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Applying Innovation Policy to the U.S. Energy/Climate Challenge

William B. Bonvillian[1]

The policy concept in the United States to price carbon to avoid the approaching climate shift came from the toolkit of its dominant economic theory: neoclassical economics.[2] Neoclassical doctrine is organized around the concept of maximizing allocation efficiency, where pricing signals – from interest rates, currency supply, monetary policy, taxes, and pricing mechanisms – are the preferred tools. Given this centrality of allocation efficiency, markets are all important, and market distortions and interventions are to be avoided whenever possible. On the other hand, market distortions are admittedly pervasive, and much of neoclassical theory deals with correcting market failures through such means as providing public goods, offsetting externalities, upholding information transparency, promoting competition, and encouraging new entrants despite economies of scale.

Neoclassical economics has used these constructs of market failure and offsetting externalities to pursue climate policy. Economic actors are assumed to pursue their rational self-interest;[3] this means that their economic activities can be measured. So the field can accordingly be measurement-based. Carbon prices - including the pricing approach proposed in the U.S. of capping total carbon emissions and allowing trading for a declining base of emissions permits (“cap and trade”) - can fit within this construct.. But if a factor cannot be measured and analyzed within a manageable number of variables, it is exogenous to neoclassical economics: outside the measurable box and so outside the system. Complex social systems, for example, fall outside its reach. Similarly, neoclassical economics has had great difficulty in addressing innovation systems, which are, of course, highly complex, with multitudes of actors and therefore variables that are not widely understood or necessarily measurable. Cap and trade, because it fits squarely within the neoclassical constructs of allocative efficiency, market failure, and offsetting externalities, was a solution set to climate change imbedded in neoclassical economics.

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[2] Discussed in, Robert D. Atkinson and Darrene Hackler, Economic Doctrines and Approaches to Climate Change Policy (Washington, DC: Information and Innovation Technology Foundation (ITIF) Oct. 2010).

[3] A growing behavioral economics literature recognizes some of the issues in this assumption. See for example, Justin Fox, From ‘Economic Man” to Behavioral Economics, *Harvard Business Review* , May 2015, 75-85.

Innovation-oriented policies for climate, because of their too often unmeasurable variables, were not well understood in the neoclassical context – they are exogenous.

The neoclassical toolkit has made major contributions in recent decades to environmental progress in the U.S. The accomplishments include, most notably, the acid rain provisions of the Clean Air Act Amendments of 1990[4] where a cap and trade system efficiently controlled sulphur dioxide power plant emissions. Other examples include a trading system under the Montreal Protocol[5] for chlorofluorocarbons (CFC's) to control ozone layer depletion and nitrogen oxides trading to limit U.S. east coast smog. These trading systems helped emitters find and adopt flexible, low-cost compliance strategies; they also encouraged prompt deployment of technological solutions. In all these cases, however, the needed technology innovations were readily at hand.

Progress on climate change, however, requires dramatic innovation advances particularly in energy.[6] While we can now see the outlines of the long series of technology pathways that will be required, most of these technologies require significant additional advance before they will be ready for deployment at scale. For example, we still don't know the optimal technology solutions required for a transport transformation – these may involve evolving electric, hybrid or biofuel vehicles, or a combination of all three. Each of these technology paths requires significant technology progress, from dramatic battery or fuel cell improvements to new biofuels, and each must go through dramatic cost reduction improvements. And each requires major new supporting infrastructure. Even where a technology pathway has appeared relatively clear, such as with carbon capture and sequestration for the multitude of coal-fired power plants, there are many years of well-monitored demonstrations at scale, so optimal operating practices and efficiencies can be thoroughly understood, plus major cost reductions, required, before the deployment box can be checked.[7] The complexity of the technology development challenge, including the scale of worldwide deployment, is profound, far more complicated than acid rain or CFC controls that proved so adaptable to emissions trading regimes understood by neoclassical economics.

