Before the
ENVIRONMENTAL PROTECTION AGENCY

In the Matter of

Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units	**Docket No. EPA-HQ-OAR-2013-0602 RIN 2060-AR33**

COMMENTS OF DR. MARK COOPER SENIOR FELLOW FOR ECONOMIC ANALYSIS INSTITUTE FOR ENERGY AND THE ENVIRONMENT, VERMONT LAW SCHOOL

Mark Cooper
504 Highgate Terrace
Silver Spring, MD 20904
(301) 384-2204
markcooper@aol.com

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I. INTRODUCTION, SUMMARY AND RECOMMENDATIONS

A. QUALIFICATIONS

My name is Mark Cooper. I am a Senior Fellow for Economic Analysis at the Institute for Energy and the Environment of Vermont Law School. I hold a Ph.D. from Yale University and I am a former Yale University and Fulbright fellow. In the past 35 years have testified about 400 times on behalf of public interest organizations before regulatory and legislative bodies at the federal and state level and written over 100 books, articles and conference papers on energy and communications policy.

I am filing these comments on my own behalf because I believe that this rulemaking and the decision to confront the challenge of climate change are the most important policy issues in my 35 years of policy analysis. Over those 35 years, I have also been a strong advocate of well-designed performance standards as an ideal policy tool, perhaps the best tool available, to deal with complex problems like energy and climate change in capitalist economies. In fact, the very first public policy issue on which I worked was Building Energy Performance Standards. The Clean Power Rule represents an important opportunity to launch a long term effort to deal with climate change.

My experience of most direct relevance to the current proceeding, as shown in Exhibit S-1, over the past four years in a series of (1) articles, (2) testimonies in regulatory proceedings, courts and legislatures as the federal and state levels, as well as (3) reports, I have published two dozen analyses of various aspects of the cost of the alternative resources available to meet electricity needs for the next several decades. I have also developed a general framework (4) that I refer to as multi-criteria portfolio analysis for evaluating and choosing between the available alternatives in the increasingly complex and ambiguous conditions of the electricity market. This body of work has focused analyses on several resources including repeated analysis of the nuclear-gas comparison driven by utility concentration on these two technologies, but also including efficiency and wind. The analysis has covered (5) regional, national and international levels, as well as on the impact of specific institutional arrangements on ratepayers.

I have also been active in public policy in the Information Communication Technology (ICT) space for almost as long as the energy space. I argue that standards played a key role in laying the groundwork for the digital revolution by establish simply regulations that unleashed innovative activity at the edge of the communication network.[1] At least two of the most important standards that opened the communications network to competition and innovation were essentially basic performance standards.[2]

I argue in these comments that the emergence of the digital revolution, which is transforming the economy broadly, is having a huge impact on the electricity sector. The convergence of the energy and ICT sectors has opened the possibility for a transformation of the electricity sector into a user/edge driven network as it decarbonizes. If well crafted, I believe the Clean Power Rule can advance that process.

[1] See Cooper, 2004, and 2014c, 2014d).

[2] The Carterphone decision which allowed user designed customer premise equipment to be attached to the network, which gave rise to the Hayes modem, and the Spread Spectrum decision, which allowed access to unlicensed spectrum, which gave rise to WiFi.

EXHIBIT S-1: RECENT ANALYSIS OF ELECTRICITY RESOURCE ACQUISITION MARK COOPER

1 "Small Modular Reactors and the Future of Nuclear Power in the United States, 2014," *Energy Research & Social Science,* 2014, 3; "The EPA carbon plan: Coal loses, but nuclear doesn't win," *Bulletin of the Atomic Scientists,* 70, 2014, *Energy Efficiency Performance Standards: Driving Consumer and Energy Savings in California,* California Energy Commission's Energy Academy, February 20, 2014, "Nuclear Safety and Affordable Reactors: Can We Have Both?," *Bulletin of the Atomic Scientists,* 2012; "Nuclear Safety and Nuclear Economics, Fukushima Reignites the Never-ending Debate: Is Nuclear Power not worth the risk at any price?," *Symposium on the Future of Nuclear Power,* University of Pittsburgh, March 27-28, 2012; "Post-Fukushima Case for Ending Price Anderson," *Bulletin of the Atomic Scientists*, October 2011; "The Implications of Fukushima: The US Perspective," *Bulletin of the Atomic Scientists* July/August 2011 67: 8-13; "Further Nuclear Power Subsidies are Wrongheaded," *Bulletin of the Atomic Scientists,* December 2009.

2 *The Economic Feasibility, Impact On Public Welfare And Financial Prospects For New Nuclear Construction, For Utah Heal*, July, 2013, Testimony and Surrebuttal Testimony on Behalf Of The Sierra Club, *Before The South Carolina Public Service Commission*, Docket No. 2012-203-E; "Direct Testimony of Dr. Mark N Cooper in Re: Nuclear Plant Cost Recovery for the Southern Alliance for Clear Energy," Before the *Florida Public Service Commission*, FPSC Docket No. 100009-EI, August 2010; '"Direct Testimony of Dr. Mark N Cooper in Re: Nuclear Plant Cost Recovery for the Southern Alliance for Clear Energy," Before the *Florida Public Service Commission*, FPSC Docket No. 090009-EI, July 15, 2009.*Nuclear Economics after Fukushima,* Before the Standing Committee on Natural Resources House of Commons, Ottawa Canada, March 24, 2011; "Testimony of Dr. Mark Cooper on House File 9," *Minnesota House of* Representatives Committee on Commerce and Regulatory Reform, February 9, 2011.

3 "Multi-Criteria Portfolio Analysis of Electricity Resources: An Empirical Framework For Valuing Resource In An Increasingly Complex Decision Making Environment", *Expert Workshop: System Approach to Assessing the Value of Wind Energy to Society, European Commission Joint Research Centre, Institute for Energy and Transport*, Petten, The Netherlands, November 13-14, 2013 *Renaissance In Reverse: Competition Pushes Aging U.S. Nuclear Reactors To The Brink Of Economic Abandonment*, Institute For Energy And The Environment, Vermont Law School, July, 2013, *Fundamental Flaws In SCE&G's Comparative Economic Analysis,* October 1, 2012; *Policy Challenges of Nuclear Reactor Construction: Cost Escalation and Crowding Out Alternatives*, September, 2010; *All Risk; No Reward,* December 2009; *The Economics of Nuclear Reactors: Renaissance of Relapse,* June 2009; *Climate Change and the Electricity Consumer: Background Analysis to Support a Policy Dialogue*, June 2008

4 "Prudent Resource Acquisition in a Complex Decision Making Environment: Multidimensional Analysis Highlights the Superiority of Efficiency," *Current Approaches to Integrated Resource Planning, 2011 ACEEE National Conference on Energy Efficiency as a Resource*, Denver, September 26, 2011; "Least Cost Planning for 21st Century Electricity Supply: Meeting the Challenges of Complexity and Ambiguity in Decision Making," *MACRUC Annual Conference*, June 5, 2011; "Risk, Uncertainty and Ignorance: Analytic Tools for Least-Cost Strategies to Meet Electricity Needs in a Complex Age," *Variable Renewable Energy and Natural Gas: Two Great Things that Go Together, or Best Not to Mix Them*. NARUC Winter Committee Meetings, Energy Resources, Environment and Gas Committee, February 15, 2011;

5 *Capturing The Value Of Offshore Wind To Promote A Secure, Affordable, Low-Carbon Electricity Future A Multi-Criteria, Portfolio Approach To Electricity Generation Resource Acquisition In The United Kingdom*, October 2012; 8 *Public Risk, Private Profit: Ratepayer Cost, Utility Imprudence: Advanced Cost Recovery For Reactor Construction Creates Another Nuclear Fiasco, Not A Renaissance,* March 2013; *Advanced Cost Recovery for Nuclear Reactors,* March, 2011; Economic Advisability of Increasing Loan Guarantees for the Construction of Nuclear Power Plants," *Domestic Policy Subcommittee, Committee on Oversight and Government Reform, U.S. House of Representatives,* April 20, 2010;

B. PURPOSE AND RECOMMENDATIONS

1. Performance Standards

In the Clean Power Rule,[3] the Environmental Protection Agency (EPA) has proposed a performance standard that affords the states wide flexibility in designing programs to achieve a target level of reduction in carbon emissions from existing sources in the electricity sector. A number of states have already adopted policies to reduce carbon emissions[4] and a number of federal policies implemented by several agencies in recent years do the same although that need not be their primary justification (e.g. the National Highway Transportation Safety Administration at the Department of Transportation has increased fuel economy standards for light duty vehicles and heavy duty trucks,[5] and the Department of Energy's appliance efficiency standards,[6] among others). The EPA's carbon rule for new generation ensures that future facilities will emit much less carbon than the existing facilities.[7] The Clean Power Rule is the first large scale U.S. national policy targeting substantial reductions in carbon emissions from existing generation in the electricity sector, which is the single largest source of greenhouse gas emissions in the U.S.[8]

In these comments I show that a well-designed performance standard is, in fact, the perfect place to launch a sustained, long-term program to address the challenge of climate change.[9] The targets will have to be raised over the years to achieve the widely accepted international goals for reduction of greenhouse gas (GHG) emissions and other policies will have to be adopted to reinforce the process of controlling greenhouse gas emissions, but a performance standards is a good first step to start this long journey. Because it is such an important beginning, it is critical to future policy development and implementation to understand why it is the correct starting point and to get it right.

There is a second reason that an in-depth analysis of performance standards is important at this stage of the EPA development of the Clean Power Rule. Performance standards have been widely applied to reduce energy consumption at the federal and state levels. The long, successful track record of boosting energy efficiency through performance standards is an important context for evaluating the Clean Power Rule. In the description of the approach EPA used in setting the target for CO_2 reductions, over half of all of the reduction in carbon emissions comes from energy efficiency. Therefore, in the scenario proffered by EPA, the feasibility and cost of saving energy is the central determinant of whether the rule can achieve its goal. In these comments I shows that improving the efficiency of energy consuming durable goods is the least cost option to lower carbon emissions, while meeting the need for electricity in a low carbon environment.

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[3] Environmental Protection Agency (EPA), 2014a. These Comments will focus primarily on the support documents, the Regulatory Impact Assessment, http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule-technical-documents.
[4] The Regional Greenhouse Gas Initiative, http://www.rggi.org, for example.
[5] U.S. National Highway Safety Administration, 2014.
[6] U.S. Department of Energy, 2014.
[7] U.S. Environmental Protection Agency, 2014b.
[8] U.S. Environmental Protection Agency, 2014c.
[9] Cooper, 2014b, 2013, 201.

Thus, EPA has made excellent choices for two of the most important principles on which to base the effort to lower carbon emissions in the U.S. electricity sector:

- The adoption of a flexible, performance standard, and
- Identification of energy efficiency as the “first fuel”[10] in carbon reduction.

2. Concerns about the EPA Analysis

However, in these comments I express concerns about the way the Clean Power Rule has been justified. In order to adopt a rule, the EPA must comply with the law and practice of the Clean Air Act (CAA) and the Administrative Procedures Act (APA). To do so, it presents a number of analyses and calculations to show that under the CAA the rule is based on the

> “best system of emission reduction” that the Administrator determines has been adequately demonstrated taking into account the cost of achieving such reduction and any non-air quality health and environmental impact and energy requirements.”[11]

Under the APA the rule must not be “arbitrary and capricious, an abuse of discretion, or otherwise not in accordance with the law."[12]

EPA’s analysis shows that the benefits of its preferred standard, Option 1, are 5 to 6 times larger than the costs. This extremely large benefit/cost ratio should leave no doubt that the rule passes the CAA economic test and the APA administrative test. In fact, it raises the concern that the rule has not gone far enough – it may have left on the table a great deal of carbon reduction that is cost beneficial, calling into question whether EPA is proposing the “best” system of emissions reduction. That is not my primary concern in these comments, although I recommend that the EPA develop and consider a higher standard.

In these comments I raise questions about the analyses EPA used to justify its proposed standards through the analysis of its preferred option. EPA makes it clear that the steps it has evaluated, which would meet the standard, are for the sole purpose of showing that the rule meets the legal standards.[13] The EPA stresses that the states have complete flexibility in designing their programs to meet the goal set by EPA, but the weaknesses in the analysis cannot be ignored for two reasons.

- If the analysis is fundamentally flawed or lacks a realistic basis in empirical facts, it might be found to be arbitrary and capricious under the APA.
- If the analysis passes APA muster in spite of its flaws, some of its more egregious flaws may influence states to make bad decisions in designing their programs.

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[10] The International Energy Administration, 2014, declares in the Table of Contents: “Energy efficiency: Still the first fuel.”

[11] EPA, 2014d, Background on Establishing New Source Performance Standards (NSPS) Under the Clean Air Act (hereafter, EPA, Background, http://www2.epa.gov/sites/production/files/2013-09/documents/111background.pdf

[12] 5 U.S.C. § 706(2)(A)

[13] EPA, 2014d.

We have already seen indications of the latter problem. Exelon, the nation's largest nuclear utility, is citing the EPA analysis to support its effort to secure major subsidies from Illinois legislators to support it aging nuclear reactors.[14] The subsidies it is seeking are more than twice as large as the subsidy EPA estimated would be necessary to save aging reactors. If the rest of the nuclear industry followed Exelon's example and secured subsidies of the magnitude Exelon is seeking, the cost of nuclear subsidies alone would be an order of magnitude higher than the total cost of the entire Clean Power Rule. EPA has made it clear that its analysis is being misused by Exelon,[15] but the tendency to do so is inevitable.

A better strategy for EPA is to

(1) get the analysis right and

(2) be technology neutral and not appear to endorse subsidies for any specific resource, as it did in the case of nuclear power.

In the process of showing that EPA should correct its nuclear mistake, these comments also show that the states can do a much better job in selecting measures to meet the standards set than is suggested by EPA's economic analysis for several reasons.

First, the EPA analysis, while adequate to justify the rule, would be a poor way to implement it. It has not chosen the least cost set of options. Showing that there are less costly ways to meet the standard can help garner more support for the current standard and make it easier to raise the standard in the future.

Second, EPA takes an approach that demonstrates each of the blocks of measures it identifies to achieve the reduction (Block 1: heat rate improvement at existing coal plants, Block 2: switching from coal to gas, Block 3: relying on low carbon, non-fossil fuels, and Block 4: increasing the role of energy efficiency) is technically feasible, economically practicable and consistent with the APA standards. The assumptions for each separate analysis are not reconciled. While this may make sense from the point of view of passing legal muster to outline worst case scenarios, the use of different and contradictory assumptions is troubling.

Third, and most importantly, EPA's economic analysis of major non-fossil fuel options to meet the need for electricity in a low carbon environment – nuclear power, non-hydro renewables and efficiency – provides a severely distorted picture of the options available to the states.

- EPA overestimates the cost and underestimates the potential contribution of efficiency (particularly compared to nuclear power).
- EPA falls to analyze how this could affect the cost and quantity of carbon

[14] Daniels, 2014a.

[15] Daniels, 2014a, In an email, an EPA spokeswoman denied that the agency was advocating a $6-per-megawatt-hour surcharge for preservation of nuclear. Rather, EPA cited studies showing that at-risk nuclear plants were up to $6 short of what they needed to cover their costs and that was a reasonable price to pay to keep those carbon-free units operating. "States have flexibility in choosing their compliance path or other compliance approach," she wrote. "EPA does not make any specific requirements to states on their nuclear fleet, fossil generation, renewables or energy efficiency."

reduction in the next two decades.

- EPA acknowledges the high cost of nuclear power,[16] but underestimates and misrepresents the cost of power from nuclear reactors that are aging or under construction.
- EPA ignores the potential to reduce carbon emissions by transforming the electricity system from the 20th century approach that increases generation to meet load to one that uses information and control technology to integrate distributed supply with active management of demand.

These flaws in the analysis highlight the mistakes EPA made in the one area where it appears to support explicit subsidies for a low carbon resource. EPA suggested that the states can put a thumb on the scale in favor of aging nuclear reactors with a direct subsidy, but failed to examine the cost of aging reactors. EPA also suggests that the tens of billions of dollars yet to be spent on nuclear reactors under construction in three states be ignored in the state planning process. In so doing, it also ignored the massive subsidies that nuclear power has received in the past and is continuing to receive in the present to build new reactors and operate aging reactors.

Ignoring the ongoing costs of nuclear power, old or new, makes no sense, particularly because there is a plethora of lower cost, low carbon resources available. If the states follow EPA's lead in dealing with nuclear compared to other non-carbon resources, they would unnecessarily raise the cost of carbon abatement. EPA should correct these mistakes in promulgating the final rule, which would help the states avoid those same mistakes.

3. Recommendations

The states can and should implement least cost carbon reduction programs based on a more rigorous analysis of the evolving economics of low carbon resources and the emerging 21st century electricity system. The EPA can and should advance the Clean Power Rule toward this goal by making several changes in its analysis of the proposed standard.

(1) EPA should correct its analysis to render it internally consistent and reflective of current costs and cost trends, taking a technology neutral approach and expunging all reference to subsidization of nuclear power.

(2) EPA should prepare a third option for consideration on the high side of the two presented.

(3) EPA should encourage the states to implement least cost approaches by indicating that the selection of resources that deviate significantly from this principle will be subject to close scrutiny.

(4) EPA should develop mechanisms that take account of and provide incentives for advance appliance efficiency standards, build energy codes combined heat and power applications implemented by the states.

[16] EPA, 2014a, p. 34870

(5) EPA should indicate that it will consider, evaluate and give full weight to state implementation approaches that incorporate the beneficial transformation of the electricity infrastructure.

As large as the benefit cost ratio is in the EPA analysis of Option 1, I believe that when these modifications are made to the economic analysis, the potential benefits of a well-designed, least cost performance standard will exceed the costs by a much greater margin than EPA's Option 1 analysis suggests. When the economic analysis is corrected and a third, "high" reduction rule analyzed, the higher standard will be very attractive. Whether or not EPA adopts the higher standard, having the more rigorous analysis of a higher standard available would serve to expand the range of options considered by the states, laying the basis for higher levels of reduction of carbon emissions in the future.

These comments focus on real world economics of electricity resources and the reduction of carbon and recommend ways in which the proposed rule can better reflect that reality. There are numerous flaws in the methodology that EPA used to develop the levels of carbon reductions that are not addressed in these comments. Needless to say, a better methodology applied to data that better reflects reality would produce a much better standard.

B. SUMMARY OF FINDINGS

1. Part I: Framework for Addressing Climate Change in the Presence of Market Barriers, Imperfections, and Failure

While some policy makers and public interest groups are still focused on attacking climate change policy by putting a hefty price on carbon, the EPA has charted a course for climate policy without a carbon price. It leaves it to the states or groups of states to decide what policies are necessary to achieve the goal set by EPA under the proposed Clean Power rule, including a price mechanism. While the failure to enact a national cap-and-trade policy may have forced the decision to adopt a performance standard, these comments demonstrate that a performance standard is the right tool to launch a national climate policy.

This conclusion is based on a review of three literatures

- the efficiency gap (Chapter II),
- the diffusion of innovation (Chapter III),
- climate change (Chapter IV),
- recent empirical analysis demonstrating market barriers in the efficiency gap and climate change area (Chapter V), and
- evaluations of policy instruments contained in these literatures (Chapter VI).

a. Key Market Barriers and Imperfections

The empirical underpinning of all three literatures rests on a simple and basic observation about energy markets that has been recognized for well over a quarter of a century, one that has particular relevance to efficiency and renewables, (See Exhibit S-2). Energy markets are very

EXHIBIT S-2: RECENT EMPIRICAL EVIDENCE ON MARKET BARRIERS AND IMPERFECTIONS

Efficiency Gap

Externalities
Public goods[1] & Bads[2]
Basic research
Network effects
Information as a public good
Learning-by-doing & Using[9]

Industry Structure
Imperfect Competition
Concentration[13]
Barriers to entry
Scale[18]
Switching costs[20]
Technology[23]
R&D
Investment[25]
Marketing
Bundling: Multi-attribute
Insweparable[26]
Substitutes[27]
Cost-Price
Limit impact of price[29]
Fragmented Mkt.[30]
Limited payback[31]

Endemic Imperfections
Asymmetric Info[3].
Agency[5]
Adverse selection[6]
Perverse incentives
Lack of capital[10]

Transaction Cost
Search and Information
Imperfect info[14]
Availability[16]
Accuracy
Search cost[21]
Bargaining
Risk & Uncertainty[24]
Liability
Enforcement
Sunk costs
Hidden cost[28]

Motivation & Values
Non-economic[4]
Influence & Commitment
Custom[7]
Social group & status[8]
Orgnaizational[38]
Perception
Bounded Vision/Attention[11]
Prospect[12]
Calculation.
Bounded rationality[15]
Limited ability to process info[17]
Heuristic decision making[19]
Discounting difficulty[22]

Political Power & Policy
Power of incumbents to hinder alternatives
Monopolistic structures and lack of competition
Importance of institutional support for Alternatives[32]
Inertia[33]
Regulation
Price[34]
Infrequent
Aggregate, Avg.-cost[35]
Lack of commitment[36]
Gold Plating [37]

Climate

EXTERNALITIES 54, 59, 64, 67, ZL
Research and Development 20, 22, 23, 48, 52, E
Importance of learning by searching 27, 31, 38, E
Deployment: Importance of learning by doing 27, 10, 31, 38, E
Economics of Scale/returns to scale 6, 38, 41, 47, G
Localization 24, 38, 45, H

ENDEMIC
Perverse incentives:
allocation of fuel price volatility 20, 50, 68, O
Asymmetric information 21, 48, Q

TRANSACTION COST *N, O*
Uncertainty: as a cause of underinvestment 8, 21, 26, 43, 47, R
Fuel price volatility 20, 33, S
High risk premia on new technologies 28, T
Information: Value of information 2, 22, 56, U
Sunk costs and embedded infrastructure 21, 48, V

BEHAVIOR
Motivation/willingness to pay 51, ZM
Sluggish demand response 20, 23, W
Agency 18, 8, X
Organizational 58,ZN
Risk Aversion 6, Y
Calculation (17, 47, Z)

MARKET STRUCTURE:
Cost Structures: Long investment cycles, increasing returns to scale, network effects 8, 28, 33, 48, I
Challenge of creating new markets: Undifferentiated product 20, 23, 28, 42, J
Entry Barriers: Capital Cost, access to network 20, 41, 47 48, K
Lack of competition hinders innovation 41, 48, L
Regulatory Risk
Carbon tax level and permanence 21, 30, 40, 44, P

POLITICAL POWER
Power of incumbents to hinder alternatives 20, 45, ZA
Monopolistic structures and lack of competition *u*, 24, 39 41, 46, 47, ZB
Importance of institutional support for Alternatives 22, 30, ZC
INERTIA:
Cost of Inertia 1, 14, 28, M
Importance of inertia/stock of knowledge 9, 24, 37, 45, N

EFFECTIVE POLICY RESPONSES
Public goods 24, 49, ZC
Institution Building 22, 30, 49, ZE
Research and Development 5, 10, 20, 23, 25, 26, 28, 32, 35, 37, 47, ZF
Capital subsidies Adders, premium prices 6, 41, ZG
Obligations/Consenting 25, 28, 35, 47, M, ZH
Standards 8, 22, ZI
Feed in Tariffs 28, 41, 45, 47, ZJ
Merit order 20, 21, ZK

EVIDENCE ON THE INEFFECTIVENESS OF PRICE/TAX AS POLICY
Price Insufficiency 4, 11, 15, 20, 19, 25, 29, 35, 41, 47, 48 A
Tax: Difficulty of setting and sustaining "optimal" levels 20, 19, 47, B
Tradable permits do not increase innovation (5, 36, C)

Sources: See Tables II-6 and II-7 and accompanying text.

imperfect, riddled with barriers and obstacles and plagued by inertia resulting in underinvestment in economically attractive opportunities to produce and conserve energy. This observation has come to be known as the “efficiency gap” or “energy paradox.” The diffusion of innovation literature broadly supports the depiction of barriers and obstacles in the efficiency gap literature.

