policies for Climate Mitigation.” Journal of Environmental Economics and Management 55(2): 142–162.

Flanagan, K., E. Uyarra, and M. Laranja. 2011. “Reconceptualising the ‘Policy Mix’ for Innovation.” Research Policy 40(5): 702–713.

Haelg, L., M. Waelchli, and T. S. Schmidt. 2018. "Supporting energy technology deployment while avoiding unintended technological lock-in: a policy design perspective." Environmental Research Letters 13(10): Article 104011. https://doi.org/10.1088/1748-9326/aae161

Howlett, M., G. Capano, and M. Ramesh. 2018. “Designing for Robustness: Surprise, Agility and Improvisation in Policy Design.” Policy and Society 37(4): 405–421.

Jaffe, A. B., R. G. Newell, and R. N. Stavins. 2005. “A Tale of Two Market Failures: Technology and Environmental Policy.” Ecological Economics 54(2–3): 164–174.

Johnstone, N., I. Haščič, and D. Popp. 2010. “Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts.” Environmental and Resource Economics 45(1): 133–155.

Li, L., and A. Taeihagh. 2020. “An In-Depth Analysis of the Evolution of the Policy Mix for the Sustainable Energy Transition in China from 1981 to 2020.” *Applied Energy* 263: 114611.

Malen, J., and A. A. Marcus. 2017. “Promoting Clean Energy Technology Entrepreneurship: The Role of External Context.” Energy Policy 102: 7–15.

Nemet, G. F. 2009. “Demand-Pull, Technology-Push, and Government-Led Incentives for Non-Incremental Technical Change.” Research Policy 38(5): 700–709.

Reichardt, K., K. S. Rogge, and M. P. Schaffer. 2024. “Detecting a Structure in the European Energy Transition Policy Instrument Mix: What Mix Successfully Drives the Energy Transition?” Energy Research & Social Science 117: 103818.

Rogge, K. S., and K. Reichardt. 2016. “Policy Mixes for Sustainability Transitions: An Extended Concept and Framework for Analysis.” Research Policy 45(8): 1620–1635.

Rosenow, J., F. Kern, and K. S. Rogge. 2017. “The Need for Comprehensive and Well Targeted Instrument Mixes to Stimulate Energy Transitions: The Case of Energy Efficiency Policy.” Energy Research & Social Science 33: 95–104.

Schneider, A., and H. Ingram. 1993. “Social Construction of Target Populations: Implications for Politics and Policy.” American Political Science Review 87(2): 334–347.

Stokes, L. C. 2020. Short Circuiting Policy: Interest Groups and the Battle Over Clean Energy and Climate Policy in the American States. Oxford University Press.

Unruh, G. C. 2002. “Escaping Carbon Lock-In.” Energy Policy 30(4): 317–325.