While the technology *development* challenge for climate may not be the most difficult we have faced, the technology *implementation* task is daunting. It involves transforming a major world economic sector fundamental to basic human needs, equivalent to at least ten percent of the world economy, with at least $15 trillion in imbedded infrastructure and investment, demanding numerous but complementary technology pathways, to be implemented over a multi-decade period. The U.S. has succeeded in remarkable single thrust technology projects achievable within a decade – the Apollo or Manhattan projects are touchstones – but has never tried anything as complex as an energy technology

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[4] The Clean Air Act Amendments of 1990, 104 Stat. 2468, P.L. 101-549.

[5] United Nations Environment Programme, Ozone Secretariat, The Montreal Protocol, text as amended at http://ozone.unep.org/new_site/en/Treaties/treaties_decisions-hb.php?sec_id=5; description, http://ozone.unep.org/new_site/en/montreal_protocol.php.

[6] This discussion draws on Charles Weiss and William B, Bonvillian, *Structuring an Energy Technology Revolution* (Cambridge, MA: MIT Press 2009); William B. Bonvillian, Time for Plan B for Climate, *Issues in Science and Technology,* Winter 2011, 55-56.

[7] MIT, *The Future of Coal* (MITEI report 2007), http://web.mit.edu/coal/.

transformation. The sheer complexity of this technology task has led to dissonance between underlying economic ideologies.

The neoclassical economic focus on allocation efficiency has been running for years into an innovation brick wall for climate because the technological solutions are not readily at hand, as they were with earlier environmental problems like acid rain. This technology challenge has presented industries faced with carbon prices with what many have viewed as a "mission impossible," multiplying their political resistance.[8] Neoclassical economics, like classical economics before it, has a great deal trouble developing a theory of economic growth. Robert Solow won the Nobel in 1987 for explaining to his neoclassical colleagues that well over half of economic growth was tied to technological and related innovation.[9] But he had trouble fitting his breakthrough theory into the neoclassical framework, concluding it was exogenous to neoclassical economics – a complex system that was outside the neoclassical box. While economists led by Paul Romer,[10] Richard Nelson,[11] Robert Lucas[12] and others have subsequently worked to develop the concepts to wrestle technological innovation into the neoclassical box – to make it endogenous – this "new growth theory"[13] is still an ongoing project because neoclassical economics has had such trouble coping with complex systems. It continues to try to treat growth as arising largely through allocative efficiency.

Climate change, despite the neoclassical approach, is not only a problem of market allocation but a profound challenge to innovation systems, so is a symptom of the same problem. Because the U.S. political system in 2010 spit out and rejected the neoclassical economics approach – a price on carbon through a cap and trade scheme[14] imposed economy-wide – it may be time to look more systematically at innovation policy in the context of the climate technology challenge. The climate issue has now exposed the policy battle lines between economic doctrinal ideologies – neoclassical economic policy verses innovation policy. It is not that neoclassical economic tools won't be needed, but that innovation policy may be a prerequisite to applying them.

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[8] Of course, technology readiness is not the only cause of industry resistance. See for example, Naomi Oreskes and Erik M. Conway, *Merchants of Doubt* (New York: Bloomsbury Press 2009).

[9] Robert M. Solow, *Growth Theory, An Exposition* (Oxford Univ. Press, New York, Oxford, 2nd edition 2000), ix-xxvi (Nobel Prize Lecture, Dec. 8, 1987).

[10] Paul Romer, Endogenous Technological Change, *Journal of Political Economy*, v. 98, (1990), 72-102.

[11] Richard R. Nelson and Nathan Rosenberg, "Technical Innovation and National Systems." In Richard R. Nelson, ed., *National Innovation Systems: A Comparative Analysis* (New York: Oxford University Press 1993), 3-21.

[12] Robert E. Lucas, Jr., On the mechanics of economic development, *Journal of Monetary Economics*, v. 22, no. 1 (July 1988), 3-42.

[13] Solow summarizes some of the issues in new growth theory in *Growth Theory and Exposition* (2000).