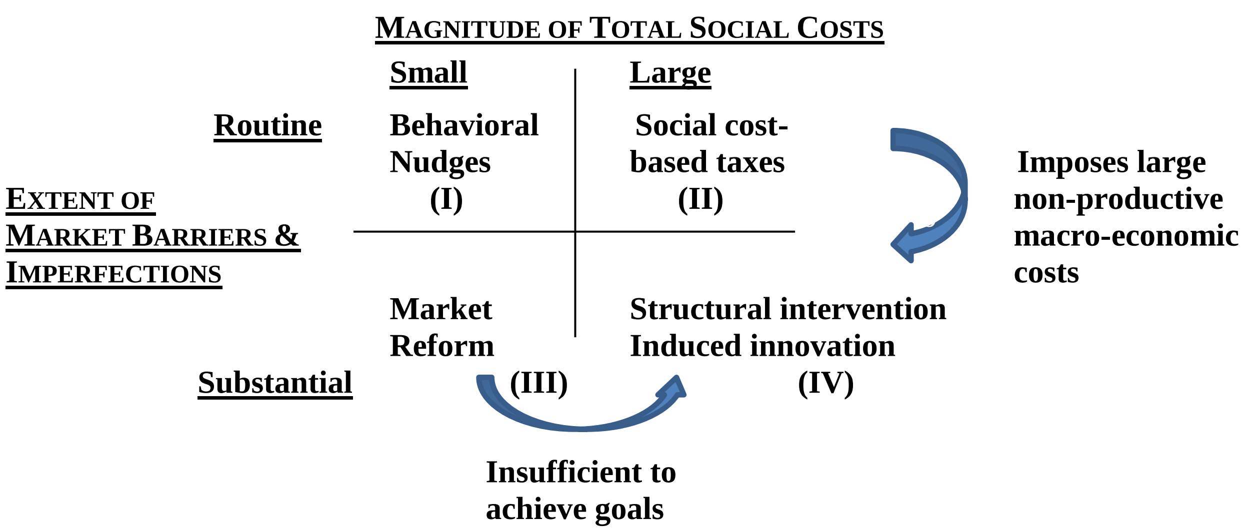
My review of the recent economic analysis of the response to climate change identifies exactly the same market barriers and obstacles that must be overcome to implement effective policies.Because the potential external costs of climate change are so large and the market barriers to overcome so severe and pervasive, particularly when confronted with the task of transforming the entire sector (not just optimizing the operation of the incumbent system), climate change puts a spotlight on technological innovation. Some analysts see a growing “innovation gap” that parallels the “efficiency gap.”

My review of the climate change literature shows that it is a policy challenge to which performance standards are ideally suited because it exhibits a specific set of characteristics.

- Significant market barriers and imperfections exist.
- Social (externalities) and transition costs are substantial.
- There is an urgent need to overcome inertia.
- Dynamic conditions make the sector ripe for a transformation that will allow goals to be achieved at a far lower cost than static analysis suggests.

At a high level, the most important implication of this broadening of the framework to include large externalities is to underscore the need for vigorous policy action to address a problem that is now seen as larger and more complex than it was in the past. As suggested by Exhibit S-3, it is the combination of substantial market imperfections and large externalities that demonstrates there is an urgent need for vigorous policy action.

EXHIBIT S-3: TYPOLOGY OF POLICY CHALLENGES AND RESPONSES



Source: See discussion in Chapter VI

If market imperfections are routine and the social costs of poor market performance are small (cell I), modest policies like behavioral nudges may be an adequate response. If market imperfections are small and costs are large (cell II), then price signals might be sufficient to deal with the externalities. If market imperfections are substantial but costs are small, market reform would be an appropriate response (cell III), since the slow response and long time needed to overcome inertia does not impose substantial costs. If both market imperfections and social costs are large (cell IV), more aggressive interventions are in order.

The challenge is to choose policies that reduce the market barriers in an effective (swift, low cost) manner. Given the magnitude and nature of climate change and the extensive nature of market imperfections, reinforced by inertia that must be overcome rapidly, each of the policy approaches (cells in Exhibit S-3) has a role to play, but the structural change is vital because it influences how effective the other policies can be. The sequence is important because addressing severe market failures that have large social costs can impose an extraordinary burden on society. The farther and faster structural change is implemented, the easier it is for the other policies to work.

The findings of this literature can be summarized at the highest level by noting that the presence of the market imperfections means that policies that successfully overcome them yield substantial benefits in terms of reducing the cost and accelerating the transition to a low carbon sector.

- A general finding that the social return to R&D is twice as large as the private return appears to hold in the energy technology space.
- Estimates of the speed of innovation suggest a one to two decade delay in the introduction of new technologies, if targeted policies to accelerate the diffusion of innovation are not adopted.
- Targeted financial incentives deliver much more monetary support for alternatives.
- Because of the magnitude of the change required, the macroeconomic impacts of policy takes on great significance, with analysis of the macroeconomic savings from a smoother, swifter transition yielding very substantial projected economic savings of at least 50%.

Achieving these benefits requires policies that address the market imperfections and barriers on both the supply and demand sides of the market.

b. Performance Standards

Performance standards have long been a staple of energy and environmental policy, with long standing standards affecting consumer durables, like light duty vehicles (fuel economy standards) and electricity efficiency standards affecting a wide range of appliances and equipment. They are a popular policy tool in market economies because, when well designed, they achieve results efficiently. **<u>They command, but they do not control</u>**. Policy sets a goal and firms acting in the market have flexibility to achieve the goal. Once the standards are set, entrepreneurs set about achieving them in the least cost manner possible. Because performance standards address more barriers and are more effective in overcoming the, they are more likely to achieve their goals, as summarized in Exhibit S-4. However, my analysis of performance standards shows that to be effective and efficient, the standards must possess key characteristics. **<u>They must really command, but not control</u>**, thereby unleashing the forces of innovation and competition in the market economy.

EXHIBIT S-4 FACTORS UNDERLYING THE SUCCESS OF PERFORMANCE STANDARDS

Causes of Market Failure Potentially Addressed by Standards

Traditional Economics & Industrial Organization

SOCIETAL FAILURES
- Externalities
- Information

STRUCTURAL PROBLEMS
- Scale
- Bundling
- Cost Structure
- Product Cycle
- Availability

New Institutional Economics

ENDEMIC FLAWS
- Agency
- Asymmetric Information
- Moral Hazard

TRANSACTION COSTS
- Sunk Costs
- Risk
- Uncertainty
- Imperfect Information

Behavioral Economics

BEHAVIORAL FACTORS
- Motivation
- Calculation/ Discounting

Characteristics of Well-Crafted Performance Standards

Encourage entrepreneurial experimentation

- Technology neutrality
- Pro-competitive
- Allow flexibility

Emphasize least cost and risk aware approaches which encourage

- consideration of all externalities and the recognition of subsidies
- consideration of lead time, scale, capital at risk and use of portfolio approaches

Take a long-term, total social cost view, which allows policy makers to

- consider cost trends (including the pattern of pay offs to social investment),
- ignore sunk costs,
- steadily raise the target, and
- explore fundamental transformation of infrastructure (physical and institutional

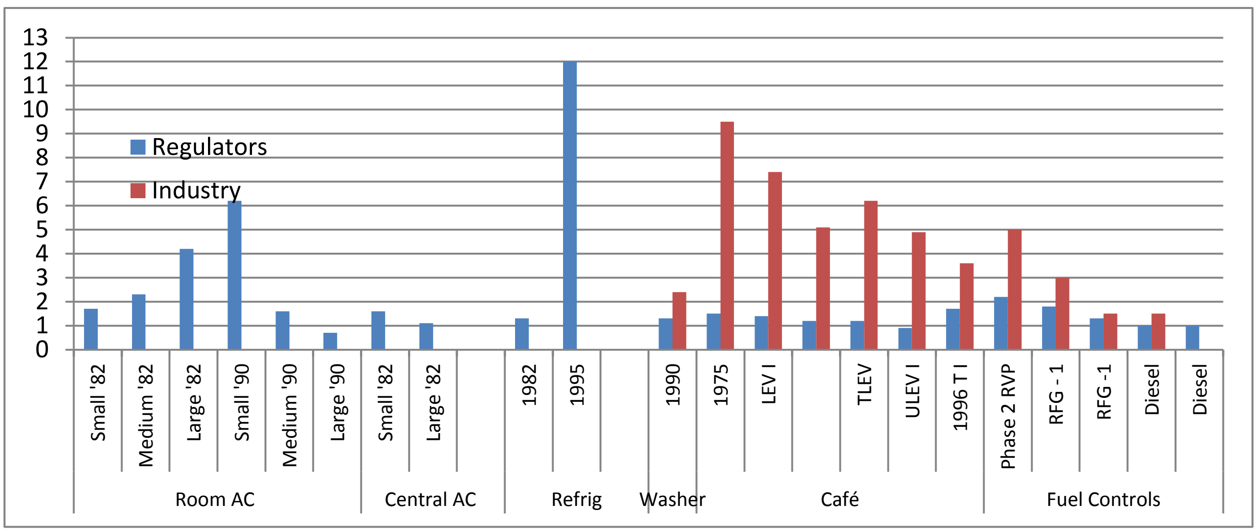
Source: See Table VI-4 and accompanying text.

My evaluation of the EPA proposal and analysis leads me to conclude that it fails to apply five of these principles – technology neutrality, consideration of subsidies, consideration of lead times and other economic characteristics, consideration of cost trends, consideration of transformation. These problems can be easily corrected by eliminating technological biases in the calculation of the threshold and identifying mechanisms that into would take account and give credit for a wider range of options. In other words, EPA needs to be technology neutral and incent more innovation.

The assessment of a large number of performance standards show that, when well designed, they cost a fraction of the pre-implementation cost projections made by regulators and industry (see Exhibit S-5).

EXHIBIT S-5: THE PROJECTED COSTS OF REGULATION EXCEED THE ACTUAL COSTS: RATIO OF ESTIMATED COST TO ACTUAL COST BY SOURCE

Long Term Appliances and Autos



Source: See Figures VIII-10 and VIII-11 and accompanying text

2. Part II. Empirical Evaluation of Low Carbon Resources and EPA's Analysis

In order to set a standard, the EPA must evaluate the options available in terms of their

- effectiveness with respect to reducing emissions,
- efficiency with respect to cost,
- impact with respect to a broad range of economic and non-economic considerations, and
- feasibility with respect to implementation.

Part II presents the necessary data to make these findings.

- Cost and cost trends of each of the low carbon resources are discussed in

Chapter VII.

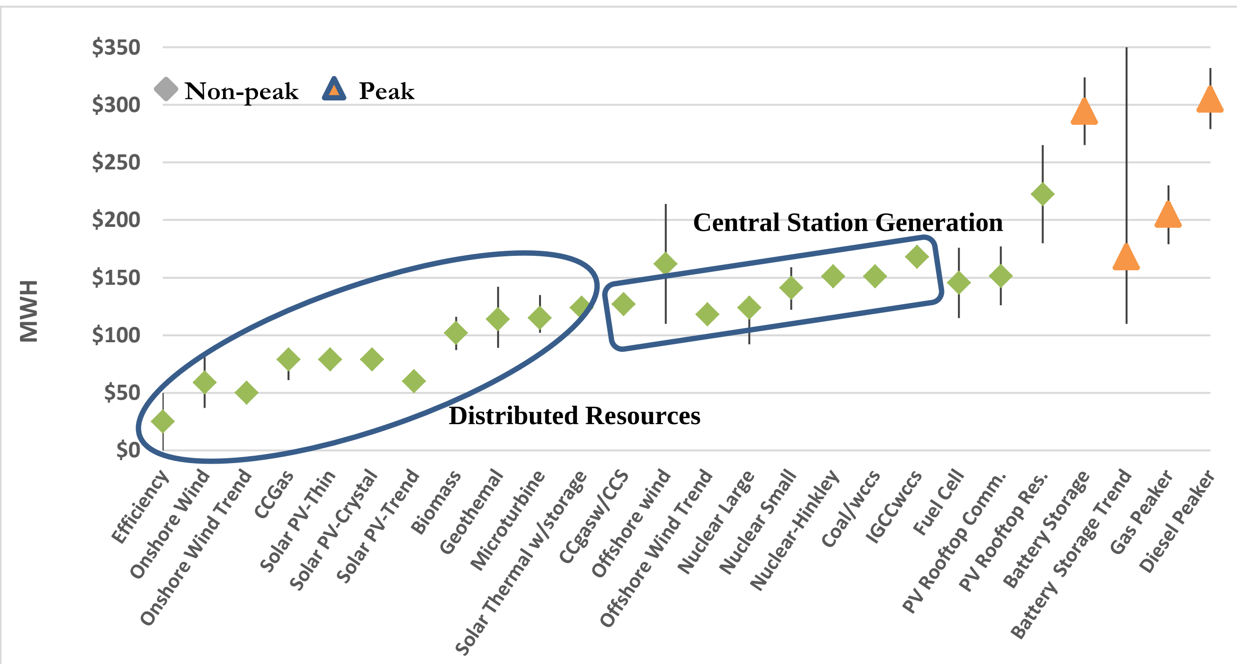
- Other economic and non-economic factors that EPA must consider are discussed in Chapter VIII.
- The potential transformation of the electricity sector, which would greatly improve the prospects for decarbonization, are discussed in Chapter IX.

With the analytic framework and data in hand, Chapter X proposes approaches that will strengthen the EPA justification for a rule and point the direction for least cost reduction in carbon emissions.

a. Cost and Cost Trends

I begin the cost analysis with estimates of the levelized cost of a number of alternatives, combining the results of the two most recent estimate of levelized cost of electricity from Lazard (See Exhibit S-6). Needless to say, there are many such estimates available. I choose Lazard as a single source for this discussion to preserve consistency in assumptions and because I believe the Lazard analysis is superior to most others and provides the basis for important and useful observations.

EXHIBIT S-6: LEVELIZED COST (LCOE) OF LOW CARBON OPTIONS WITH TRENDS



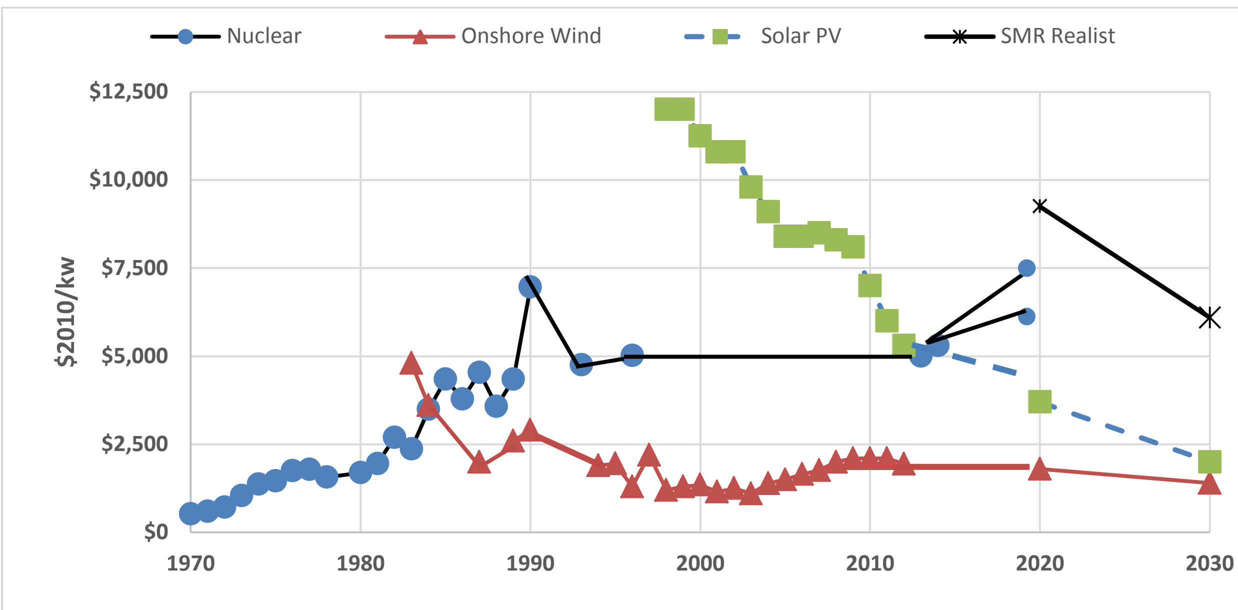
Source: See Figure VII-1 and accompanying text.

To compare apples-to-apples and do mid-term analysis, I highlight the midpoint, unsubsidized cost projection and compare it to the other mid-points unsubsidized. I include important cost trends that affect mid-term comparisons. I also present the range.

Figure S-6 delivers a message that has been clear to energy analysts for quite some time. There are a large number of alternatives that are relatively inexpensive, compared to current costs of production, even in a low carbon environment. It also reminds us that reducing peaks is a very valuable undertaking, since peaking power is (1) so costly and (2) primarily generated by carbon emitting fossil-fuel fired sources.

The cost trends underlying the cost projections for the period in which the EPA targets will drive resource acquisitions have been dramatic (See Exhibit S-7), so dramatic in fact that independent analysts and some in the industry call them "transformative" and "disruptive," rendering the 20th century approach an "antiquated" "dinosaur" that is "doomed" by a "change or die" challenge. The primary driver of change has been the rapid decline in costs of the main non-hydro renewables, wind and solar, but recent developments in storage technology are adding to the pressures

Exhibit S-7: Cost Trends Driving the Transformation of the Electricity Sector Overnight Cost Trends: Nuclear, Wind and Solar



Source: see Figures VII-2 and VII-3 and accompanying text.

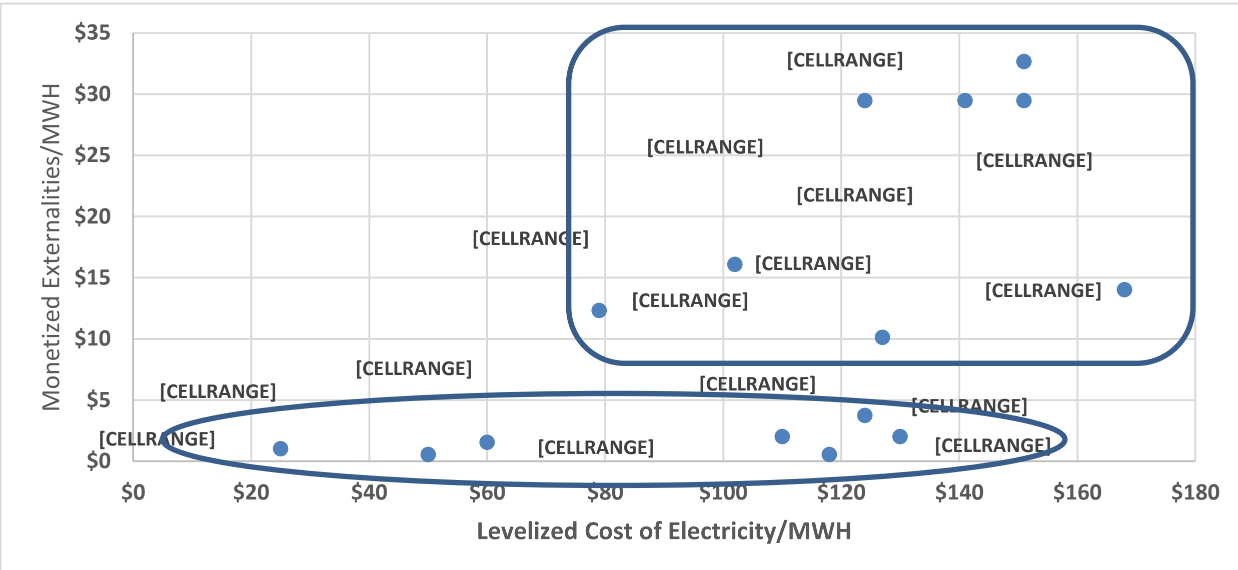
b. Other Economic and Non-economic Factors

Other characteristic of low carbon resources strengthen the basic finding that renewables and efficiency are the most attractive resources to meet the need for electricity in a low carbon sector. The advantage enjoyed by these resources include

- economic characteristics of the resources: size, flexibility, time to market, sunk costs;
- the impact of the development of the resources on the economy: macroeconomic multipliers and job creation; and
- non-economic impacts: environmental, health, security, sustainability

As shown in Exhibit S-8, including all of the non-carbon externalities associated with these resources strongly reinforces the case for building a low carbon sector on the basis of efficiency and renewables.

EXHIBIT S-8: LEVELIZED COST AND MONETIZE EXTERNALITIES OF LOW CARBON RESOURCE, WITH MID-TERM COST TRENDS



Source: See Figures VIII-8 and VIII-9 and accompanying text.

While all of the economic and non-economic characteristics of efficiency and renewables make them the preferable resources on which to build the response to the challenge of climate change, the potential transformation of the electricity sector by integrating distributed resources with aggressive management of demand increases the attractiveness of these resources.

C. WEAKNESSES IN THE EPA ANALYSIS

1. Efficiency and Renewables

Although the EPA has shown that the proposed rule meets and exceeds the cost benefit test under the statute, the EPA analysis does not reflect the full economic and non-economic benefits of expanding efficiency and renewables in several ways.

- While EPA quantifies some of the non-carbon environmental benefits, it does not quantify all of them. It also does not consider macroeconomic effects.
- EPA has overestimated the cost of efficiency by assuming a real rate of increase in costs that is not supported in the proposed rule or the empirical evidence available. Since the cost of efficiency is the single largest component of the cost of the rule, this error significantly overestimates the cost of implementation.
- EPA underestimates the amount of efficiency and renewable resources that could be economically deployed to meet the need for electricity while

reducing carbon emissions.

- EPA has failed to develop mechanisms to account and give credit for a number of significant additional course of carbon reduction, like appliance efficiency standards, building energy codes and combined heat and power applications that can be adopted or enforced at the state level. These could deliver more carbon reduction than either Block 1 of Block 2 of the reductions it has modelled.

As shown in Exhibit S-9, independent analysts have been projecting that efficiency and renewables can play a much larger role in meeting the need for electricity than is reflected in the targets set by EPA. The much larger potential reduction of carbon emissions that could result from more efficiency and renewables is further evidence that they rule can be accomplished by the states, but it also raises questions about whether the EPA standard is a Best System of Emission Reduction.

2. The EPA Treatment of Nuclear

The EPA analysis of nuclear power in the Clean Power Rule violates the most basic and fundamental principles of economic analysis. For both ageing and new reactors EPA essentially assumes that nuclear has zero cost of construction and operation for purposes of selecting future resources.

a. Aging Reactors

Nuclear power is the only technology that the EPA explicitly identifies as in need of a subsidy and puts forward a concrete proposal.[17] It argues that a $6/MWH subsidy would keep aging nuclear reactors that are not covering their costs online as low carbon resources. The analysis is incorrect at a number of levels.

First, the operating costs of aging reactors are substantial and growing rapidly. The shortfall is dependent on market conditions, which are moving in a direction that suggests the shortfall will continue to increase. If one compares the full cost of keeping aging reactors online to the full cost of the alternatives, it is not at all clear that subsidizing nuclear is cost effective.

Second, even if subsidizing ageing reactors was a sound economic recommendation, which it is not, the EPA's analysis makes no sense. Its proposal is based on the assumption that the risk of closure is randomly distributed throughout the nuclear fleet. It is not; the risk is concentrated in specific types of reactors (small, single units) in specific markets (pure wholesale markets). As a result the vast majority of the subsidy (94%) suggested by EPA is targeted at reactors that are not at risk.

The fact that EPA has singled out aging nuclear reactors as a potential target of additional subsidies not only violates the principle of technological neutrality, it also violates the principle of least cost in in several respects.

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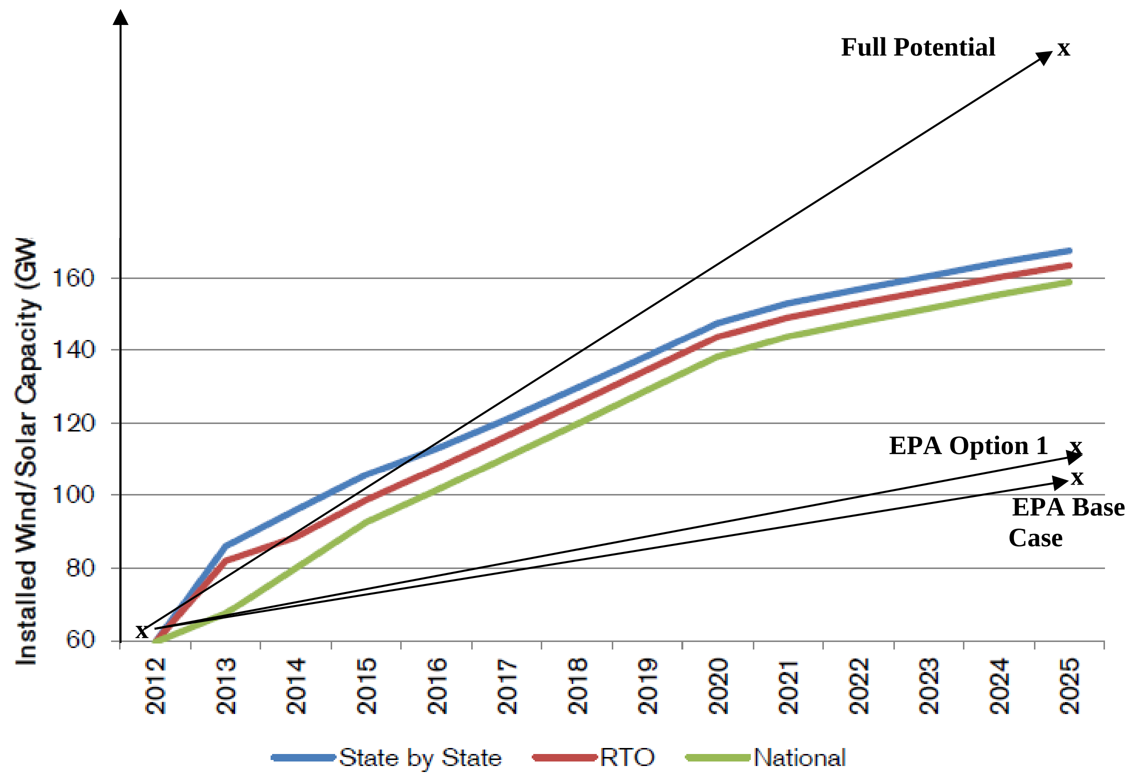
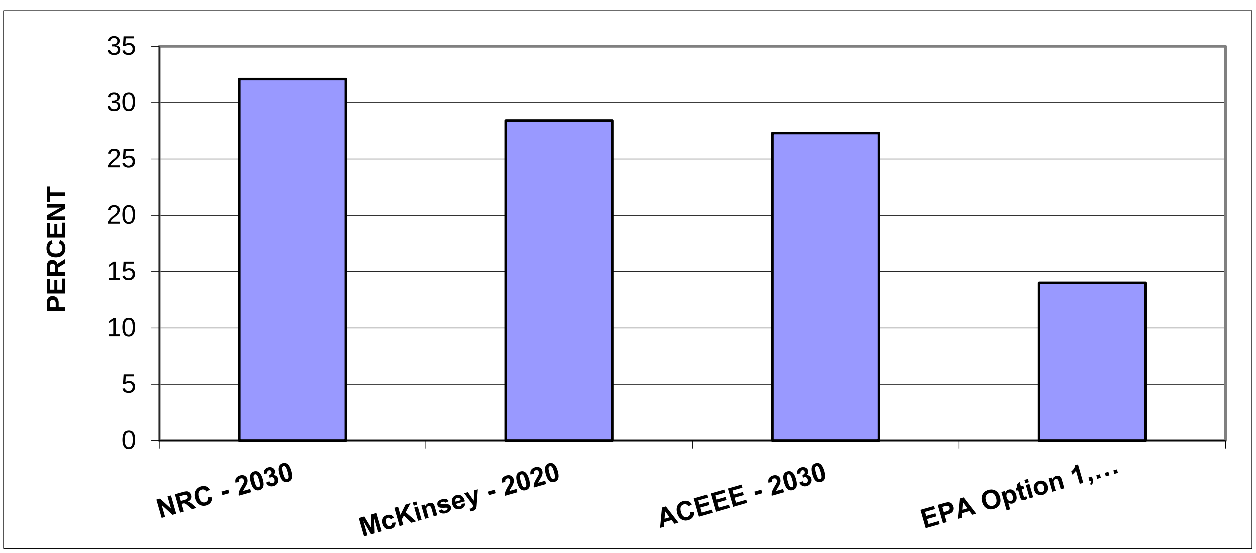
[17] The methodology for setting the target reductions clearly provides implicit incentives for other technologies.

EXHIBIT S-9: EPA LEFT A LOT OF POTENTIAL CARBON REDUCTION ON THE TABLE

Projection of Renewable Growth Compared to EPA Option 1



Efficiency Potential from Major National Studies Compared to EPA Option 1

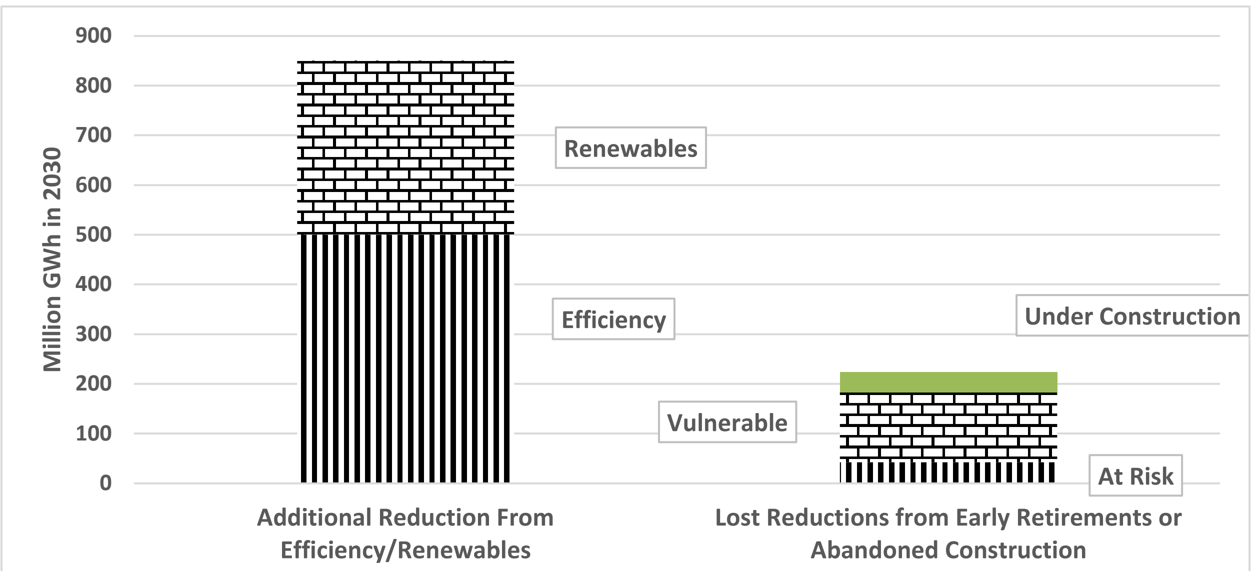


Sources: See Figures X-1and X-2 and accompanying text

The resource cost estimates for efficiency, wind and in the mid-term solar, suggest that these alternatives produce electricity at lower in cost than aging reactors and much lower than new reactors. Taking all costs into account, on a megawatt hour basis, the cost of keeping the at-risk reactors online is much higher than $6/MWH and higher than efficiency or wind. The burden of the subsidy would fall on the individual states where the reactors are located and would be much heavier than suggested by EPA. Moreover, as shown in Exhibit S-10, there is no doubt that the potential contribution of these resources could easily offset the loss of low carbon output that might be lost as a result of the retirement of vulnerable aging reactors.

The social rate of return to subsidies has been much higher for renewables than for nuclear power both in terms of price and in terms of innovation. Subsidizing old reactors makes no contribution to future innovation. If subsidies are necessary to improve prospects for carbon reduction, the last place they should go is to nuclear power.

EXHIBIT S-10: THE UNTAPPED CARBON REDUCTION POTENTIAL FROM EFFICIENCY COMPARED TO POTENTIAL EARLY RETIREMENTS AND ABANDONMENT OF REACTORS UNDER CONSTRUCTION



Source: See Figure X-4 and accompanying text.

b. Under Construction Reactors

Ignoring the cost of constructing new reactors (because the decision to build has been made), as suggested by EPA is incorrect because **<u>the costs have not yet been sunk.</u>** The incremental or "to go" cost are substantial. In a competitive market economy, decisions to invest must be constantly revisited. If the cost of the project rises or costs for alternative projects fall sufficiently to make continuing on the chosen path uneconomic, the project should be abandoned. In South Carolina, my analysis showed that continuing to build the Summer reactors would cost ratepayers $10 billion more than terminating the project. In that analysis, the comparison was with natural gas because that was the referent that the utility had incorrectly, selected. If the full range of alternatives were considered in making the decision to continue construction, the waste of resources would be even greater.

In fact, the initial decision to commence construction of the reactors was fundamentally flawed because it did not consider the full range of alternatives. The EPA should not be rewarding such economically flawed analysis and decision making. Under the principle of allowing the states flexibility, it is their prerogative to impose uneconomic costs on their ratepayers, but the EPA should not be encouraging such behavior. If anything, the EPA should state a strong preference for least cost solutions under the proposition that the lower the cost of carbon abatement, the greater the reduction is likely to be.

Beyond the basic economic cost of present and future low carbon alternatives, there is another reason that the EPA should not be favoring nuclear power. The contribution of many of the lower cost, low carbon alternatives requires a transformation away from reliance on large central station generation that simply matches load toward a utility system that actively manages supply and demand by using intelligence, information and control technologies to integrate distributed resources and demand response. Because nuclear reactors require large costs, long lead times and deliver large, inflexible increments of supply, they create an obstacle to the development and implementation of the alternative electricity system. Nuclear power has always crowded out the alternatives because of its high cost and drain on management, physical and financial resources, but the threat of crowding out is greater today because reliance on nuclear power stymies the much more profound transformation of the electricity system that has become possible with technological progress.

Thus, the decision to internalize the external costs of carbon in resource selection comes at a moment when fundamental choice about the structure of the 21st century electricity system is being made. The transformation of the electricity system and the reduction of carbon emissions are perfectly compatible and should not be made more difficult by putting a thumb on the scale in favor of a technology that is antithetical to the emerging system.

D. Conclusion

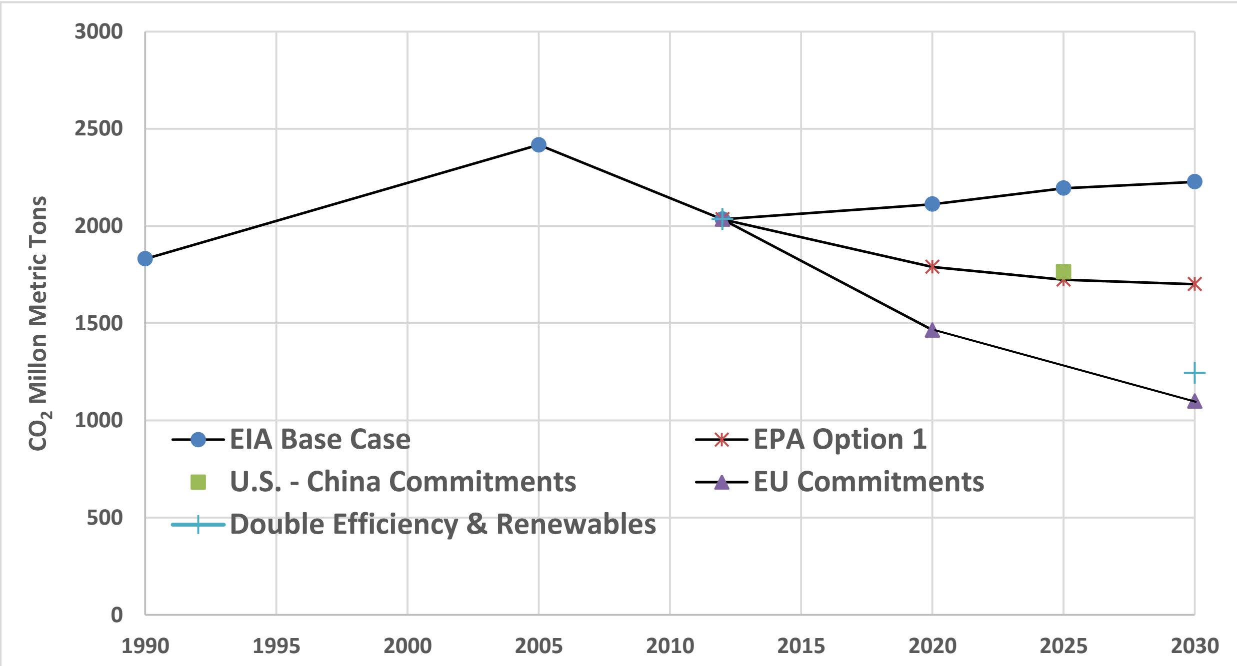
This analysis indicates that EPA could set the carbon reduction target at a much higher level and meet the requirements of the Clean Air Act and the Administrative Procedures Act. Given that so much potential for low cost carbon reduction has been left on the table, it appears that a doubling of the contribution of efficiency and renewables, as some have suggested,[18] would be readily achievable and yield a substantially positive benefit cost ratio.

In the past month, the U.S. and China made important commitments on carbon reduction and the European Union put forward a much more aggressive proposal. Together these nations account for well over half of all annual carbon emissions and the commitments help to place the EPA proposal in perspective. As shown in Exhibit S-11, EPA Option 1 is consistent with the U.S. China announcement. At the same time, a doubling of the carbon reduction from efficiency and renewables would still be considerably less than the target set by the European Union, in

[18] Union of Concerned Scientist, 2014.

spite of the fact that the U.S. emissions are more than twice those of the EU per capita and three times those of China.

EXHIBIT S-11: EPA OPTION 1 COMPARED TO RECENT CARBON REDUCTION COMMITMENTS



Source: See Figure X-9 and accompanying text.

It is critically important at this turning point in global climate change policy for EPA and the U.S. to lay a strong foundation for a century of policy. A well-crafted performance standard that looks to the future by highlighting the role of efficiency, renewables and transformation of the system is an ideal place to start.

PART I.
THE IMPLICATIONS OF MARKET BARRIERS, IMPERFECTIONS AND FAILURE FOR ENERGY AND CLIMATE POLICY

II. THE EFFICIENCY GAP

This part develops an empirically supported, analytic framework that shows the value of well-crafted performance standards. It begins in this Chapter with a review of the efficiency gap literature, which has been a major theme in energy policy since the oil embargoes of the 1970s. Chapter III shows that the insights gained from the analysis of the efficiency gap are consistent with and reinforced by the more general literature on the diffusion of innovation. Chapter IV shows that the framework of market barriers and imperfections at the heart of the efficiency gap literate is identical to the market barrier analysis in the climate change literature. Chapter V reviews the empirical evidence from the recent literature that supports the analytic framework. Chapter VI concludes this part by reviewing the policy implications of these three literatures and the policy evaluations contained within each that support well-crafted performance standards as a very attractive instrument to address the challenge of climate change.

A. INTRODUCTION

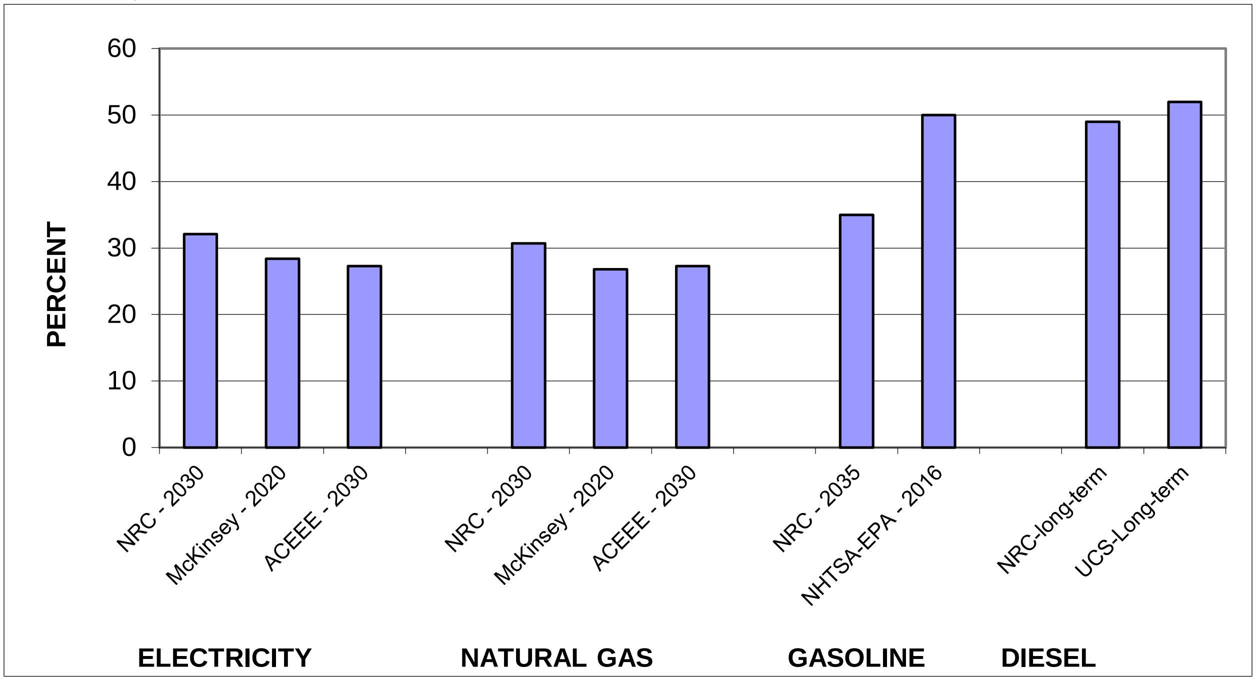
For over 30 years, economists, engineers and policy analysts have described a phenomenon in energy markets that came to be known as the "energy paradox" or the "efficiency gap."[19] Engineering/economic analyses showed that technologies exist that could potentially reduce the energy use of consumer durables (from light bulbs to air conditioners, water heaters, furnaces, building shells and automobiles) and producer goods (like motors, HVAC, and heavy duty trucks). Because the reduction in operating costs more than offset the initial costs of the technology, resulting in substantial potential net economic benefits, we confront the "paradox:" "Why don't consumers purchase more economically efficient durable goods that result in net economic savings.

For example, Figure 1, shows that several major research institution estimate that there is a large potential to reduce the consumption of each of the forms of energy consumed by most households (electricity, natural gas, gasoline, and diesel), all of which are substantial emitters of carbon. Figure II-1 shows that a 20 to 30 percent reduction in consumption for energy sources consumed directly by households is technically feasible and economically practicable. The potential long-term reduction in consumption of diesel fuel, which is used by heavy duty trucks is considerably larger, primarily because the first fuel economy standards were only recently adopted, almost forty years after the first fuel economy standards for light duty vehicles were adopted.

Recently, energy efficiency standards have become a hot topic in energy policy circles. They had a very prominent place in the recent articulation of the Administration's climate policy[20] and several major standards are moving through analytic and regulatory reviews at the federal and state levels. Among the most prominent examples are major appliance efficiency standards in Washington D.C.[21] and Sacramento,[22] a sharp increase in energy efficiency building

[19] Stavins and Jaffee, 1994., Golove and Eto, 1996.
[20] Executive Office of the President, 2013.
[21] Appliance Standards Awareness Project, 2013a.
[22] Appliance Standards Awareness Project, 2013b.

FIGURE II-1: THE SIZE OF THE EFFICIENCY GAP ACROSS ENERGY MARKETS: TECHNICALLY FEASIBLE, ECONOMICALLY PRACTICABLE POTENTIAL ENERGY SAVINGS



Sources and Notes: Electricity and natural gas savings based on Gold, Rachel, Laura, et. al., *Energy Efficiency in the American Clean Energy and Security Act of 2009: Impact of Current Provisions and Opportunities to Enhance the Legislation*, American Council for an Energy Efficient Economy, September 2009), McKinsey Global Energy and Material, *Unlocking Energy Efficiency in the U.S. Economy* (McKinsey & Company, 2009); National Research Council of the National Academies, *America's Energy Future: Technology and Transformation, Summary Edition* (Washington, D.C.: 2009). The NRC relies on a study by Lawrence Berkeley Laboratory for its assessment (Richard Brown, Sam Borgeson, Jon Koomey and Peter Biermayer, *U.S. Building-Sector Energy Efficiency Potential* (Lawrence Berkeley National Laboratory, September 2008).

Gasoline based on: U.S. National Highway Traffic Safety Administration, *Corporate Average Fuel Economy for MY2012-MY 2016 Passenger Cars and Light Trucks*, *Preliminary Regulatory Impact Analysis*, Tables 1b, and 10. The 7 percent discount rate scenario is used for the total benefit = total cost scenario; NAS -2010, National Research Council of the National Academy of Science, *America's Energy Future* (Washington, D.C.: 2009), Tables 4.3, 4.4; MIT, 2008, Laboratory of Energy and the Environment, On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions Cambridge: July, 2008), Tables 7 and 8; EPA-NHTSA - 2010, Environmental Protection Agency Department of Transportation In the Matter of Notice of Upcoming Joint Rulemaking to Establish 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards, Docket ID No. EPA-HQ-OAR-0799 Docket ID No. NHTSA-2010-0131, Table 2, CAR – 2011.

Diesel based on: Northeast States Center for a Clear Air Future, International Council on Clean Transportation and Southwest Research Institute, *Reducing Heavy Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions*, October *2009;* Don Air, *Delivering Jobs: The Economic Costs and Benefits of Improving the Fuel Economy of Heavy-Duty Vehicles*, Union of Concerned Scientists, May 2010; Committee to Assess Fuel Economy for Medium and Heavy Duty Vehicles, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*, National Research Council, 2010; Go 60 MPG, *Delivering the Goods: Saving Oil and Cutting Pollution from Heavy Duty Trucks.*

codes,[23] and National Research Council review of the fuel economy of medium and heavy duty trucks[24] tied to the first ever fuel economy standards for these vehicles.[25]

At the same time, the cost benefit analysis used to support recent performance standards across a broad range of consumer durables has been criticized, with a great deal of attention placed on the recent increase in CAFE standards that governs cars and pickup trucks (light duty vehicles).[26] Perplexed by the fact that in the EPA/NHTSA light duty vehicle fuel economy standard analysis "the preponderance of the estimated benefits stems from private benefits to consumers,"[27] the Mercatus Center argued that the market cannot possibly perform his poorly with respect to energy efficiency.