[14] The American Clean Energy and Security Act of 2009, 111 Cong., 1st Sess., H.R.2454 (Waxman-Markey Bill), passed the House of Representatives on June 26, 2009 on a 219-212 vote). The Senate version of the legislation, however, did not pass. See, The American Power Act of 2010 (the Kerry-Lieberman bill), which became S. 1733, 111th Cong., 2nd Sess., released May 12, 2010. Summarized at, World Resources Institute, Summary of the American Power Act, June 2010, http://pdf.wri.org/wri_summary_american_power_act_2010-06-07.pdf. This legislation in turn descended from three earlier versions of the Climate Stewardship Act introduced in 2003 (S. 139), 2005 (S 1151) and 2007 (S. 280) by Senators Lieberman and McCain.

U.S. policymakers in the have assumed for fifteen years that putting a price on carbon would be the strategy for addressing climate change. Remarkably, they have never assembled a systematic backup plan to carbon pricing. Innovation policy offers such an approach, and we are starting to see its elements.

On the "front-end" of the U.S. energy innovation system new R&D institutions have been formed within the Department of Energy to better translate research into actual technology advance, including:

- Energy Frontier Research Centers (EFRCs)[15] provide $3 million to $5 million a year to competitively selected university and laboratory teams working on basic research problems, tied to breakthrough advances in energy technologies. Over thirty are now operating.
- Energy innovation "Hubs" [16] in solar, advanced nuclear, batteries, critical materials and buildings. Whereas EFRCs are searching for new energy opportunities in the basic research space, the Hubs work to push emerging energy advances at a larger scale toward commercialization. Reflecting their scaling role, the five Hubs each receive around $20 million in annual funding.
- The Advanced Research Projects Agency-Energy (ARPA-E),[17] funded at around $300m a year, is modeled on DARPA. It has adopted DARPA's "right-left" model of seeking particular technology advances on the right side of the innovation pipeline and then looking on the left side for revolutionary breakthroughs to get there, and DARPA's "hybrid" model of building research groups around smaller companies and university researchers to ease technology transition. Its projects aim at accelerating innovation, moving from ideas to proof-of-concept or prototype in three to five years. It is working in what it calls "the white space" of technology opportunities, higher-risk projects that could be transformational where little work previously has been undertaken.
- The SunShot Initiative[18] in DOE's Energy Efficiency and Renewable Energy office (EERE) with around $70 to $100m in annual R&D to promote technology and process advances to make solar energy cost competitive with fossil fuels by 2020.
- The Clean Energy Manufacturing Initiative[19] in EERE aims at applied technology advances to drive down production costs for new energy technologies to make them competitive, and to improve overall industrial efficiency. The program has set up three advanced manufacturing institutes, industry-university collaborations as testbeds for power electronics, advanced composites, and "smart"

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[15] DOE, Office of Science, Energy Frontier Research Centers, http://science.energy.gov/bes/efrc/.

[16] DOE, Energy Innovation Hubs, http://energy.gov/science-innovation/innovation/hubs; http://energy.gov/articles/what-are-energy-innovation-hubs.

[17] William B. Bonvillian and Richard Van Atta, ARPA-E and DARPA, Applying the DARPA Model to Energy Innovation, *Journal of Technology Transfer,* Oct. 2011.

[18] DOE, Energy Efficiency and Renewable Energy, SunShot Initiative, http://energy.gov/eere/sunshot/sunshot-initiative.

[19] DOE, Energy Efficiency and Renewable Energy, Clean Energy Manufacturing Initiative, http://energy.gov/eere/cemi/clean-energy-manufacturing-initiative.

manufacturing, which are cost shared with around $70m in federal funds each over five years.

On the back-end of the U.S. energy innovation system, scaffolding support is needed to bring new technologies toward implementation and deployment. The programs and incentives include:

- Tax incentives for new energy technologies.[20]
- DOE financing for energy technologies through loan guarantees.[21]
- Government procurement, particularly through the Department of Defense when its missions require energy advances.[22]
- Existing federal regulatory authority, for reduced emissions and energy consumption from power plants,[23] automobiles and trucks,[24] and appliances.[25]
- Regulatory authority and incentives at the state level. States and regions in the U.S. can amount to nation-sized economies and some have taken leadership in pressing for new energy technologies, particularly California[26] and the northeast. Some three fifths of the states, for example, have renewable portfolio standards requiring power producers to provide a set minimum share of their electricity from renewable resources.[27]

None of these programs are operating at the scale of investment and support required for an energy transformation[28] and both front and back ends of the innovation system remain subject to the ups and downs of the political process. However, the outline of a much stronger energy innovation system is starting to unfold.