> How can it be that consumers are leaving billions of potential economic gains on the table by not buying the most energy-efficient cars, clothes dryers, air conditioners, and light bulbs? Moreover, how can it also be the case that firms seeking to earn profits are likewise ignoring highly attractive opportunities to save money? If the savings are this great, why is it that a very basic labeling approach cannot remedy this seemingly stunning example of completely irrational behavior? It should be quite simple to rectify decisions that are this flawed.[28]

The Mercatus view is that since "the preponderance of the assessed benefits is derived from an assumption of irrational consumer choice"[29] and such behavior is easily rectified by labeling programs, which already exist, "the main failure of rationality is that of the regulators themselves."[30] In their view, the fault lies in the agencies, whose analysis must be wrong because it was prepared under legal mandates structured so that "government officials act as if they are guided by a single mission myopia that leads to the exclusion of all concerns other than their agency's mandate."[31]

The other and correct answer to the question is well-known.[32] Energy markets are imperfect, riddled with barriers and obstacles to efficiency, especially the market for electricity. Market imperfections lead to market failures and underinvestment in energy saving technologies. McKinsey and company offered the following framing in one of a series of analyses addressing various aspects of the ongoing transformation of the electricity sector.

> "the highly compelling nature of energy efficiency raises the question of why the economy has not already captured this potential, since it is so large and attractive. In fact, much progress has been made over the past few decades throughout the U.S., with even greater results in select regions and applications. Since 1980, energy consumption per unit of floor space has decreased 11 percent in residential and 21 percent in commercial sectors, while industrial energy consumption per real dollar of GDP output has decreased 41 percent. As impressive as the gains

[23] U.S. Department of Energy (DOE), 2013; California Energy Commission, 2012.
[24] Committee to Assess Fuel Economy for Medium and Heavy Duty Vehicles, 2010.
[25] U.S. Environmental Protection Agency and Department of Transportation, 2011.
[26] Grayer and Viscusi, 2012.
[27] Grayer and Viscusi, 2012, p. i.
[28] Id., p. 37.
[29] Id., p. 1.
[30] Id., p. 37.
[31] Id., p. 38.
[32] The analytic weaknesses and biases in the recent criticism of the efficiency gap have been demonstrated by others. See for example Nadel and Langer, 2012, responding to Alcott and Greenstone, 2012, Alcott and Wozny, 2011.

> have been, however, an even greater potential remains due to multiple and persistent barriers present at both the individual opportunity level and overall system level. By their nature, energy efficiency measures typically require a substantial upfront investment in exchange for savings that accrue over the lifetime of the deployed measures. Additionally, efficiency potential is highly fragmented, spread across more than 100 million locations and billions of devices used in residential, commercial, and industrial settings. This dispersion ensures that efficiency is the highest priority for virtually no one. Finally, measuring and verifying energy not consumed is by its nature difficult. Fundamentally, these attributes of energy efficiency give rise to specific barriers that require opportunity-specific solution strategies and suggest components of an overarching strategy. [33]

Even in the industrial sector, where firms are considered to be motivated primarily by economic profitability incentives, the efficiency gap is evident. A recent review of 160 studies of industrial energy efficiency investments conducted for the United Nations Industrial Development Organization (UNIDO) framed the analytic issues by posing and answering the key questions as follows:

> Why do organizations impose very stringent investment criteria for projects to improve energy efficiency?
>
> Why do organizations neglect projects that appear to meet these criteria?
>
> Why do organizations neglect energy efficient and apparently cost-effective alternatives when making broader investment, operational, maintenance and purchasing decisions?[34]
>
> Because of barriers to energy efficiency these seemingly profitable measures are not being adopted… There is a large body of literature on the nature of barriers to energy efficiency at the micro and the macro level, which draws on partly overlapping concepts from neo-classical economics, institutional economics (including principal-agent theory and transaction cost economics), behavioral economics, psychology and sociology. Barriers at the macro level involve price distortions or institutional failures. In comparison, the literature on barriers at the micro level tries to explain why organizations fail to invest in energy efficiency even though it appears to be profitable under current economic conditions determined at the macro level.[35]

The Mercatus critique of the efficiency gap concept embodies a second flaw that the efficiency gap analysts have overcome in the past decade – defining the problem as solely a consumer information problem. In fact, in the last decade the important role that market imperfections play on the supply-side of the market has been noted. The market outcome reflects both the supply of and demand for technologies. As Carl Blumstein has noted:

> But what if the energy-efficiency gap was regularly framed as a *supply-side* problem, such as a concern about whether problems in the *supply-chain* create a gap between the energy-efficiency potential of goods and services and the adoption of energy-efficient goods and services? After all, in many instances consumer choices are constrained because it is not practical for manufacturers to produce a continuum of choices; suppliers can only provide a limited set of discrete choices within a range of prices, functionality and energy efficiency. In addition, even

[33] McKinsey, 2009, p. viii,
[34] Sorrel, Mallet and Nye , 2011, p. 11
[35] Schleich and Gruber, 2008, pp. 1-2. A similar formulation is offered by Thollander, Palm and Rohdin, p.3.

> when the choice set of energy users is not constrained, limitations related to the behavior of actors in the supply chain may restrict consumer choices.[36]

When the market barriers and imperfections on the supply and demand sides of the energy market are properly comprehended, it is clear that the performance standards are not an example of "overriding consumer preferences with energy regulations,"[37] based on an assumption of consumer irrationality as Mercatus claims, rather, even without significant externalities (like climate change)

- Energy performance standards are a well-justified effort to overcome severe market obstacles constraints and cognitive limitations on human decision making that impose huge, unnecessary energy costs on consumers and the economy.

B. Comprehensive Explanations of the Efficiency Gap

This Chapter presents a comprehensive analytic framework that explains the energy efficiency gap by examining several frameworks that have been developed over the past two decades. These frameworks rest upon a strong foundation of empirical analysis that has been developed over more than a quarter of a century and strengthened considerably in the past decade. After developing the overall framework, in Chapter V I review the recent empirical evidence that supports key pieces of the framework.

1. Lawrence Berkeley Laboratory (LBL)

Table II-1 summarizes a1996 paper prepared by analysts at the LBL.[38] The analysis was framed in terms of the role of policy intervention to promote efficiency as states restructured the electricity market. The paper "focuses on understanding to what extent some form of future intervention may be warranted and how we might judge the success of particular interventions."[39] Restructuring did not spread throughout the utility industry and in the past few years, reliance on interventions in the market to increase efficiency and renewables has grown, even in the deregulated states.[40] The growth of market interventions is consistent with the conclusions in the LBL paper.

> We conclude that there are compelling justifications for future energy-efficiency policies. Nevertheless, in order to succeed, they must be based on a sound understanding of the market problems they seek to correct and a realistic assessment of their likely efficacy.[41]

As shown in Exhibit II-1, the Golove and Eto paper identified four broad categories of factors that inhibited investments in energy efficiency – barriers, transactions costs, market failures, and behavioral (noneconomic) factors. It identifies about two dozen specific factors spread roughly equally across these four categories. A key aspect of the analysis is to identify

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[36] Blumstein and Taylor, 2013, p.2.
[37] Grayer and Viscusi, 2012, p. 1.
[38] Golove and Eto, 1996.
[39] Golov and Eto, 1996, p. iv.
[40] There has recently been a dramatic re-commitment to publicly-sponsored energy efficiency and a substantial increase in allocated resources, Sanstad, Hanemann and Auffhammer, 2006, p. 6-5.
[41] Golove and Ito, 1996, p. x.

each of the categories as coming from a different tradition in the economic literature. The barriers category is made up of market structural factors. The market failure category is made up of externalities and imperfect competition. However, the LBL paper bases a substantial part of its argument on a transaction cost perspective as a critique of neo-classical economics.

> Neo-classical economics generally relies on the assumption of frictionless transactions in which no costs are associated with the transaction itself. In other words, the cost of activities such as collecting and analyzing information; negotiating with potential suppliers, partners and customers; and risk are assumed to be nonexistent or insignificant. This assumption has been increasingly challenged in recent years. The insights developed through these challenges represent an important way to evaluate aspects of various market failures (especially those associated with imperfect information).[42]

TABLE II-1: LBL MARKET BARRIERS TO ENERGY EFFICIENCY

Barriers[1]	Market Failures	Transaction Cost[2]	Behavioral factors[16]
Misplaced incentives	Externalities	Sunk costs[3]	Custom[17]
Agency[4]	Mis-pricing[20]	Lifetime[5]	Values[18] & Commitment[19]
Capital Illiquidity[8]	Public Goods[22]	Risk[6] & Uncertainty[7]	Social group & status[21]
Bundling	Basic research[23]	Asymmetric Info.[9]	Psychological Prospect[24]
Multi-attribute	Information	Imperfect Info.[10]	Ability to process info[27]
Gold Plating[11]	(Learning by Doing)[25]	Availability	Bounded rationality[26]
Inseparability[13]	Imperfect Competition/	Cost[12]	
Regulation	Market Power[28]	Accuracy	
Price Distortion[14]			
Chain of Barriers			
Disaggregated Mkt.[15]			

William H. Golove and Joseph H. Eto, ***Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency;***

1) Six market barriers were initially identified: 1) misplaced incentives, 2) lack of access to financing, 3) flaws in market structure, 4) mis-pricing imposed by regulation, 5) decision influenced by custom, and 6) lack of information or misinformation. Subsequently a seventh barrier, referred to as "gold plating," was added to the taxonomy (9).
2) Neo-classical economics generally relies on the assumption of frictionless transactions in which no costs are associated with the transaction itself. In other words, the costs of such activities as collecting and analyzing information; negotiating with potential suppliers, partners, and customers; and assuming risk are assumed to be nonexistent or insignificant. This assumption has been increasingly challenged in recent years. The insights developed through these challenges represent an important new way to evaluate aspects of various market failures (especially those associated with imperfect information). Transaction cost economics examines the implications of evidence suggesting that transaction costs are not insignificant but, in fact, constitute a primary explanation for the particular form taken by many economic institutions and contractual relations (22).
3) Transaction cost economics also offers support for claims that the illiquidity of certain investments leads to higher interest rates being required by investors in those investments (23).
4) Misplaced, or split, incentives are transactions or exchanges where the economic benefits of energy conservation do not accrue to the person who is trying to conserve (9).
5) Thus, as the rated lifetime of equipment increases, the uncertainty and the value of future benefits will be discounted significantly. The irreversibility of most energy efficiency investments is said to increase the cost of such investments because secondary markets do not exist or are not well-developed for most types of efficient equipment. This argument contends that illiquidity results in an option value to delaying investment in energy efficiency, which multiplies the necessary return from such investments (16)
6) If a consumer wishes to purchase an energy-efficient piece of equipment, its efficiency should reduce the risk to the lender (by improving the borrower's net cash flow, one component of credit-worthiness5) and should, but does not, reduce the interest rate, according to the proponents of the theory of market barriers. (p.10). Potential investors, it is argued, will increase their discount rates to account for this uncertainty or risk because they are unable to diversify it away. The capital asset pricing model (CAPM) is invoked to make this point (16).

---

[42] Golove and Eto, p. 22.

7) Perfect information includes knowledge of the future, including, for example, future energy prices. Because the future is unknowable, uncertainty and risk are imposed on many transactions. The extent to which these unresolvable uncertainties affect the value of energy efficiency is one of the central questions in the market barriers debate. Of course, inability to predict the future is not unique to energy service markets. What is unique is the inability to diversify the risks associated with future uncertainty to the same extent that is available in other markets (20).

8) In practice, we observe that some potential borrowers, for example low-income individuals and small business owners, are frequently unable to borrow at any price as the result of their economic status or "credit-worthiness." This lack of access to capital inhibits investments in energy efficiency by these classes of consumers (10).

9) Finally, Williamson (1985) argues that the key issue surrounding information is not its public goods character, but rather its asymmetric distribution combined with the tendency of those who have it to use it opportunistically (23).

10) [K]nowledge of current and future prices, technological options and developments, and all other factors that might influence the economics of a particular investment. Economists acknowledge that these conditions are frequently not and in some cases can never be met. A series of information market failures have been identified as inhibiting investments in energy efficiency: (1) the lack of information, (2) the cost of information, (3) the accuracy of information, and (4) the ability to use or act upon information (20).

11) The notion of "gold plating" emerged from research suggesting that energy efficiency is frequently coupled with other costly features and is not available separately (11).

12) Even when information is potentially available, it frequently is expensive to acquire, requiring time, money or both (20).

13) Inseparability of features refers specifically to cases where availability is inhibited by technological limitations. There may be direct tradeoffs between energy efficiency and other desirable features of a product. In contrast to gold plating where the consumer must purchase more features than are desired, the inseparability of features demands purchases of lower levels of features than desired. (2)

14) The regulation barrier referred to mis-pricing energy forms (such as electricity and natural gas) whose price was set administratively by regulatory bodies (11).

15) On the cost-side of the equation, the critics contend that, among other things, information and search costs have typically been ignored or underestimated in engineering/economic analyses. Time and/or money may be spent: acquiring new information (search costs), installing new equipment, training operators and maintenance technicians, or supporting increased maintenance that may be associated with the energy efficient equipment (p.16). [T]he class, itself, consists of a distribution of consumers: some could economically purchase additional efficiency, while others will find the new level of efficiency is not cost effective (13).

16) Discounted cash-flow, cost-benefit, and social welfare analyses use price as the complete measure of value although in very different ways; behavioral scientists, on the other hand, have argued that a number of "noneconomic" variables contribute significantly to consumer decision making (17).

17) [C]ustom and information have evolved significantly during the market barrier debate (11).

18) In the language of (economic) utility theory, the profitability of energy efficiency investments is but one attribute consumers evaluate in making the investment. The value placed on these other attributes may, in some cases, outweigh the importance of the economic return on investment (19).

19) [P]sychological considerations such as commitment and motivation play a key role in consumer decisions about energy efficiency investments (17).

20) Externalities refer to costs or benefits associated with a particular economic activity or transaction that do not accrue to the participants in the activity (18).

21) Other factors, such as membership in social groups, status considerations, and expressions of personal values play key roles in consumer decision-making (17). In order for a market to function effectively, all parties to an exchange or transaction must have equal bargaining power. In the event of unequal bargaining positions, we would expect that self-interest would lead to the exploitation of bargaining advantages (19).

22) Public goods are said to represent a market failure. It has been generally acknowledged by economists and efficiency advocates that public good market failures affect the energy services market. (19) [T]he creation of information is limited because information has public good qualities. That is, there may be limits to the creator's ability to capture the full benefits of the sale or transfer of information, in part because of the low cost of subsequent reproduction and distribution of the information, thus reducing the incentive to create information that might otherwise have significant value (20).

23) Investment in basic research in believed to be subject to this shortcoming; because the information created as a result of such research may not be protected by patent or other property right, the producer of the information may be unable to capture the value of his/her creation (19).

24) Important theoretical refinements to this concept, known as prospect theory, have been developed by Tversky and Kahneman (1981, 1986). This theory contends that individuals do not make decisions by maximizing prospective utility, but rather in terms of difference from an initial reference point. In addition, it is argued that individuals value equal gains and losses from this reference point differently, weighing losses more heavily than gains (21).

25) The information created by the adoption of a new technology by a given firm also has the characteristics of a public good. To the extent that this information is known by competitors, the risk associated with the subsequent adoption of this same technology may be reduced, yet the value inherent in this reduced risk cannot be captured by its creator (19).

26) This work is consistent with the notion of bounded rationality in economic theory. In contrast to the standard economic assumption that all decision makers are perfectly informed and have the absolute intention and ability to make decisions that

maximize their own welfare, bounded rationality emphasizes limitations to rational decision making that are imposed by constraints on a decision maker's attention, resources, and ability to process information. It assumes that economic actors intend to be rational, but are only able to exercise their rationality to a limited extent (p.21).

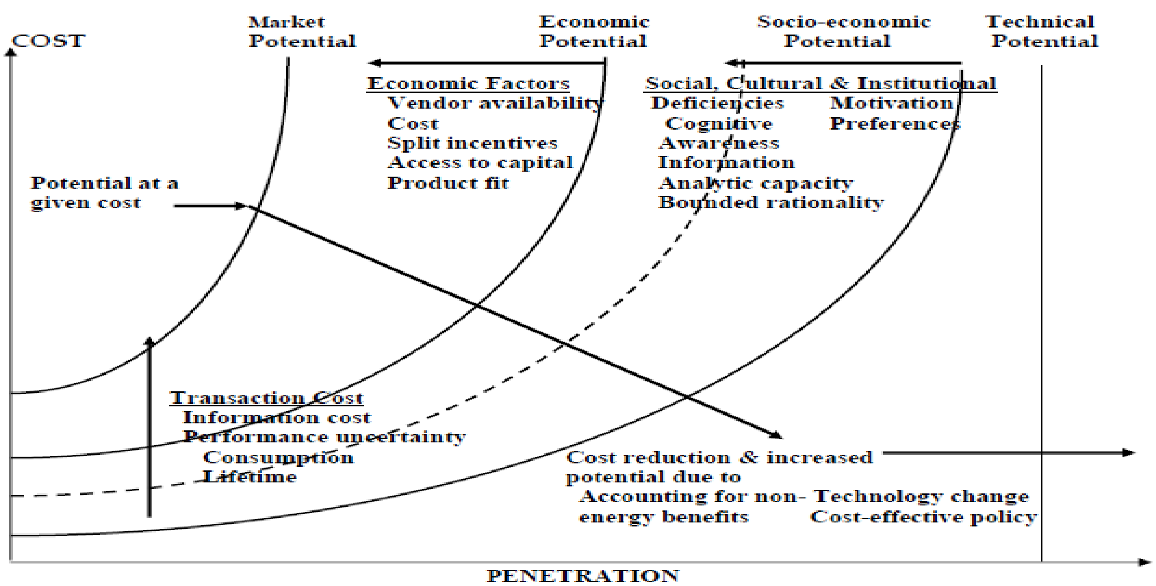
27) Finally, individuals and firms are limited in their ability to use — store, retrieve, and analyze — information. Given the quantity and complexity of information pertinent to energy efficiency investment decisions, this condition has received much consideration in the market barriers debate (20).

28) This barrier suggests that certain powerful firms may be able to inhibit the introduction by competitors of energy-efficient, cost-effective products (10).

Starting from the observation that "transaction costs are not insignificant but, in fact, constitute a primary explanation for the particular form taken by many economic institutions and contractual relations"[43] the LBL paper identifies such costs and information as a critical issue, pointing out that "the key issue surrounding information is not its public goods character, but rather its asymmetric distribution combined with the tendency of those who have it to use it opportunistically."[44]

A second analytic framework that rests on a technology investment approach was offered more recently by other analysts at LBL. As shown in in Figure II-2, one can use a technology investment framework to assess the factors that cause investment in energy efficiency to fall well short of the technical potential.

FIGURE II-2: PENETRATION OF MITIGATION TECHNOLOGIES: A CONCEPTUAL FRAMEWORK



Source: Jayant Sathaye and Scott Murtishaw, *Market Failures, Consumer Preferences, and Transaction Costs in Energy Efficiency Purchase Decisions* (California Energy Commission, November 2004), p. 11.

The LBL study identified broad categories of market imperfections, barriers, and obstacles that are important in determining the level of investments – economic, transaction cost, and social cultural and institutional. The analysis emphasizes the important role that policy can play in determining where the market will settle.

[43] Golove and Eto, p. 23.
[44] Golove and Eto, p. 23.

Thus, there are six broad categories of factors that must be incorporated into the analysis of the level of investment in energy saving technologies. Market performance is influenced by: behavioral factors (social, cultural & institutional), economic factors, transaction cost, externalities (non-energy costs), technological change, public policy.

2. Resources for the Future

A more recent paper from Resources for the Future (RFF), entitled *Energy Efficiency Economics and Policy,* addresses exactly the same issues as the earlier LBL paper – the debate over the efficiency gap observed in energy markets. The authors of the RFF paper characterize the efficiency gap debate as follows:

> Much of the literature on energy efficiency focuses on elucidating the potential rationales for policy intervention and evaluating the effectiveness and cost of such interventions in practice. Within this literature there is a long-standing debate surrounding the commonly cited "energy efficiency gap..." Within the investment framework… the energy efficiency gap takes the form of under investment in energy efficiency relative to a description of the socially optimal level of energy efficiency. Such under investment is also sometimes described as an observed rate or probability of adoption of energy-efficient technologies that is "too slow."[45]

Table II-2 presents my summary of the RFF framework. The RFF paper suggests three broad categories of market failures – the individual, the interaction between economic agents and the fit between economic agents and society. I refer to these three levels as the behavioral, the market structural and the societal levels. In the present context, I consider behavioral failures to represent consumer behavior that is inconsistent with utility maximization, or in the current context, energy service cost-minimization. In contrast, market failure analysis is distinct in presupposing individual rationality and focusing on the conditions surrounding interactions among economic agents and society.[46] The societal level market failures are closest to what the traditional sources of the economic literature refers to as market failure. These are primarily externalities and public goods. In the market failure category, the Figures shows the distinction between the structural and societal levels suggested by the paper. It also includes a few more specific failures that were discussed in the text, but not included in the original table. There are about a dozen specific market failures spread across these categories. These were also considered market failures in the LBL framework. The LBL barriers and transaction costs fit in the category of interactions between economic agents, as would imperfect competition.

One obvious point is that, as in the case of the LBL framework, information problems occur in all categories of the RFF analysis, with several manifestations in each. Also note that RFF ties the investment framework to the innovation adoption framework. In this analysis I do so through the analysis of market imperfections.

[45] Gillingham, Newell and Palmer, p. 7.
[46] Id., p. 8.

TABLE II-2: RFF MARKET AND BEHAVIORAL FAILURES RELEVANT TO ENERGY EFFICIENCY

Societal Failures	***Structural Failures***	***Potential Behavioral Failures***[11]
Energy Market Failures	Capital Market Failures	Prospect theory[12]
Environmental Externalities[1]	Liquidity constraints[5]	Bounded rationality[13]
Energy Security	Information problems[6]	Heuristic decision making[14]
Innovation market failures	Lack of information[7]	Information[15]
Research and development spillovers[2]	Asymmetric info. >	
Learning-by-doing spillovers[3]	Adverse selection[8]	
Learning-by-using[4]	Principal-agent problems[9]	
	Average-cost electricity pricing[10]	

1) Externalities: the common theme in energy market failures is that energy prices do not reflect the true marginal social cost of energy consumption, either through environmental externalities, average cost pricing, or national security (9).
2) R&D spillovers may lead to underinvestment in energy-efficient technology innovation due to the public good nature of knowledge, whereby individual firms are unable to fully capture the benefits from their innovation efforts, which instead accrue partly to other firms and consumers (11).
3) Learning-by-doing (LBD) refers to the empirical observation that as cumulative production of new technologies increases, the cost of production tends to decline as the firm learns from experience how to reduce its costs (Arrow 1962). LBD may be associated with a market failure if the learning creates knowledge that spills over to other firms in the industry, lowering the costs for others without compensation.
4) Positive externalities associated with learning-by-using can exist where the adopter of a new energy-efficient product creates knowledge about the product through its use, and others freely benefit from the information generated about the existence, characteristics, and performance of the product (12).
5) Capital: Some purchasers of equipment may choose the less energy-efficient product due to lack of access to credit, resulting in underinvestment in energy efficiency and reflected in an implicit discount rate that is above typical market levels (13).
6) Information: Specific information problems cited include consumers' lack of information about the availability of and savings from energy-efficient products, asymmetric information, principal-agent or split-incentive problems, and externalities associated with learning-by-using (11).
7) Lack of information and asymmetric information are often given as reasons why consumers systematically underinvest in energy efficiency. The idea is that consumers often lack sufficient information about the difference in future operating costs between more-efficient and less-efficient goods necessary to make proper investment decisions (11).
8) Asymmetric information, where one party involved in a transaction has more information than another, may lead to adverse selection (11).
9) Agency: The principal-agent or split-incentive problem describes a situation where one party (the agent), such as a builder or landlord, decides the level of energy efficiency in a building, while a second party (the principal), such as the purchaser or tenant, pays the energy bills. When the principal has incomplete information about the energy efficiency of the building, the first party may not be able to recoup the costs of energy efficiency investments in the purchase price or rent charged for the building. The agent will then underinvest in energy efficiency relative to the social optimum, creating a market failure (12).
10) Prices faced by consumers in electricity markets also may not reflect marginal social costs due to the common use of average-cost pricing under utility regulation. Average-cost pricing could lead to under- or overuse of electricity relative to the economic optimum (10).
11) Systematic biases in consumer decision making that lead to underinvestment in energy efficiency relative to the cost-minimizing level are also often included among market barriers. (8); The behavioral economics literature has drawn attention to several systematic biases in consumer decision making that may be relevant to decisions regarding investment in energy efficiency. Similar insights can be gained from the literature on energy decision-making in psychology and sociology. The evidence that consumer decisions are not always perfectly rational is quite strong, beginning with Tversky and Kahneman's research indicating that both sophisticated and naïve respondents will consistently violate axioms of rational choice in certain situations (15).
12) The welfare change from gains and losses is evaluated with respect to a reference point, usually the status quo. In addition, consumers are risk averse with respect to gains and risk seeking with respect to losses, so that the welfare change is much greater from a loss than from an expected gain of the same magnitude (Kahneman and Tversky 1979). This can lead to loss aversion, anchoring, status quo bias, and other anomalous behavior (16).
13) Bounded rationality suggests that consumers are rational, but face cognitive constraints in processing information that lead to deviation from rationality in certain circumstances (16); Assessing the future savings requires forming expectations of future energy prices, changes in other operating costs related to the energy use (e.g., pollution charges), intensity of use of the product, and equipment lifetime. Comparing these expected future cash flows to the initial cost requires discounting the future cash flows to present values (3).
14) Heuristic decision-making is related closely to bounded rationality and encompasses a variety of decision strategies that differ in some critical way from conventional utility maximization in order to reduce the cognitive burden of decision-making. Tversky (1972) develops the theory of elimination-by-aspects," wherein consumers use a sequential decision making process where they first narrow their full choice set to a smaller set by eliminating products that do not have some desired feature or aspect (e.g., cost above a certain level), and then they optimize among the smaller choice set, possibly after eliminating further products. (16) For example, for decisions regarding energy-efficient investments consumers tend to use a simple payback measure where the total investment cost is divided by the future savings calculated by using the energy price today, rather than the price at the time of the savings— effectively ignoring future increases in real fuel prices (p. 17). The salience effect may influence energy efficiency decisions, potentially contributing to an overemphasis on the initial cost of an energy-efficient purchase, leading to an underinvestment in energy efficiency. This may be related to evidence suggesting that decision makers are more sensitive to up-front investment costs than energy operating costs, although this evidence may also be the result of inappropriate measures of expectations of future energy use and prices (17).
15) Alternatively, information problems may occur when there are behavioral failures, so that consumers are not appropriately taking future reductions in energy costs into account in making present investments in energy efficiency (12).

Source: Kenneth Gillingham, Richard G. Newell, and Karen Palmer, *Energy Efficiency Economics and Policy* (Resources for the Future, April 2009)

3. The United Nations Industrial Development Organization

Table II-3 summarizes a recent comprehensive review of the causes of the efficiency gap in industrial sectors across the globe. It is based on a conceptualization and analysis prepared for the United Nations Industrial Organization by analysts at universities in the United Kingdom (hereafter UNIDO). It is based on a review of over 160 studies of barriers to energy efficiency in industrial enterprises.

It can be argued that the analysis of industrial sectors provides the most compelling evidence that an energy efficiency gap exists, since these are contexts in which the incentive to adopt economically rational technologies should be strong, if not pure, and the knowledge and ability to evaluate alternatives should be greater than society at large. Moreover, since energy is a cost of doing business, records and data should be superior to the residential sector, so evaluation and calculation should be better. In spite of these factors pointing toward economic rationality, and notwithstanding assumptions of motivation and capability, these authors find solid empirical evidence that the efficiency gap exists.

As was the case in the LBL analysis, the UNIDO analysis identified a school of economic thought that can be closely associated with each of the categories of market barriers and imperfections. The broad categories in the UNIDO analysis match up well with the perspectives offered by LBL and RFF with the addition of the category of externalities. The UNIDO document offers six broad types of barriers, with two dozen subtypes.

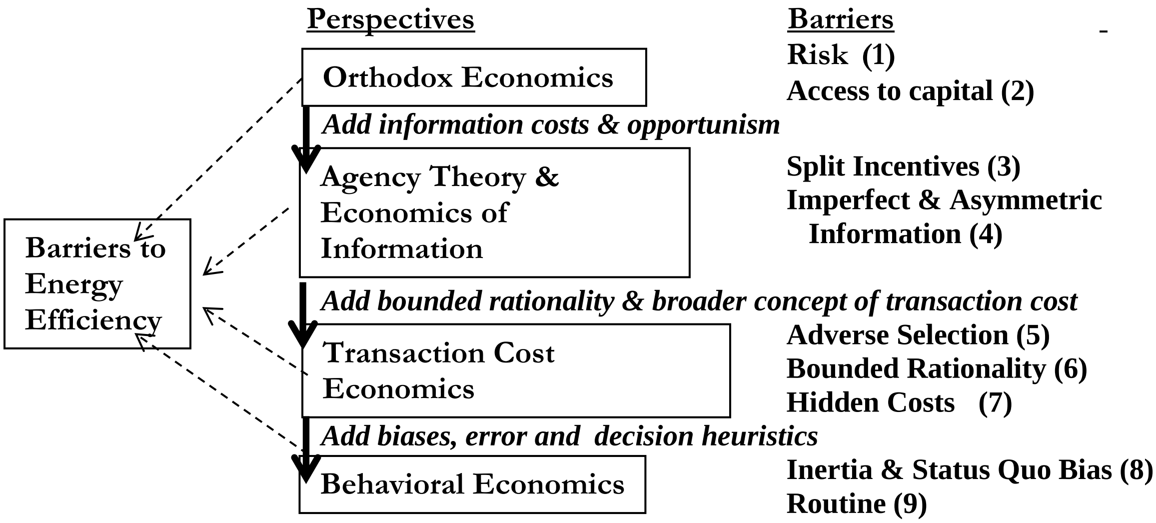
4. McKinsey and Company

A fourth comprehensive approach that adds depth to the analysis is the framework offered in a detailed analysis of efficiency in the building sector prepared by McKinsey and Company, which is described in Table II-4. The McKinsey conceptualization of barriers and obstacles to energy efficiency uses three broad categories – structural, behavioral and availability. There are about two dozen specific barriers described. Moreover, McKinsey identifies nine different clusters of activity in the building sector. The manifestation of the barriers is different in the clusters, so McKinsey ends up with fifty discrete barriers.

5. California Energy Institute

Table II-5 presents the framework utilized by the California Energy Institute in evaluating policies to increase energy efficiency in businesses. It is notable in two respects. First, it is oriented toward businesses, which is a useful antidote to the overemphasis on residential consumers in the efficiency gap debate. Second, it explicitly endeavors to summarize and compile the various approaches to analyzing the "efficiency gap," used by others. In doing so, it returns to the traditional distinction that is made between market failures, which are recognized in neoclassical approaches, and other obstacles to investment in energy efficiency in.

TABLE II-3: BARRIERS TO INDUSTRIAL ENERGY EFFICIENCY



Steve Sorrell, Alexandra Mallett & Sheridan Nye. *Barriers to industrial energy efficiency, A literature review,* United Nations Industrial Development Organization, Vienna, 2011, Figure 3.1 & Section 3.

(1) Risk: The short paybacks required for energy efficiency investments may represent a rational response to risk. This could be because energy efficiency investments represent a higher technical or financial risk than other types of investment, or that business and market uncertainty encourages short time horizons.

(2) Access to capital: If an organization has insufficient capital through internal funds, and has difficulty raising additional funds through borrowing or share issues, energy efficient investments may be prevented from going ahead. Investment could also be inhibited by internal capital budgeting procedures, investment appraisal rules and the short-term incentives of energy management staff.

(3) Split incentives: Energy efficiency opportunities are likely to be foregone if actors cannot appropriate the benefits of the investment. Wide applicability… Landlord-tenant problems may arise in the industrial, public and commercial sectors through the leasing of buildings and office space. The purchaser may have a strong incentive to minimize capital costs, but may not be accountable for running costs….maintenance staff may have a strong incentive to minimize capital costs and/or to get failed equipment working again as soon as possible, but may have no incentive to minimize running costs. If individual departments within an organization are not accountable for their energy use they will have no incentive to improve energy efficiency.

(4) Imperfect information: Lack of information on energy efficiency opportunities may lead to cost-effective opportunities being missed. In some cases, imperfect information may lead to inefficient products driving efficient products out of the market. Information on: the level and pattern of current energy consumption and comparison with relevant benchmarks; specific opportunities, such as the retrofit of thermal insulation; and the energy consumption of new and refurbished buildings, process plant and purchased equipment, allowing choice between efficient and inefficient options.
Asymmetric information exists where the supplier of a good or service holds relevant information, but is unable or unwilling to transfer this information to prospective buyers.

(5) Asymmetric information may lead to the adverse selection of energy inefficient goods.

(6) Bounded rationality: Owing to constraints on time, attention, and the ability to process information, individuals do not make decisions in the manner assumed in economic models. As a consequence, they may neglect opportunities for improving energy efficiency, even when given good information and appropriate incentive consumers do not attempt to maximise their utility or producers their profits.

(7) Hidden costs Engineering-economic analyses may fail to account for either the reduction in utility associated with energy efficient technologies, or the additional costs associated with them. As a consequence, the studies may overestimate energy efficiency potential. Examples of hidden costs include overhead costs for management, disruptions to production, staff replacement and training, and the costs associated with gathering, analysing and applying information.
General overhead costs of energy management: employing specialist people (e.g., energy manager); energy information systems (including: gathering of energy consumption data; maintaining sub metering systems; analysing data and correcting for influencing factors; identifying faults; etc.); energy auditing;
Costs involved in individual technology decisions: i) identifying opportunities; ii) detailed investigation and design; iii) formal investment appraisal; formal procedures for seeking approval of capital expenditures; specification and tendering for capital works to manufacturers and contractors additional staff costs for maintenance; replacement, early retirement, or retraining of staff; disruptions and inconvenience;
Loss of utility associated with energy efficient: problems with safety, noise, working conditions, service quality etc. (e.g., lighting levels); extra maintenance, lower reliability,

(8) Inertia and the status quo bias: Routines can be surprisingly persistent and entrenched. … This type of problem has been labeled *inertia* within the energy efficiency literature and identified as a relevant explanatory variable for the efficiency gap

(9) Routines as a response to bounded rationality the use of formal capital budgeting tools within investment decision-making. Other types of rules and routines which may impact on energy efficiency include: operating procedures (such as leaving equipment running or on standby); safety and maintenance procedures; relationships with particular suppliers; design criteria; specification and procurement procedures; equipment replacement routines and so on.

TABLE II-4: MCKINSEY AND COMPANY MARKET BARRIERS TO HOME ENERGY EFFICIENCY

Kckinsey Category	McKinsey Nature	McKinsey Description	Cluster
Behavioral	Awareness	Low priority, Preference for other attributes	CD, RLA
Availability	Availability	Restricted procurement, 1st cost focus	CD
Behavioral	Awareness	Shop for price and features	RD
Behavioral	Awareness	Limited understanding of use and savings	CEPB, EH, GB, RLA
Behavioral	Custom & Habit	Little attention at time of sale	NH
Behavioral	Custom & Habit	Underestimation of plug load	RD
Behavioral	Custom & Habit	Aversion to change	CI,
Behavioral	Custom & Habit	CFLS perceived as inferior	RLA
Behavioral	Hurdle	Payback-Hurdle, 28% discount rate	CEPB
Behavioral	Hurdle	Payback-Hurdle,40% discount rate	EH
Behavioral	Use	Improper use and maintenance	CEPB, EH, RD
Behavioral	Awareness	Not accountable for efficiency	CI
Availability	Capital	Competing use of capital	EH, GB, RLA, CI
Structural	Agency	Tenant pays, builder ignores	CEPB, EH, RD
Availability	Availability	Lack of contractors	EH
Availability	Availability	Lack of availability in area	NH
Availability	Availability	Lack of demand => lack of R&D	RD
Availability	Availability	Emergency replacement	RLA
Availability	Bundling	Efficiency bundled with other features	RLA
Structural	Owner Transfer	Lack of premium at time of sale	CD, NH, NPB, RLA
Structural	Owner Transfer	Limits payback to occupancy period	EH
Structural	Transaction	Lack of information	NPB
Structural	Transaction	Disruption during improvement process	EH
Structural	Transaction	Difficult to identify efficient devices	RD
Behavioral	Risk/Uncertainty	Business failure risk	CEPB
Behavioral	Risk/Uncertainty	Lack of reliability	CI
Structural	Transaction	Research, procurement and preparation	EH, GB, RLA

SOURCE:
McKinsey and Company, *Unlocking Energy Efficiency in the U.S. Economy,* July 2009, Tables 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, Exhibits 14, 15, 16, 19, 21, 24, 26, 27, 29, 30.

Clusters
CD = Commercial Devices;
CEPB = Commercial Existing Private Buildings;
CI = Commercial Infrastructure;
EH = Existing Homes;
GB = Government Buildings;
NH = New Homes;
NPB = New Private Commercial Buildings;
RD = Residential Devices;
RLA = Residential Lighting and Appliances

McKinsey Categories Defined:

Structural. These barriers arise when the market of environment makes investing in energy efficiency less possible or beneficial, preventing measures that would be NPV-positive from being attractive to an end-user:

Agency issues energy efficiency less possible or beneficial, preventing a measure that would be NPV misaligned between economic actors, primarily between landlord and tenant These barriers arise when the market or environment makes investing in (split incentives), in which energy bills and capital rights are

Ownership transfer issues, in which the current owner cannot capture the full duration of benefits, thus requiring assurance they can capture a portion of the future value upon transfer sufficient to justify upfront investment; this issue also affects builders and buyers… Because developers do not receive the future energy savings from efficient buildings and are often unaware or uncertain of the market premium energy efficient building can command, developers have little financial incentive to invest in energy efficiency above the required minimum.

"Transaction" barriers, a set of hidden "costs" that are not generally monetizable, associated with energy efficiency investment; for example, the investment of time to research and implement a new measure High transaction barriers arise as consumers incur significant time "costs" in researching, identifying, and procuring efficiency upgrades

Pricing distortions, including regulatory barriers that prevent savings from materializing for users of energy-savings devices.

Behavioral: These barriers explain why an end-user who is structurally able to capture a financial benefit still decides not to

Risk and uncertainty over the certainty and durability of measures and their savings generates an unfamiliar level of concern for the decision maker. Many operators are risk averse and put a premium on reliability; they may not be inclined to pursue energy efficiency activities for fear of disrupting essential services.

Lack of awareness, or low attention, on the part of end-users and decision makers in firms regarding details of current energy consumption patterns, potential savings, and measures to capture those savings. Homeowners typically do not understand their home energy consumption and are unaware of energy-saving measures.

Custom and habit, which can create inertia of "default choices" that must be overcome. Enduring lifestyle disruptions during the improvement process. End-users retain preconceived and often inaccurate ideas about differences in functionality that limit the acceptance of certain products.

Elevated hurdle rates, which translate into end-users seeking rapid pay back of investments - typically within 2 to 3 years. This expectation equates to a discount rate of 40 percent for investments in energy efficiency, inconsistent with the 7-percent discount rate they implicitly use when purchasing electricity (as embodied by the energy provider's cost of capital). It is beyond the scope of this report to evaluate the appropriate risk-adjusted hurdle rate for specific end-users, though it seems clear that the hurdle rates of energy delivery and energy efficiency are significantly different.

Availability: These barriers prevent adoption even for end-users who would choose to capture energy efficiency opportunities if they could

Adverse bundling or "gold plating," situations in which the energy efficient characteristic of a measure is bundled with premium features, or is not available in devices with desirable features of higher priority, and is therefore not selected

Capital constraints and access to capital, both access to credit for consumers and firms and (in industry and commerce) competition for resources internally within balance-sheet constraints. Energy efficiency projects may compete for capital with core business projects.

Product (and service) availability in the supply chain; energy efficient devices may not be widely stocked or available through customary purchasing channels, or skilled service personnel may not be available in a particular market

Inconsistent quality of installation (sizing, sealing and charging, code compliance and enforcement) and improper use eliminates savings

TABLE II-5: MARKET FAILURES, BARRIERS AND NON-ECONOMIC FACTORS

Neo Classical Economics

Explanations for the gap:

1. The gap is illusory
2. There are hidden or unaccounted for costs of energy efficiency investments
3. Consumer markets are heterogeneous
4. High discount rates assigned to energy efficiency investments resulting from perceived risk

Conditions that are known to cause market failure:

1. externalities
2. public goods
3. imperfect information
4. imperfect competition

Market Barriers

1. Situations involving Misplaced or Split Incentives (also called agency problems)
2. Limited Availability of Capital,
3. Market Power
4. Regulatory Distortions
5. Transaction Costs
6. Inseparability of energy efficiency features from other desirable or undesirable product features

Non-Economic Explanations

1. Rationality is only one of several decision-making heuristics that may be applied in a given decision-making situation.
2. Decision makers employ varying decision-making heuristics depending on the situation.
3. Decision-making units are often not individuals.
4. Decisions made by organizations are affected by a wide variety of social processes and heavily influenced by the behaviors of their leaders.

Organizational Influences:

Authority

Size

Hierarchy of needs (1. Health and Safety Requirements,2. Regulatory Compliance, 3. Corporate Improvement Initiatives, 4. Maintenance) 5. Productivity, 6. Importance of Energy Efficiency to Profitability

Management policy 1. Whether the organization has annual energy efficiency goals. 2. Whether reserves and budgets are established for funding energy efficiency investments. 3. Whether hurdle rates for energy efficiency investments are high or low. 4. The review process that is to be used to evaluate energy efficiency improvements. 5. Who is responsible for "managing" the company's energy efficiency program).

Sources: Edward Vine, 2009, *Behavior Assumptions Underlying Energy Efficiency Programs For Businesses,* California Institute for Energy and Environment, January.

the market. It identifies two other broad categories – market barriers and non-economic factors. The California Energy Institute also devotes a great deal of attention to behavioral factors

The importance of behavioral economics in the contemporary analysis must be highlighted. The findings of behavioral economics can be usefully divided into three groups – motivation, perception and calculation. As shown in Table II-6, Wilkinson, 2008, has two sets of chapters, one foundational, one advanced, that can be organized according to this scheme described in Table II-6.

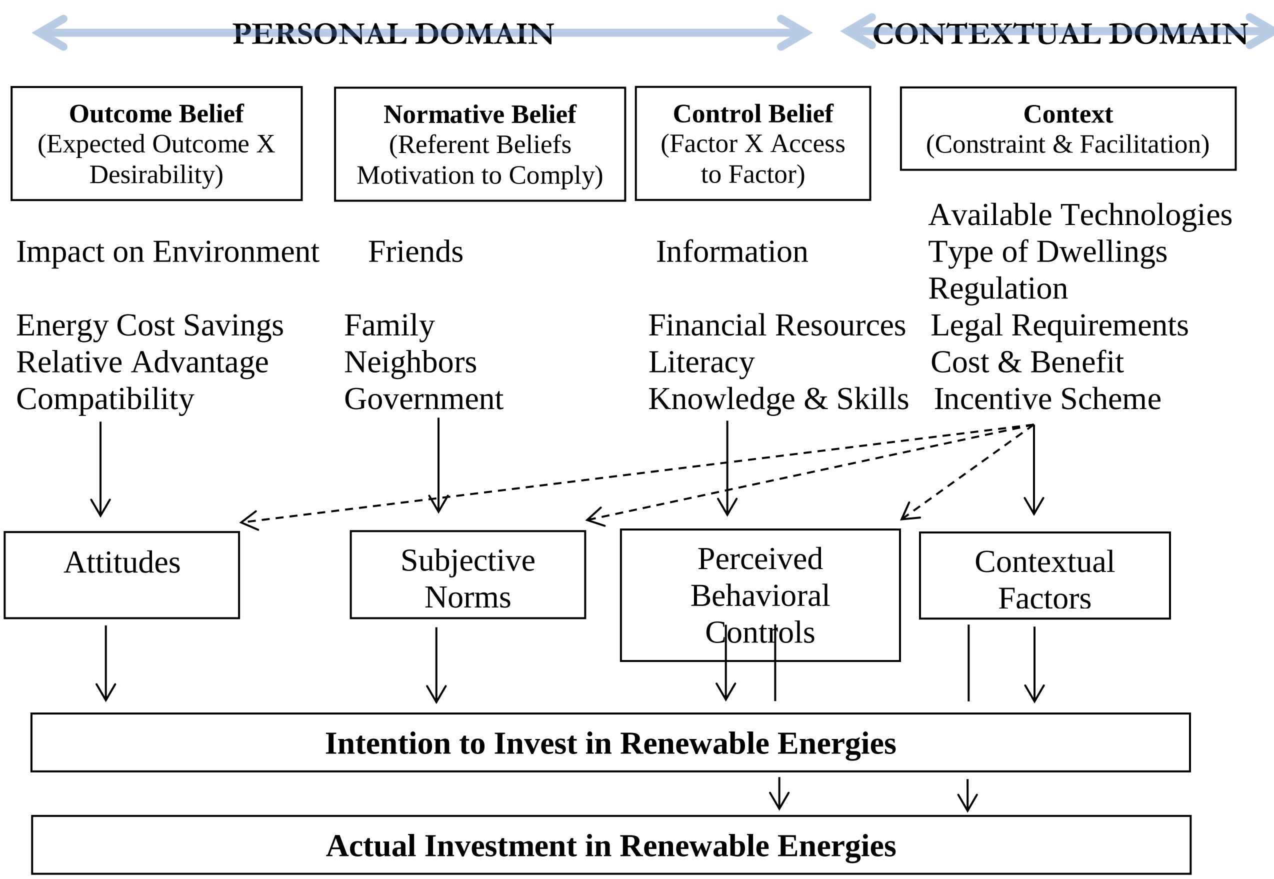
Figure II-3 presents a common framing of the behavioral considerations Note that this approach to adoption of innovation takes up the investment theme at the level of individual action.