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[20] Congressional Research Service, *Federal Renewable Energy R&D Funding History: A Comparison with Funding for Nuclear Energy, Fossil Energy and Efficiency* R&D (March 7, 2012), http://www.fas.org/sgp/crs/misc/RS22858.pdf. See also, MIT Energy Initiative, *The Future of Solar Energy* (May 2015), 209-229 (efficiency issues with current U.S. tax subsidy for solar).

[21] DOE, Loan Programs Office, http://energy.gov/lpo/loan-programs-office.

[22] See, generally, on DOD role, Alic, John, Daniel Sarewitz, Charles Weiss, and William Bonvillian, A New Strategy for Energy Innovation, *Nature*, Vol. 466, July 15, 2010, pp. 316-317; William B. Bonvillian, Forum: DOD's Role in Energy Innovation, *Issues in Science and Technology* (Winter 2015) 10-14.

[23] Environmental Protection Agency, Carbon Pollution Standards, http://www2.epa.gov/carbon-pollution-standards/what-epa-doing

[24] Environmental Protection Agency, EPA and NHTSA Set Standards…[for] Model Years 2017-2025 Cars and Light Trucks, http://www.epa.gov/otaq/climate/documents/420f12051.pdf.

[25] DOE, Energy Efficiency and Renewable Energy, Appliance and Equipment Standards Program, http://energy.gov/eere/buildings/appliance-and-equipment-standards-program.

[26] See, for example, CA Energy Efficiency Strategic Plan, Jan. 2011 Update, http://www.energy.ca.gov/ab758/documents/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

[27] DOE, Energy Information Administration, Most States have Renewable Portfolio Standards (Feb. 3, 2012), http://www.eia.gov/todayinenergy/detail.cfm?id=4850#; National Renewable Energy Laboratory (NREL), State and Local Governments, Renewable Portfolio Standards, http://www.nrel.gov/tech_deployment/state_local_governments/basics_portfolio_standards.html.

[28] See, for example, Gregory F. Nemet, and Daniel M. Kammen. U.S. Energy R&D: Declining Investment, Increasing Need, and the Feasibility of Expansion. *Energy Policy* 35 (2007), 746-755; Breakthrough Institute, Brookings Institution, World Resources Institute, Beyond Boom and Bust, (report April 12, 2012) 12-21, http://thebreakthrough.org/blog/Beyond_Boom_and_Bust.pdf; International Energy Agency, *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050* (June 6, 2008).

Cap-and-trade is strong on "demand pull" but short on "technology push." Both may be needed, but they do not have to operate in parallel; progress on the latter may be a requirement for implementation of the former because it is an enabler. An amalgam of policies in the U.S. that could comprise a backup plan on climate is emerging. The plan includes technology push mechanisms that have been strengthened in the past decade, with a focus on both front and back ends of the innovation system. The plan relies for needed demand pull on current regulatory tools and incentives that are less economically efficient than cap-and-trade but will allow for interim progress. And more innovation system elements will need to evolve; for example, there is a significant gap in the system for scale-up financing for production of new energy technologies.[29] This evolving innovation system, however, appears more palatable politically because it applies a series of more manageable policy bricks that can be put in place by many different actors, unlike the far-reaching, single, economy-wide, economic construct of cap-and-trade.

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[29] Elizabeth Reynolds, et al, Learning by Building (chapt. 4), in Richard Locke and Rachel Wellhausen, *Production in the Innovation Economy* (Cambridge, MA: MIT Press 2014) (study of production financing challenge for venture funded startups); Richard Lester and David Hart, *Unlocking Energy Innovation* (Cambridge, MA: MIT Press 2012).