TABLE II-6: THREE DIMENSIONS OF BEHAVIORAL ECONOMICS

Motivation:	Foundations: Values, Attitudes, Preferences and Choice, Nature and Measurement of Utility, Advanced: Fairness and Social Preferences
Perception	Foundations: Decision-making under Risk and Uncertainty, Utility Theory, Prospect Theory, Reference Points, Loss aversion, Decision Weighting Advanced: Behavioral Game Theory, Bargaining, Signaling, Learning
Calculation	Foundations: Mental Accounting, Framing and Editing, Budgeting and Fungibility, Choice Bracketing, Advanced: The Discounted Utility Model, Alternative Intertemporal Choice Models.

Source: Wilkinson, Nick, *An Introduction to Behavioral Economics,* 2008.

FIGURE IV-3: INTEGRATED MODEL TO EVALUATE DETERMINANTS OF ENERGY EFFICIENT TECHNOLOGY UPTAKE



Source: Marius Claudy and Aidan O'Driscoll, "Beyond Economics: A Behavioral Approach to Energy Efficiency in Domestic Buildings," *Dublin Institute of Technology*, 2008; based on Stern, Paul C., "Towards a Coherent Theory of Environmentally Significant Behavior, *Journal of Social Issues,* 56: 2000; see also, Charlie Wilson and Hadi, Dowlatabadi, "Models of Decision Making and Residential Energy Use, *Annual Review of Environmental Resources,* 32:2007, p. 183.

III. DIFFUSION OF INNOVATION AND THE POLICY IMPLICATIONS OF THE MARKET BARRIER ANALYSIS

A. RECOGNIZING THE ROLE OF SUPPLY AND DEMAND

The innovation diffusion process has typically been represented as a logistic (S) curve that represents the overall flow of product development and adoption actions (see Figure III-1). The analysis of the diffusion of products has shifted its focus between the supply-side of the market and the demand side several times over the past century. The pre-World War II focus was on “”invention and innovation,” but the three decades after the war focused much more on the demand side, so much so that by the 1990s, the field was criticized for ignoring the importance of the supply-side.[47]

The upper graph of Figure III-1 shows the demand-side process of adoption, which has generally been the focal point of the efficiency gap literature. On the demand side, the process begins with initial adoption by market mavens and innovators, then spreads through early adopters, early and late majorities and finally laggards. The adoption process accelerates rapidly with takeoff then slows with maturity. The speed and ultimate level of adoption have been primary focal points of analysis on the demand side.

The supply-side has received increasing attention. As shown in the lower graph of Figure III-1, it has also been depicted as an S-curve. The process moves through a number of phases. On the supply side, in the first phase, technology incubates and emerges from research and development to be launched. The early supply-side period is very challenging and has been called the “valley of death” that must be traversed if the product is to advance.[48] The product undergoes continuous development as it is commercialized and is successful, a process that has been called the slope of enlightenment.[49] The product stabilizes as it matures and then saturates the market. Saturation may not be at 100 percent, since some parts of the market may never adopt a product for a variety of reasons.

Figure I-2 integrates the supply side and the demand side and identifies the periods and processes that take place in each. The definition of technological diffusion offered in a 1998 review of the field, reflects the tension between a supply-side and a demand side focus.

[47] Figure III-1 is are drawn from the following sources: Mahajan, Vijay, Eitan Muller and Frank M. Bass,1990, “New Product Diffusion Models in Marketing: A Review and Directions of Research,” Journal of Marketing, 54; Rick Brown, “Managing the “S” Curve of Innovation,” 1992, Journal of Consumer Marketing; Fenn, Jackie, 1995, When to Leap on the Hype Cycle, Gartner Group; Paul Gilder and Gerard J. Tellis, 1997, “Will it Ever Fly? Modeling the Takeoff of Really New Consumer Durables,” Marketing Science, 16: 3, “Growing, Growing Gone: Cascades, Diffusion, and Turning Points in the Product Life Cycle,” Marketing Science, 23: 2 (2004); Kohli, Rajeev Donald R. Lehman and Jae Pae, 1999,“Extent and Impact of Incubation Time in New Product Diffusion, Journal of Product Innovation Management, 16; Osawa, Yshitaka and Kumiko Miazaki, 2006, “An Empirical Analysis of the Valley of Death: Large Scale R&D Project Performance in a Japanese Diversified Company,” Asian Journal of Technology Innovation, 14:2; Sood, Ashish, et al., 2012, “Predicting the Path of Technological Innovation: SAW vs. Moore, Bass, Gompertz and Jryder,” Marketing Science, 31: 6; Gartner, 2013, Interpreting Technology Hype.

[48] Osawa and Miazaki, 2006.

[49] Gartner, 2013,

FIGURE III-1: THE DIFFUSION OF INNOVATIVE TECHNOLOGIES

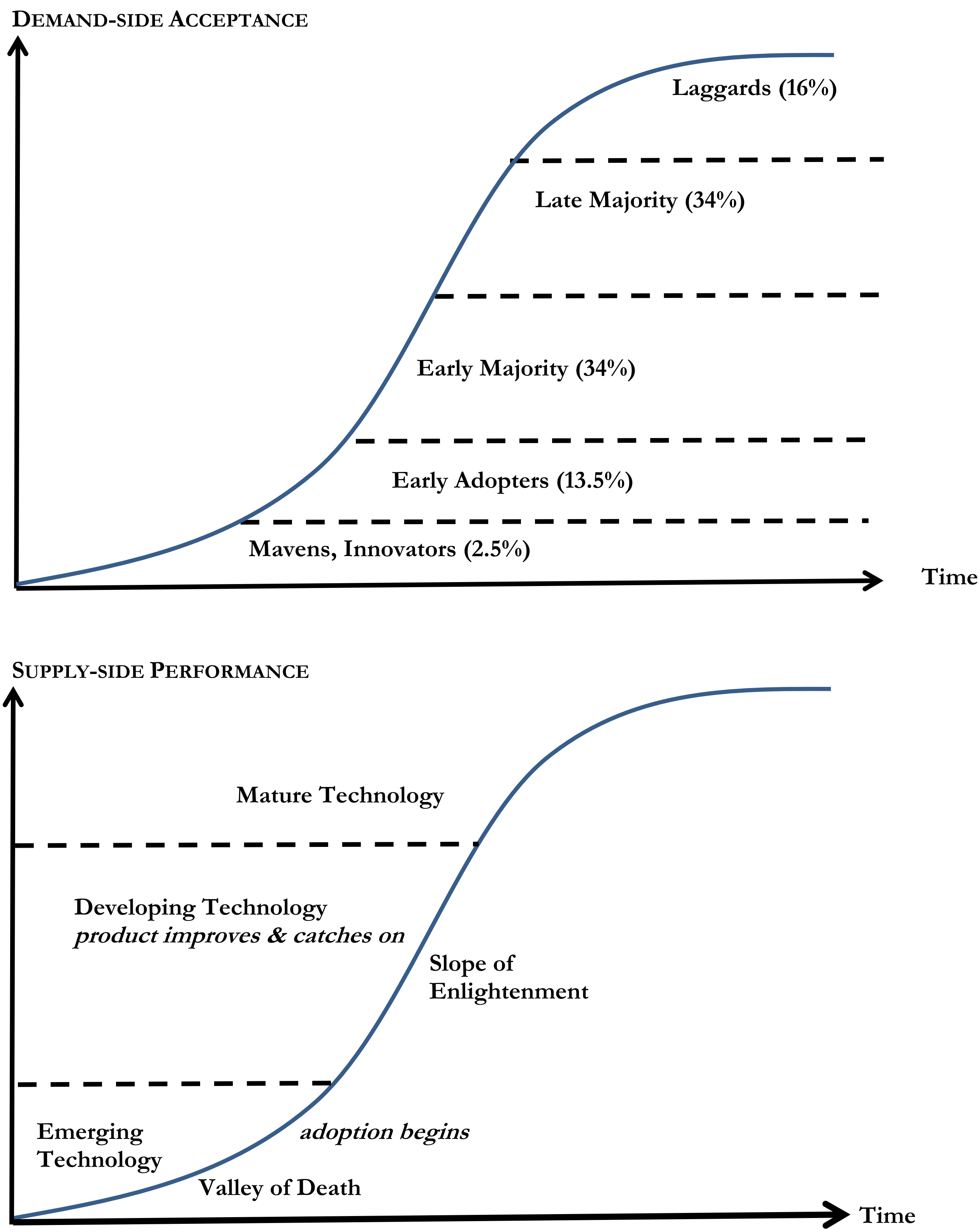
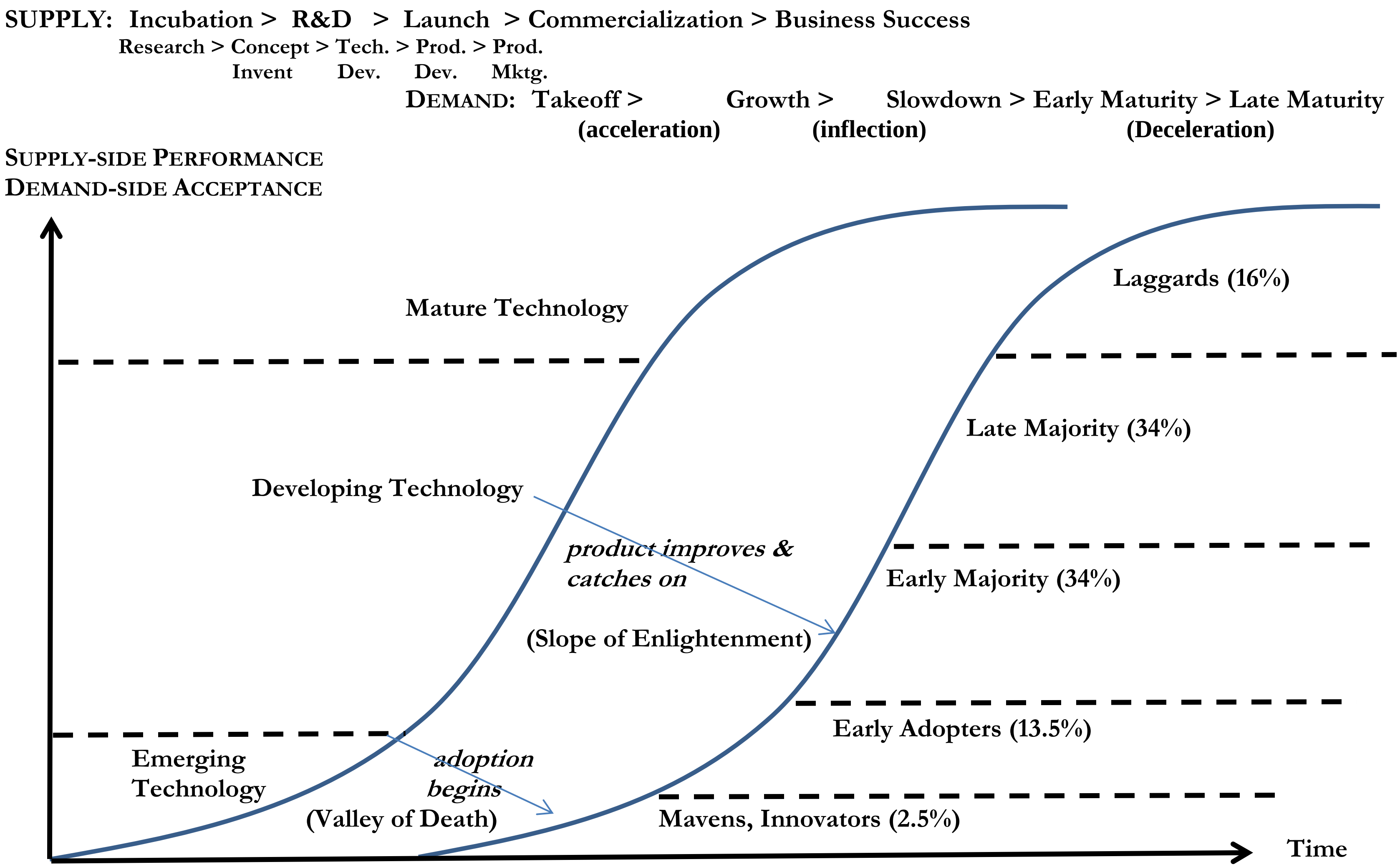


Figure III-2: The Interaction of Supply and Demand in the Creation/Diffusion of Innovative Technologies



> Technological diffusion can be defined as a mechanism that spreads successful varieties of products and processes through an economic structure and displaces wholly or partly the existing 'inferior' varieties. While the process of invention and innovation are necessary preconditions for the development of a new technology, it is the process of diffusion that determines the extent to which the new technology is being put to productive use.[50]

The bottom line was a call for balance, "What is needs to be achieved in the field of diffusion research now is a *Balance* between the two archetypical modeling mechanisms of diffusion, their underlying assumptions, and the postulated modes of interaction."[51]

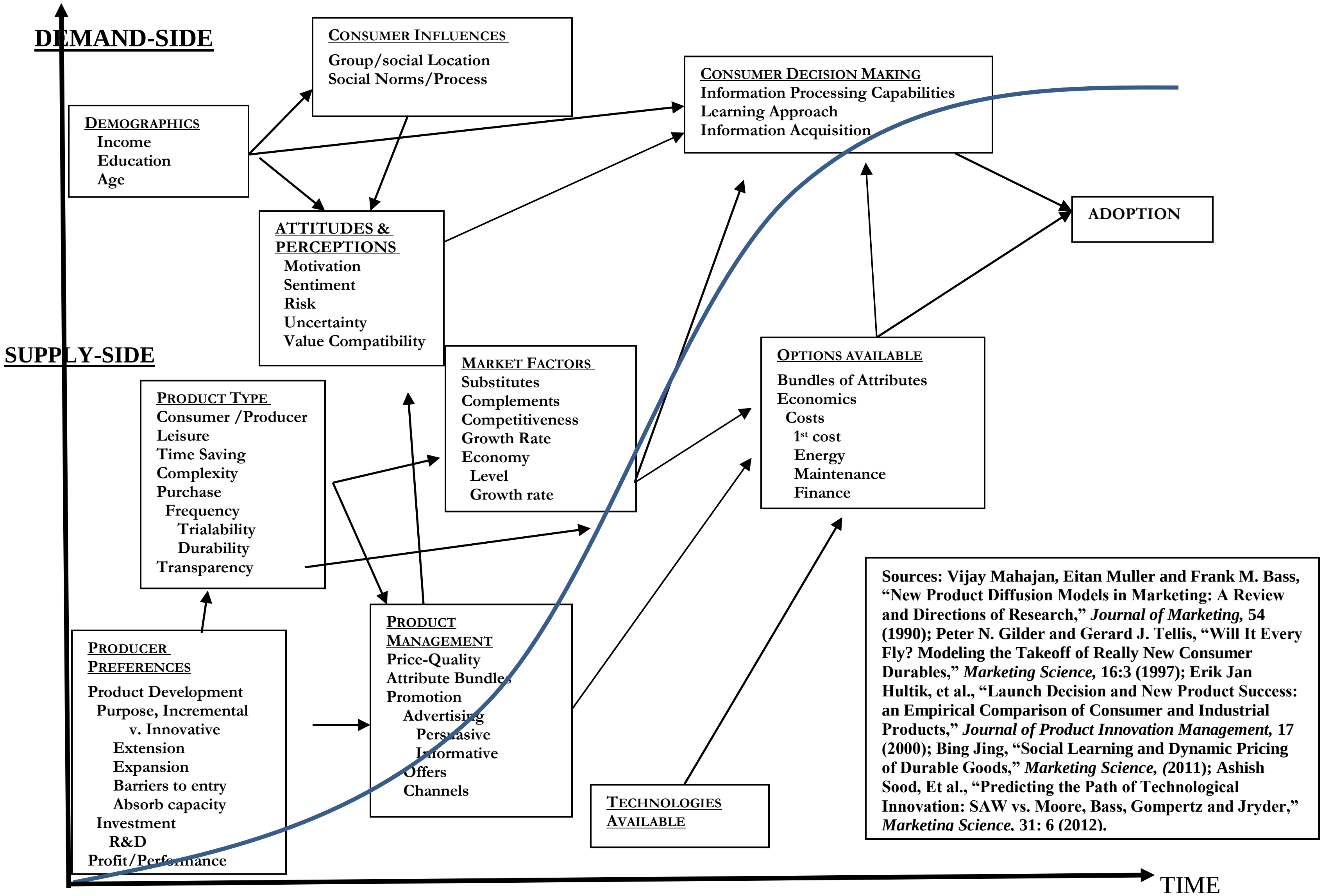
Figure III-3 shows the factors that have been identified as affecting the diffusion process. The challenge of diffusion is first, and foremost, a matter of supply-side innovation. This is a perspective that had been significantly under-analyzed in the efficiency gap literature. The assumption frequently made, particularly among the critics of the efficiency gap is that the demand-side totally dominates the outcome, with suppliers, passively responding to consumer demand. This unbalanced approach has been rejected in the broader literature on the diffusion of innovation. To put the matter simply, consumers cannot adopt technologies until they are offered to them in the marketplace. Innovation must precede diffusion.

> Marketing literature has traditionally portrayed new product development as essentially a market/consumer-led process, but paradoxically, many, major market innovations appear in practice to be technology driven, to arise from a technology seeking a market application rather than from a market opportunity seeking a technology. This, of course, is the antithesis of the marketing concept, which is to start with the customer, then design something to meet his needs. While this may be intuitively reasonable, and indeed appropriate in a market where changes are slow and can reasonably be anticipated, it may be less appropriate in faster changing markets with higher technology content. However, for successful technology-driven market development, in addition to a technological discovery, there needs to be an element of insight as to how it should be applied… It would seem that innovation is fundamental to the strategic management of businesses, but that it is a complex and potentially risk-laden activity… No doubt the debate over the extent to which radical innovation is caused by "technology push or by "market pull" will continue [52]

Recognition of the importance of the supply-side also reflects a greater emphasis on the role of entrepreneurship and management in the innovation process because "takeoff is not instantaneous and requires patience and careful planning on the part of managers."[53] Management faces a variety of challenges in shepherding innovative technologies to business success.[54]

[50] Sarkar, 1998:131.
[51] Sarkar, 1998:167.
[52] Brown, 1992, p. 65.
[53] Gilder and Tellis, 1997, p. 267.
[54] Gilder and Tellis, 1997, p. 267. [O]ther variable may also help explain the takeoff of new durables… technological change, product quality, relative advantage of the new product over substitute products, availability of complementary products that increase the utility of the new product, and the number of competitors.

FIGURE III-3: CAUSAL FACTORS THAT DRIVE THE SUPPLY AND DIFFUSION OF INNOVATIVE PRODUCTS



Management can have different motives for technology innovation and use different tools to increase the likelihood that the technology will achieve a large enough market to be profitable.[55] Entrepreneurs make the decisions about what technologies to develop and products to market, as well as how those products are priced, brought to market and promoted. They do so in response to their perception of the market they are located in and their understanding of consumers, as well as their own preferences. Their ability to perform these activities is neither perfect nor uniform.[56]

Of course, the demand side is important too. The causal factors on the demand-side of the diffusion process are presented in the upper part of Figure III-3. The literature identifies four broad categories of factors that affect adoption on the demand side: demographics, social influences, attitudes and the ability to make calculations. Because of its focus on the consumer adoption decision, the diffusion literature was very sensitive to causal factors that drive diffusion, factors that are grounded in behavioral economics including: "Perception: Type of Uncertainty, Uncertainty Model, Preference Structure: Attributes, Risk Attitude, Adoption Decision Rules: Maximize Expected Utility, Learning: Model, Sources of Information."[57]

On the demand side, the assumption is that the underlying process "is a social learning process which results in consumers slowly changing their attitudes and values… some individuals change their views quicker than others; it is a "rolling snowball" phenomenon which

[55] Gilder and Tellis, 1997, p. 267 Increasing the rate of price reduction *increases the peak probability* of takeoff in each curve, as well as *advances the time* at which the peak occurs. Ironically, as Hultik, et al., 2000, p. 5, point out, the advice given to management in the standard texts does not reflect the findings of the analysis of innovation diffusion, "The relationship found in these data between success and launch decisions differ quite markedly from the standard normative prescriptions… None of the extensive advice provided in the normative literature on competitive or innovation strategy decisions, as found, in this research, to be associated with success. Additionally, a number of strategic objectives related to success for consumer goods were identified in this study, none of which are mentioned in the normative literature."

[56] Gilder and Tellis, 1998, pp. 263-264. "No matter how inexpensive the product is, or how high consumers' incomes are or how strong consumer sentiment is, the likelihood of purchase still increases as products become more visible and available to consumers. Widespread distribution will lead to higher market presence and will tend to increase the likelihood of new product success. Market presence reflects the opportunities that potential consumers have to observe a product. These opportunities occur in several ways. First, as sales increase, interest and excitement among consumers about a product increases… Second, as sales of a product increase, retail promotions will increase leading to enhanced visibility. Since store displays are designed to attract consumers' attention and led to sales, retailers promote products they know consumers have some interest in buying. Therefore, products capable of accomplishing this objective are those that already have a demonstrated sales record. Third, as sales increase, the number of stores carrying a product will increase leading to enhanced visibility. Once consumers begin to buy a new product, additional stores carry that product." These authors conclude that "Individual level diffusion models or models that combine economic and communications elements seem especially promising," pointing to a number of studies including Chatterjee and Eliashberg, 1990; Horky, 1990' Kalish, 1985; Lattin and Roberts, 1989. Brown, 1992: 73, "Consider, for example, the development of the market for pocket calculators… The first purchasers were engineers and scientists because they had extensive can complex calculations to perform and existing technology (the slide rule and the log table)… As the early manufacturers of calculators began to benefit from technological advances and from economies of experience and scale prices began to fall. Calculators then began to become attractive to accountants and other commercial users… Compared to engineers and scientists, accountants and commercial users have a lower utility value and could only justify purchase when the price came down… As calculator prices fell still further, so they began to become attractive to the general public. Of course, the utility value to these users was lower than to commercial users, but again the potential larger."

[57] Mahajan, Muller and Bass, 1990: 6-7.

starts with just a few people and gets bigger as it gathers momentum."[58] The demand side approach looked both at the aggregate level of penetration and the individual adoption decisions.

> [A]ttempts have been made… to develop diffusion models by specifying adoption decisions at the individual level. In these models… a potential adopter's utility for an innovation is based on his uncertain perception of the innovation's performance, value or benefits. The potential adopter's uncertain perception of the innovation, however, changes over time as he learns more about the innovation from external sources (e.g., advertising) or internal sources (e.g., word of mouth). Therefore, because of this learning, whenever his utility for the innovation becomes greater than the status quo, (he is better off with the innovation), he adopts the innovation. [59]

In Figure III-4 I have adapted a recent application of the diffusion of innovation approach to adaptation to climate change that fits well into this framework above framework. The diffusion process is seen as going through five phases from research and development to diffusion. The key tasks or challenges to be overcome that affect the flow of the process are technology selection, predominantly a supply-side issue, and technology adoption, a demand-side issue. Six sets of factors are seen as influencing the outcome of these two tasks. Technology and user characteristics and the social context are the dominant factor what affect both technology selection and diffusion. There are many themes common to the framework in the efficiency gap literature.

B. THE IMPORTANCE OF TRANSACTION COSTS AND BEHAVIORAL FACTORS

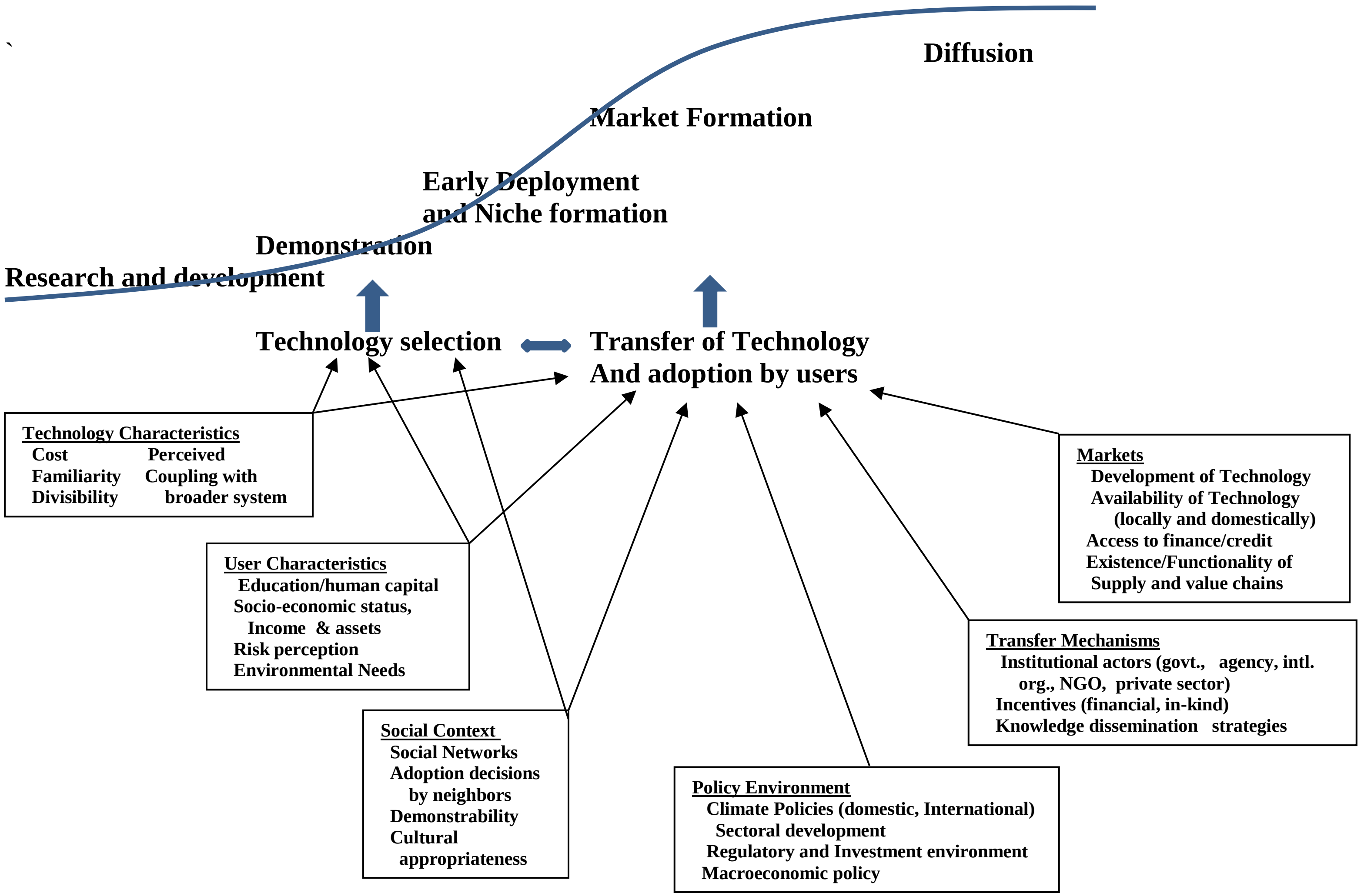
The larger field of the analysis of innovation diffusion has grappled with exactly the same issues that we have seen in efficiency gap analysis. A major source of tension in the innovation diffusion field flows from the approach to modeling behavior and process, which is similar to the tension that has typified the efficiency gap literature: the efficient market hypothesis underlying neoclassical economics v. institutional, transaction and behavioral economics views of imperfect markets.

> The issue relates to whether the diffusion process should be formalized as [*neoclassical equilibrium*]… with diffusion patterns reflecting a sequence of shifting equilibria over time in which agents are fully adjusted…modeled as being infinitely rational and fully informed… or as a disequilibrium process… modeled as being constrained by lack of information or understanding on the part of adopters about the worth of an innovation.[60]

The dramatic difference between the approaches to the analysis of innovation diffusion parallels the division in the efficiency gap debate closely, as shown on the in the side-by-side comparison of the two dominant approaches to different summarized in Table III-1 shows. As described in a 1998 survey of the literature (published two years after the major LBL analysis presented by Golove and Eto), the two schools of thought differ on the quality of information, nature of rationality, extent of disequilibrium and the possibility of inefficiency.

[58] Brown, 1992, p. 62.
[59] Mahajan, Muller and Bass, 1990, pp. 6-7.
[60] Sarkar, 1998:132.

FIGURE III-4: MODEL OF TECHNOLOGY TRANSFER AND ADOPTION EMPHASIZING IMPORTANCE OF TECHNOLOGY SELECTION AND TRANSFER FOR ADOPTION



Source: Bonizella Biagini1, et al.,"technology transfer for adaptation," Nature Climate Change, 4 (2014), p. 829.

TABLE III-1: DECISION THEORETIC APPROACHES TO MODELING DIFFUSION

	Neoclassical Equilibrium	Evolutionary Disequilibrium
Scientific Analogy	**Newtonian mechanics**	**Evolutionary Biology**
Assumptions:	**Full/limited information**	**Necessarily limited-information**
	Infinite rationality	**Bounded rationality**
	Equilibrium mechanism	**Disequilibrium mechanism**
	Exogenous/endogenous	**Necessarily endogenous**
	Continuous & Quantitative	**Continuous & Quantitative (Darwinian)**
		Discontinuous & qualitative (non-Darwinian)
Characteristics of the	**Predictable**	**Unpredictable**
Diffusion Process	**Ahistorical**	**Path-dependent (historicity)**
	Efficient	**Efficient (Darwinian)**
		Possible inefficiency (non-Darwinian)

Source: Jayati Sarkar, "Technological Diffusion: Alternative Theories and Historical Evidence, *Journal of Economic Surveys*, 2: 1998, p. 149.

The broad critique of the neoclassical economic model that echoes in the efficiency gap debate rested primarily on the fact that the underlying assumptions of infinitely rational/fully informed actors in the neoclassical model does not fit real world behaviors at all.

> As Simon stressed in his Nobel Memorial Lecture, the classical model of rationality requires knowledge of all the relevant alternatives, their consequences and the probabilities, and a predictable world without surprises. These conditions, however, are rarely met for problems that individuals and organizations face. Savage, known as the founder of modern Bayesian decision theory, called such perfect knowledge small worlds… In large worlds, part of the relevant information is unknown or has to be estimated from small samples, so that the conditions for rational decision theory are not met, making it an inappropriate norm for optimal reasoning. In a large world…one can no longer assume that "rational" models automatically provide the correct answer.[61]

The effort to understand the complex influences on human behavior has moved well beyond the simple "rational v. irrational" dichotomy.[62] The middle ground recognizes that "intelligent choice," "useful inferences" and "smart" decisions are possible without reference to "the classic model of rationality."[63] "Ecological rationality" is a term applied to this middle ground that recognizes the limitations imposed on choice by the environment and the capacity of individuals to make decisions.

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[61] Gigerenzer and Gaissmaier, 2011, p. 453.

[62] However, stepping back from the assumption of perfect rationality can lead to an overemphasis on the irrational, or error in decision making. Hoffrage and Reimer, 2004, p. 456 "[H]euristics were invoked as explanation for systemic errors found in human reasoning – mainly deviation from the laws of probability. Although Tversky and Kahneman repeatedly asserted that heuristics sometimes succeed and sometimes fail, they and many of their colleagues focused on the latter category and interpreted their experimental findings as indicating some kind of fallacy…."

[63] Hoffrage and Reimer, 2004, p. 456, "Fast and frugal heuristics, in contrast, are not associated with the value laden term bias. On the contrary, by taking advantage of the structure of information in the environment, these heuristics can lead to accurate and useful inferences; hence they do not necessarily lead to biases but they can "make us smart." Gigerenzer and Gaissmaier, 2011, p. 473 quoting James March [I]f behavior that apparently deviates from standard procedures of calculated rationality can be shown to be intelligent, then it can plausibly be argued that models of calculated rationality are deficient not only as descriptors of human behavior but also as guides to intelligent choice.

> The study of ecological rationality is related to the view that human cognition is adapted to its past environment. [64]
>
> In a complex and uncertain world, humans draw inferences and make decisions under the constraints of limited knowledge, resources, and time…. These heuristics perform well because they are ecologically rational: they explore the structure of environmental information and are adapted to this structure.
>
> Models of ecological rationality describe the structure and representation of information in actual environments and their match with mental strategies, such as bounded rational heuristics. The simultaneous focus on the mind and its environment, past and present, put research on decision making under uncertainty into an evolutionary and ecological framework, a framework that is missing in most theories of reasoning, both descriptive and normative.[65]

If the baseline assumption of infinite rationality and full information is as far from reality as this discussion suggests, it is reasonable to argue that the baseline should shift to a set of assumptions that are closer to reality. This would make it more likely that the model will avoid the error of assuming that a little more information fed into a context where the underlying forces are almost right will solve the problem. It will avoid the Mercatus Center mistake.[66]

Recognizing the environmental and cognitive constraints on decision making shifts the focal point of the analysis to internal criteria of performance. The focus of study shifts to the origin and impact of constraints on decision making and the tools humans use to make decisions under those constraints.

> Within ecological rationality it is of utmost importance to look at how the environment influences the tasks and how the environment shapes and has shaped the cognitive capacity of social actors. Humans have an evolutionary past in which they constantly learned and adapted to the biological and social environment and this shaped their cognitive capacities… In addition, humans are not error free and, even more importantly; they face a wide range of tasks in a modern technological environment.[67]

C. Market Barriers and the Innovation Diffusion Process

Figure III-5 locates impediments to diffusion in the broad categories of market failure identified in in the "efficiency gap" analysis of Chapter II. I locate the barriers and imperfections at different points in the flow of innovation/diffusion. I include the three major types of behavioral factors on both the supply-side and the demand side.

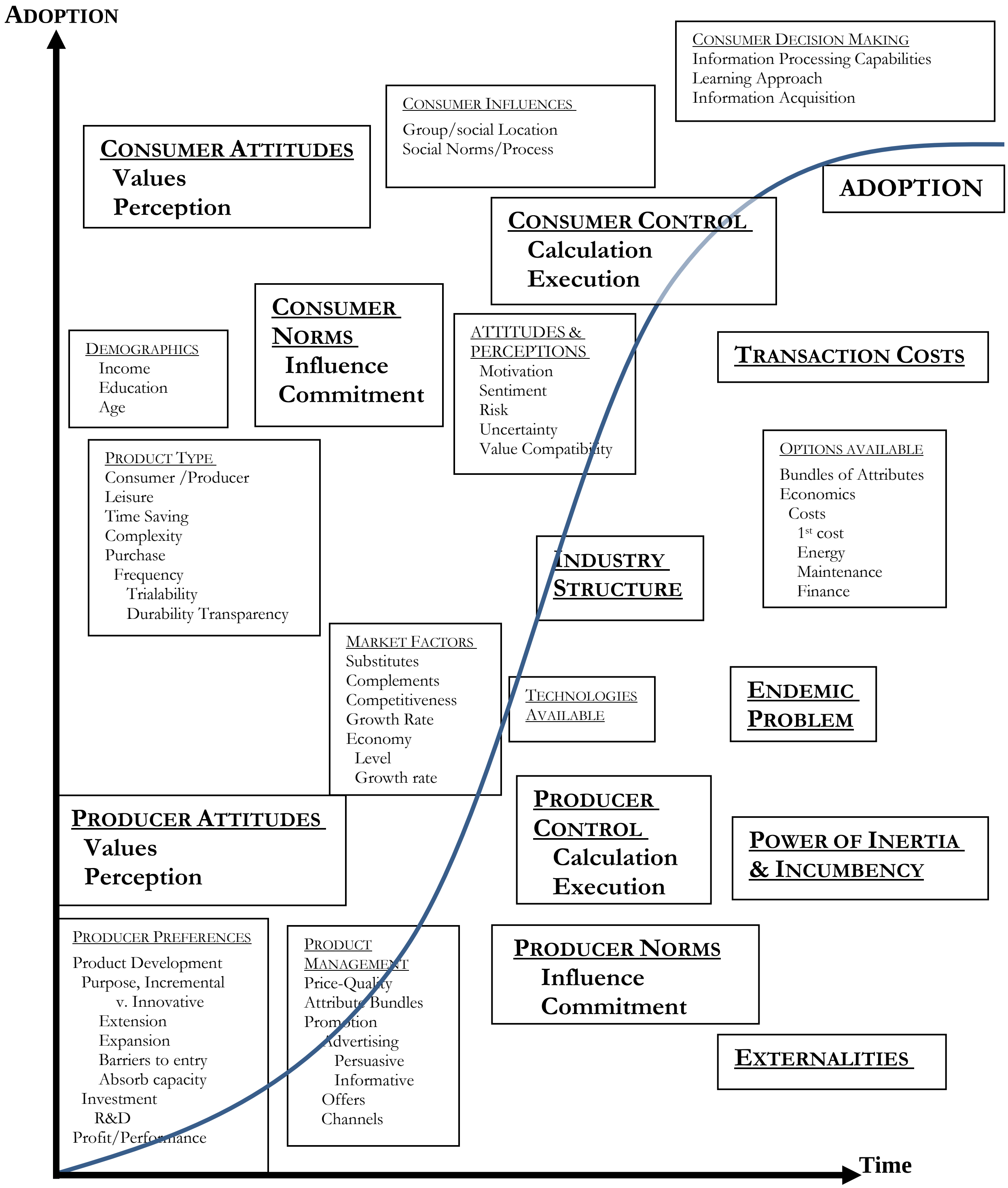
Figure III-5: Market Barriers and Imperfections and the Causal Factors that Drive the Supply and Diffusion of Innovation

[64] Gigerenzer and Gaissmaier, 2011, 2011, pp. 457-458.

[65] Hoffrage and Reimer, 2004, p. 442 cited in Basel and Bruhl, 17-1; Hoffrage and Reimer, 2004, p. 443.

[66] Hoffrage, and Reimer, 2004, p. 437, From such a perspective it is straightforward to study the adaptation of mental and social strategies to real-world environments rather than compare strategies to the norms of probability theory (e.g., *Bayes's rule*, which can be used to update prior beliefs in the light of new data) and logic (e.g., the *conjunction rule*… Rather, the performance of a heuristic is evaluated against a criterion that exists in the environment – the distinction between internal consistency versus external correspondence.

[67] Basel and Bruhl, 2011, p. 19.



Arguably, the supply- side is less affected by these factors, since the assumption of profit (welfare) maximizing economic enterprises fits the supply-side better. However, the fit is certainly not perfect and several of the barriers that we observe on the supply-side, like status quo bias and internal structural constraints fit in the behavioral arena. I also include the power of inertia and incumbents on both the supply and demand sides of the market.

The central questions in the efficiency gap analysis involve the process of the adoption of new technologies. Treating the efficiency gap as a special case of the diffusion of innovations allows us to draw on the much broader study of the factors that affect the speed with which technologies are developed and sold to the public. By examining some of the key themes and developments in innovation diffusion literature, we deepen the understanding of the efficiency gap.

- The literature emphasizes the importance of the supply-side, which had not received sufficient attention in the efficiency gap literature because of the focus on consumer behavior.
- The literature identifies the factors that account for slow innovation and diffusion on both the supply and demand sides of the market.

The innovation diffusion literature exhibits concerns about factors that affect adoption that are similar to the market imperfections and barriers identified in the efficiency gap literature.

IV. THE CLIMATE CHANGE LITERATURE

The climate change analysis reviewed in this chapter reinforces the lessons of the efficiency gap and innovation diffusion literatures. The climate change literature has squarely confronted the problem of market barriers and imperfections that affect innovation and diffusion of new technologies. In order to induce rapid change in economic activities, policy must overcome the inertia created by established investment and behavior patterns built up over decades. The set of factors that underlies the inertia to respond to climate change are similar to and magnifythe market barriers and imperfections that underlie the efficiency gap. Targeted innovations and induced technological change are advocated.

Over the course of the last decade, the climate change analysis has come to highlight the question of the extent to which market processes through the reaction to price increases can be relied upon, or policies that seek to direct, target and accelerate technological innovation and diffusion are needed. The evidence suggests that the cost of inertia is quite large, whereas targeted approaches lower costs and speed the transition.[68]

Thus, the debate among economists grappling with the analysis of climate change replicates and parallels the efficiency gap debate. The conceptual and empirical analysis of climate change adds a great deal of evidence to reinforce the conclusions about the barriers and imperfections that affect energy markets. Because the potential external costs are so large, climate change puts a spotlight on technological innovation. The growing concern over adjustment leads to concern over an “innovation gap.”[69]

A. OVERCOMING INERTIA AND ENDING THE IMPLICIT SUBSIDY ON FOSSIL FUELS

Because decarbonization is such a large commitment, placing the decision to decarbonise in a broader historical context provides an important perspective to help appreciate both the challenge and the opportunity. The existing structure of resources centered on fossil fuels has been in place for a long period and has a great deal of inertia on its side. Change is being dictated by the decarbonization policy. Without policies to break the inertia of fossil fuels, change will not come about, or will be slower and more costly than need be.

For the past two centuries fossil fuels have been the primary form of energy that powered the industrial revolution, having replaced wind, water and draught animals directly in the 19th century and indirectly through the use of electricity in the 20th century.[70] Fossil fuels were

[68] Acemoglu, et al, 2012, pp. 132.
[69] Gross, et al., 2012.
[70] Arbuthnott and Dolter, 2013, p. 7, There is no doubt that the discovery of fossil fuels (coal, oil, natural gas), and development of the countless tools that operate by their stored energy, has been a great boon to humanity. Since the industrial revolution, fossil fuels have enabled economic growth that has greatly increased the ease and scope of life for increasing numbers of people. Much of modern civilization (i.e., cultural infrastructure and processes) is based on these technologies, and it is likely that we could not have achieved the complexity of modern civilization without them. For consumers, fossil fuel technologies supply the energy for temperature management of our buildings, the production of inexpensive food, local and global transportation, and other technological and domestic tools. For producers, fossil fuels supply both the means of production (e.g., electricity for factories), and enable global transport of inputs and products.

preferred because they were inexpensive for the power they delivered. Capitalist societies burned the cheap fuel and invested in technologies to save on other factors of production that are less abundant and more costly.

There were a number of reasons that fossil fuels were an attractive energy resource, three of which are quite relevant to the current policy context. First, fossil fuels have moderate levels of energy intensity, which means that the technologies needed to turn fossil fuels into power are comparatively simple, relatively inexpensive and extensions of existing technologies. Resources with much lower intensity require more capital investment to extract useful power. Resources with much higher levels of energy intensity require much higher levels of capital investment to control the release of power. As a result, fossil fuels required relatively little capital investment and were lower in cost.

Second, part of the relatively low cost of fossil fuels also reflected the availability of the resource in deposits that were relatively easy to exploit. In short, fossil fuels were easy to supply and easy to use. In recent years the economic cost of production of fossil fuels has begun to rise as the more easily exploited resources have been depleted.

Third, part of the relatively low cost of fossil fuels reflected a market imperfection, the failure of the market price to reflect the external costs (environmental and health effects) that fossil fuels imposed on society, which represented an implicit subsidy. About a half century ago, society began to force fossil fuels to bear some of the external costs by imposing regulations that required them to control the waste products of their consumption, like smog and the precursors of acid rain, as well as the external costs of their production. The decision to decarbonise the economy in recognition of the harm that burning fossil fuels does is a dramatic change, compared to previous policies, and it will have a much larger impact on the cost of fossil fuels.

Fourth, given the attractive economic characteristics of fossil fuels, the supremacy of fossil fuels was reinforced by massive investment in infrastructure to support their production and use. The massive enterprise, which protected a vital input to economic activity, also came to have an immense amount of political clout, which secured explicit and implicit subsidies to further reinforce their economic position and power.

If the only barrier to an efficient response to the end of the implicit subsidy for fossil fuels was the internalization of the cost of carbon, policy makers could just impose a substantial tax on carbon and let the marketplace work. Unfortunately, that simple approach will not be effective because the electricity market is plagued by other significant barriers and imperfections. Many of the market barriers and imperfections identified in the efficiency gap literature will afflict the transition away from fossil fuels and these will be magnified by two centuries of inertia behind fossil fuels.[71]

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[71] Popp. Newell and Jaffe, 2010, p. 877, "The generation of knowledge through the innovative process contrast sharply with the negative externalities from pollution. Because of the public goods nature of knowledge, a firm that invests in or implements a new technology typically creates benefits for others while incurring all of the costs. The firm therefore lacks the incentive to increase those benefits by investing in technology… Technology creates positive externalities, and so the invisible hand of the market produces too little of it."

B. THE ECONOMIC DEBATE IN THE CLIMATE POLICY ARENA

The intense interest in the issues of barriers to change has broken through to the popular press, as demonstrated by a report by Ryan Avent, the Washington-based economic correspondent for the *Economist.* Reporting on "a great session on climate policy"[72] focused on "the environment and directed technical change." Avent noted that it suggested

> [E]conomics is clearly moving beyond the carbon=tax alone position on climate change, which is a good thing. If the world is to reduce emissions, it needs technologies that are both green and cheap enough to be attractive to economically-stressed countries and people. And a carbon tax alone may not generate the necessary innovation… [T]he carbon externality isn't the only relevant externality in the mix. There is another important dynamic in which technological innovation draws on previous research, and so firms are more likely to continue on established innovation trajectories than to start new ones."[73]

About a year later, David Leonhardt, an economic columnist for the New York Times, discussed the practical implications of the growing recognition of the challenge of overcoming inertia and closing the "innovation gap."

> "Over the last several years, the governments of the United States, Europe and China have spent hundreds of billions of dollars on clean-energy research and deployment. And despite some high-profile flops, like ethanol and Solyndra, the investments seem to be succeeding more than they are failing… The successes make it possible at least to fathom a transition to clean energy that does not involve putting a price on carbon — either through a carbon tax or a cap-and-trade program that requires licenses for emissions… To describe the two approaches is to underline their political differences. A cap-and-trade program sets out to make the energy we use more expensive. An investment program aims to make alternative energy less expensive… Most scientists and economists, to be sure, think the best chance for success involves both strategies: if dirty energy remains as cheap as it is today, clean energy will have a much longer road to travel… Still, the clean-energy push has been successful enough to leave many climate advocates believing it is the single best hope… Governments have played a crucial role in financing many of the most important technological inventions of the past century. That's no coincidence: Basic research is often unprofitable. It involves too much failure, and an inventor typically captures only a tiny slice of the profits that flow from a discovery. Although government officials make mistakes when choosing among nascent technologies, one success can outweigh many failures."[74]

An exchange in *Energy Economics* provides background and a direct link from the climate change debate to the central issue of the market imperfection/barrier framework. It was set up as a debate between William Nordhaus and Jon Weyant who offered contrasting points of view, with Roger Noll commenting. Table IV-1 summarizes the market barriers and imperfections identified in the exchange between Nordhaus, Weyant and Noll. It sorts the specific barriers into six generic categories that I have identified in the efficiency gap literature.

Nordaus' defense of what he calls the "price fundamentalism" approach to climate change analysis and policy making concedes a long list of exceptions to "price fundamentalism"

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[72] Avent, 2011.
[73] Avent, 2011.
[74] Leohhardt, 2013.

that are seen as extremely important by a growing number of energy analysts. [75]

TABLE IV-1: MARKET BARRIERS & IMPERFECTIONS: NORDHAUS, WEYANT AND NOLL

SOCIAL EXTERNALITIES
Sufficiently high & "right" price on the externality
Other externalities
Research & Development
- Non-profit
- Private Appropriability
  - Process innovation
  - Transparency of innovation
  - Institutional innovation

Network Effects
Global Connections

ENDEMIC PROBLEMS
Asymetrric (Strategically Withheld) Information
Principle Agent problems
Lack of financing opportunities
Insufficient incentive to make optimal investment

BEHAVIORAL
Consumer Decision Making Limitations
- Knowledge
- Time
- Calculation

TRANSACTION COSTS
Uncertainty
Risk
Information
- Lack
- Difficulty

MARKET STRUCTURE
Large Scale
Oligopolistic structure
Regulation

POLITICAL
Incumbent incentives to delay
Political inability to sustain tax

Source: Author, see text.

> Getting the price of carbon right is fundamentally important for stimulating innovations in technologies to mitigate global warming. The major necessary condition for ensuring that climate friendly innovation occurs is that the price of carbon is sufficiently high…Under very limited conditions, setting carbon prices to reflect the damages from carbon emission is also a sufficient condition for the appropriate innovation to be undertaken in market-oriented sectors. This conclusion, which I have labeled "price fundamentalism," must be qualified if the price is wrong and for those parts of research that are not profit-driven (particularly basic research), and when energy investments have particular burdens such as networking or large scale…
>
> If the environmental externality is mispriced, the marginal social return to green investment will be misaligned with those in normal industries…
>
> Technology policy may not optimally internalize the innovation spillovers. This may occur because appropriability differs across sectors and technologies and perhaps even within technologies. It is clear that appropriability is low for fundamental research. Some economists believe that appropriability is low for process (as opposed to product) innovations, transparent (as opposed to easily hidden) innovations, administrative or institutional (as opposed to production) innovations, and networked (as opposed to stand-alone) innovations…

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[75] Sometimes the exception proves the rule. That is the case when the exception is rare and demonstrates the robustness of the rule's underlying assumption. However, when the exceptions are numerous and important, they are more likely to consume the rule than prove it. Wikipedia, "Scientific sense: A case may appear at first sight to be an exception to the rule. However, when the situation is examined more closely, it is observed that the rule does not apply to this case, and thus the rule is shown to be valid after all." Wikipedia, http://en.wikipedia.org/wiki/Exception_that_proves_the_rule The statement may also be an argument that the initial rule is flawed, and instead the exception should be the rule….: "Exception that was successful enough to create a new rule or prove the assumed rule was flawed". It could also be argued the rule simply changed." http://en.wikipedia.org/wiki/Exception_that_proves_the_rule

> A final important qualification is that this analysis applies primarily to research that is profit-oriented… One issue involves sectors that have a substantial component of not-for-profit research…A second important question is where government should draw the line between areas that are viewed as appropriate for not-for-profit support and those that are governed by the market...
>
> Most other possible qualifications turn out to be specific applications of one of the first three.
>
> [Qualification 1]… Energy production has many other externalities… Energy technology has a particularly global dimension.
>
> [Qualification 2]… Green innovations have important network characteristics… Green innovations require especially large investments (or involve a large component of basic research, or have great inertia)… Outcomes of energy research are highly uncertain.[76]

What Nordhaus calls qualifications are frequently called market imperfections or barriers. Weyant starts with the R&D imperfection.

> This lack of "appropriability" of the benefits of one's own innovation creates a strong motivation for public support of R&D. Such support augments the extent to which simply increasing the price of clean energy relative to that of dirty energy induces innovation. A number of studies… estimate the social rate of return for innovation expenditures at approximately double the rate of return on private R&D expenditures… a close look at the energy sector industries and their potential entrants leads to the conclusion that they are industries where appropriability is difficult.[77]

However, Weyant elaborates on and goes well beyond the list of qualification offered by Nordhaus. He sees several additional supply-side problems.

> A close look at the energy industries and their potential entrants leads to the conclusion that… entry is risky and expensive, market organization is more likely to be oligopolistic than perfectly competitive, and information is strategically held and difficult to obtain…
>
> Further complicating matters, existing companies in energy-related industries --- those that produce energy, those that manufacture the equipment that produces, converts and uses energy, and those that distribute energy – can have substantial incentives to delay the introduction of new technologies. This can happen if their current technologies are more profitable than the new ones that might be (or have been) invented, or if they are in explicitly (oil and gas) or implicitly (electric generation equipment producers and automakers) oligopolistic structured, or if they are imperfectly regulated (electric and gas utilities). The incentive arises partly because the infrastructure for producing, distributing, and promoting the industries' current products require large investments that have already been incurred.[78]

He also looks beyond the early phases of research and development on which Nordhaus focuses and notes market imperfections that may retard the adoption and diffusion of technologies on the demand-side.

> Imperfections in the market for energy-converting and energy-consuming equipment may be impeding the rate of diffusion of new technologies that are already economically competitive

[76] Nordhaus, 2011, pp. 672… 670-671.
[77] Weyent, 2011, pp. 675.
[78] Weyent, 2011, pp. 677.

> and welfare improving. This situation can result for several different types of market failure, including poor or asymmetric information available to purchasers, limits on individual's ability to make rational decisions because of time or skill constraints, principal-agent incongruities between building owners and building residents, and lack of financing opportunities.[79]

Roger Noll looks at the contrasting views and concludes that

> Superficially, these messages conflict, but both are offered with sufficient caveats that, with minor amendments, these articles provide the right approach to near-term U.S. climate policy. Here I elaborate on the amendments that integrate these articles.[80]

His amendments add important considerations that further complicate the terrain of policymaking.

> In principle, one could impose taxes on GHG emissions that correct for information imperfection, coordination failures, and market concentration, but the financial cost to consumers of using price instruments to overcome these problems plausibly could be too high to be politically feasible and higher than the cost of simply subsidizing green energy R&D…
>
> In the absence of targeted government interventions utilities are unlikely to make socially optimal investments in these technologies simply on the basis of an optimal emissions tax and a general R&D subsidy… potential entrants face a problem that, for the foreseeable future, the infrastructure is… a complement as well as a substitute… Thus, efficient diffusion of new green technologies requires involving the incumbents.[81]

Noll worries about the "misapplication of a valid principal," and cautions that "the key question is how much delay in the commercialization of new green technologies likely to occur even if Pigovian taxes and subsidies are imposed. The answer to this question remains unclear." While the available answer is not precise, the evidence discussed below suggests that the cost of inertia is quite large and targeted approaches lower costs and speed the transition.[82]

C. Comprehensive Frameworks

Figure IV-1 combines the market barriers and imperfections frameworks from comprehensive frameworks offer by analysts at Resources for the Future and Oak Ridge National Laboratory. have offered a comprehensive examination of policy options to address climate change. Similar to Nordhaus, the RFF analysis tends to emphasize the more traditional barriers – externalities, market structure and transaction costs. The analysis conducted by Oak Ridge National Laboratory was in response to a congressionally mandated "report describing barriers to GHG [Greenhouse Gas] intensity reducing technologies. It covers 15 technologies that would affect four goals "reducing emissions from energy end use and infrastructure, reducing emissions from energy supply, capturing and sequestering carbon dioxide, and reducing emissions of non-CO_2 GHGs."

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[79] Weyent, 2011, pp. 675.
[80] Noll, 2011, pp. 683.
[81] Noll, 2011, pp. 685.
[82] Acemoglu, et al, 2012, pp. 132.

FIGURES IV-1: MARKET BARRIERS AND IMPERFECTION IN CLIMATE CHANGE ANALYSIS

Resources for the Future

EXTERNALITIES
Knowledge Externalities that are not captured by markets, a, *a*
Research and Development b
Importance of learning by searching c
Deployment: Importance of learning by doing c
Economics of Scale/returns to scale d
Network effects d

ENDEMIC
Principle agent *w*
Shot-term view, g, i
Incomplete markets i

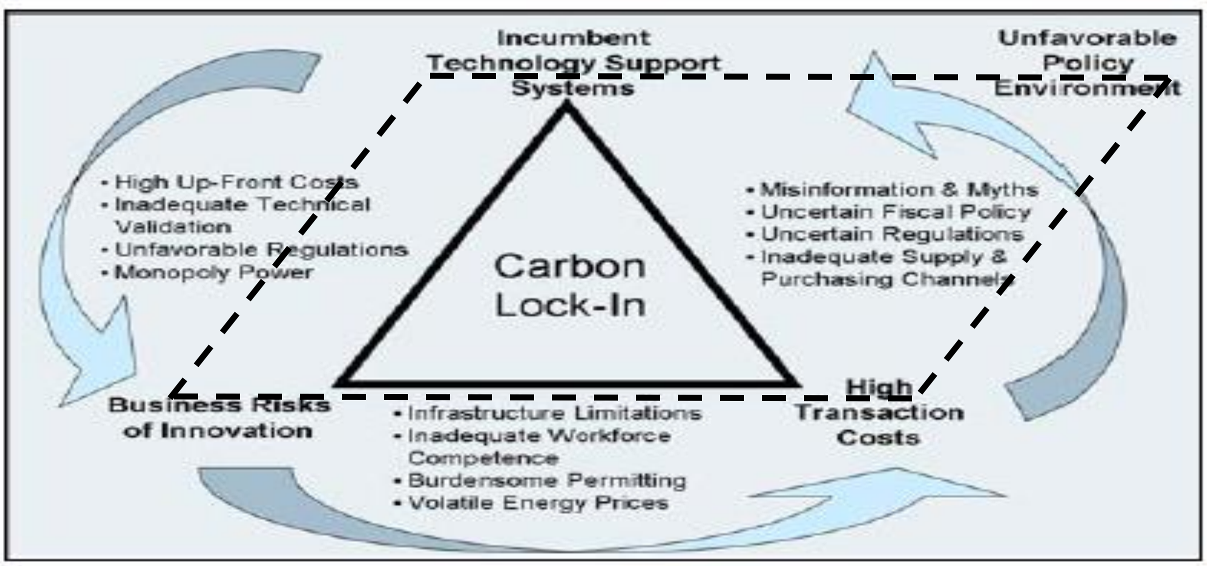
TRANSACTION COST
Uncertainty: as a cause of underinvestment *b, d, e,*
High risk premia on new technologiesf
Information: Value of information *d, f, r, s*
Sunk costs and embedded infrastructure

MARKET STRUCTURE:
Cost Structures: Long investment cycles, increasing returns to scale, network effects e, j, *b*
Challenge of creating new markets: Undifferentiated product i
Lack of competition hinders innovation *h*
Regulatory Risk g, j, *g, j, k, l, x*
Carbon tax level and permanence g
Fiscal policy *g*

POLITICAL POWER
Monopolistic structures and lack of competition *u*
INERTIA:
Cost of Inertia 1

POLICY
Lack of leadership, *x*
Statutory, *k, l, o, p*

Oak Ridge



CAUSES OF CARBON LOCK-IN

Business Innovation Risk/Cost Effectiveness and Fiscal Barriers
Technical risk
Volatile Energy Prices
Market risk
High up-front costs

Transaction Costs
Inadequate workforce/infrastructure
Misinformation
Imperfect information
Lack of specialized
Inadequate validation
Volatile Energy Prices

Policy Obstacles – Regulatory/ Statutory barriers
Unfavorable policy environment
Unfavorable regulation
Uncertain Regulations
Burdensome Permitting
Uncertain/Unfavorable fiscal policy
Misplaced incentives

Incumbent Support
Industry structure
Inadequate supply chain
Monopoly power

Source:
Lower case letters (a) from Raymond J. Kopp and William A Pizer, *Assessing U.S. Climate Policy Options* (Washington, D.C.: November 2007)

***Italicized Letters (a) are from* Marylin A. Brown, et al., *Carbon Lock-In: Barriers to Deploying Climate Mitigation Technologies*, Oak ridge National Laboratory, January 2008.**

a) Public Goods: Similarly, rationales for public support of technology demonstration projects tend to point to the… inability of private firms to capture the rewards for rewards for designing and constructing first-of-a-kind facilities. (p. 120)

(b) R&D tends to be underprovided in a competitive markets because its benefits are often widely distributed and difficult to capture by individual firms…. economics literature on R&D points to the difficulty firms face in capturing all the benefits from their investments in innovation, which tend to spill over to other technology producers and users.. (pp. 118-120); In addition, by virtue of its critical role in the higher education system, public R&D funding will continue to be important in training researchers and engineers with the skill necessary to work in either the public or private sector to product GHG-reducing technology innovations (p. 120)… Generic public funding for research tends to receive widespread support based on significant positive spillovers that are often associated with the generation of new knowledge. (p. 136).

(c) Another potential rationale involves spillover effects that he process of so-called "learning-by-doing" – a term that describes the tendency for production costs to fall as manufacturers gain production experience."(p. 136)

(d) Network Effects: Network effects provide a motivation for deployment policies aimed at improving coordination and planning – and where appropriate, developing compatibility standards – in situations that involve interrelated technologies, particularly within large integrated systems (for example, energy productions, transmission, and distribution networks). Setting standards in a network context may reduce excess inertia (for example, the so-called chicken-and-egg problems with alternative fuel vehicles), while simultaneously reducing search and coordination costs, but standard scan also reduce the diversity of technology options offered and may impede innovation over time. (p. 137)

(e) Similarly, rationales for public support of technology demonstration projects tend to point to the large expense; high degree of technical, market and regulatory risk; and inability of private firms to capture the rewards for rewards for designing and constructing first-of-a-kind facilities. (p. 120)

(f) Finally, incomplete insurance markets may provide a rationale for liability protection or other policies for certain technology options (for example, long-term CO2 storage). (p. 137)

(g) Regulatory risk: Similarly, rationales for public support of technology demonstration projects tend to point to the… high degree of technical, market and regulatory risk. The problem of private-sector under investment in technology innovation may be exacerbated in the climate context where the energy assets involved are often very-long lives and where the incentives for bringing forward new technology rest heavily on domestic and international policies rather than natural market forces. Put another way, the development of climate-friendly technologies has little market value absent a sustained, credible government commitment to reducing GHG emissions. (p. 120)

(h) The mismatch between near-term technology investment and long-term needs is likely to be even greater in situation where the magnitude of desired GHG reductions can be expected to increase over time. If more stringent emissions constraint will eventually be needed, society will benefit from near-term R&D to lower the cost of achieving those reductions in the future. (p. 120)."

(i) Finally, incomplete insurance markets may provide a rationale for liability protection or other policies for certain technology options (for example, long-term CO2 storage, (p.137)."

(j) The problem of private-sector under investment in technology innovation may be exacerbated in the climate context where the energy assets involved are often very-long lives and where the incentives for bringing forward new technology rest heavily on domestic and international policies rather than natural market forces… "Put another way, the development of climate-friendly technologies has little market value absent a sustained, credible government commitment to reducing GHG emissions (p.12).

Cost-Effectiveness Barriers

a) External Benefits and Costs: External benefits of GHG-reducing technologies that the owners of the technologies are unable to appropriate (e.g., GHG emission reductions from substitutes for high GWP gases and carbon sequestration).

b) External costs associated with technologies using fossil fuels (e.g., GHG emissions and health effects from small particles) making it difficult for higher priced, GHG-reducing technologies to compete.

c) High Costs: High up-front costs associated with the production and purchase of many low carbon technologies; high operations and maintenance costs typical of first-of-a-kind technologies; high cost of financing and limited access to credit especially by low-income households and small businesses.

d) Technical Risks: Risks associated with unproven technology when there is insufficient validation of technology performance. Confounded by high capital cost, high labor/operating cost, excessive downtime, lack of standardization, and lack of engineering, procurement and construction capacity, all of which create an environment of uncertainty.

e) Market Risks: Low demand typical of emerging technologies including lack of long-term product purchase agreements; uncertainties associated with the cost of a new product vis-à-vis its competitors and the possibility that a superior product could emerge; rising prices for product inputs including energy feedstocks; lack of indemnification.

f) Lack of Specialized Knowledge: Inadequate workforce competence; cost of developing a knowledge base for available workforce; inadequate reference knowledge for decision makers.

Fiscal Barriers

g) Unfavorable Fiscal Policy: Distortionary tax subsidies that favor conventional energy sources and high levels of energy consumption; fiscal policies that slow the pace of capital stock turnover; state and local variability in fiscal policies such as tax incentives and property tax policies. Also includes various unfavorable tariffs set by the public sector and utilities (e.g., import tariffs for ethanol and standby charges for distributed generators) as well as unfavorable electricity pricing policies and rate recovery mechanisms.

h) Fiscal Uncertainty Short-duration tax policies that lead to uncertain fiscal incentives, such as production tax credits; uncertain future costs for GHG emissions.

Regulatory Barriers

i) Unfavorable Regulatory Policies: Distortionary regulations that favor conventional energy sources and discourage technological innovation, including certain power plant regulations, rules impacting the use of combined heat and power, parts of the federal fuel economy standards for cars and trucks, and certain codes and standards regulating the buildings industry; burdensome and underdeveloped regulations and permitting processes; poor land use planning that promotes sprawl.

j) Regulatory Uncertainty: Uncertainty about future regulations of greenhouse gases; uncertainty about the disposal of spent nuclear fuels; uncertain siting regulations for off-shore wind; lack of codes and standards; uncertainty regarding possible future GHG regulations.

Statutory Barriers

k) Unfavorable Statutory Policies: Lack of modern and enforceable building codes; state laws that prevent energy saving performance contracting.

l) Statutory Uncertainty: Uncertainty about future statutes including renewable and energy efficiency portfolio standards; unclear property rights relative to surface injection of CO2, subsurface ownership of CO2 and methane, and wind energy.

Intellectual Property Barriers

m) High Intellectual Property

n) Transaction Costs: High transaction costs for patent filing and enforcement, conflicting views of a patent's value, and systemic problems at the USPTO

o) Anti-competitive Patent Practices Techniques such as patent warehousing, suppression, and blocking.

p) Weak International Patent Protection: Inconsistent or nonexistent patent protection in developing countries and emerging markets.

q) University, Industry, Government Perceptions: Conflicting goals of universities, national laboratories, and industry concerning CRADAs and technology commercialization.

Other Barriers*r)* Incomplete and Imperfect Information: Lack of information about technology performance – especially trusted information; bundled benefits and decision-making complexities;

s) High cost of gathering and processing information; misinformation and myths; lack of sociotechnical learning; and lack of stakeholders and constituents

t) Infrastructure Limitations: Inadequate critical infrastructure – including electric transmission capabilities and long-term nuclear fuel storage facilities; shortage of complementary technologies that encourage investment or broaden the market for GHG-reducing technologies; insufficient supply and distribution channels; lack of O&M facilities and other supply chain shortfalls

u) Industry Structure: Natural monopoly in utilities disenabling small-scale competition

v) Industry fragmentation slowing technological change, complicating coordination, and limiting investment capital.

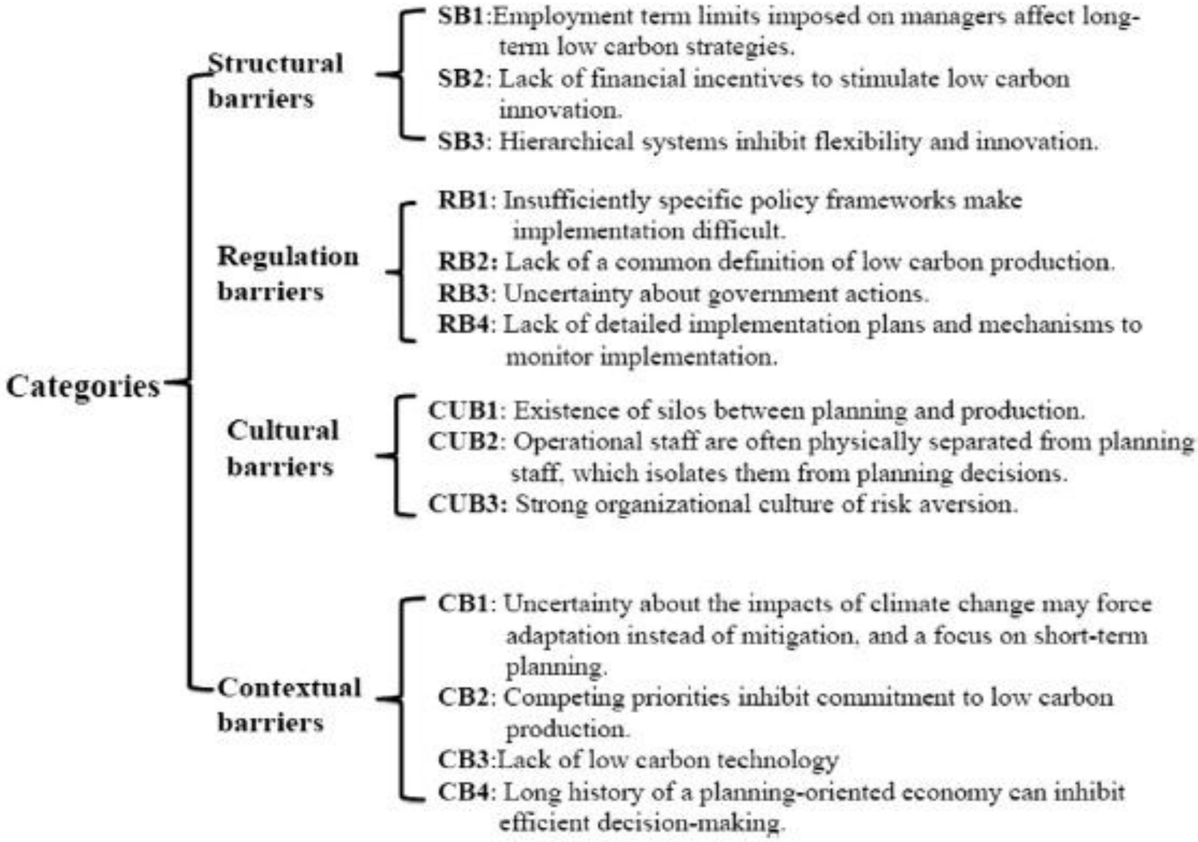
w) Misplaced Incentives: Misplaced incentives when the buyer/owner is not the consumer/user (e.g., landlords and tenants in the rental market and speculative construction in the buildings industry) – also known as the principal-agent problem.

x) Policy Uncertainty: Uncertainty about future environmental and other policies; lack of leadership

The Oak Ridge document refers to an Iron Triangle of Barriers defined by Incumbent Support, Transaction Costs and Business Innovation Risk. In fact, as shown in Figure IV-1, in one representation of the analysis it is really an Iron Parallelogram with unfavorable and uncertain policy in a number of areas as the fourth side. The Oak Ridge analysis also highlights the power of incumbents, which is identified as an important barrier in the climate change literature.

Figure IV-2 presents another comprehensive categorization of barriers to low carbon technologies based on a comparative case study of interview with 189 senior management personnel at 98 Chinese firms. While the categories differ, the discrete barriers are similar to those identified in the analyses reviewed above that focus on industrial firms.

FIGURE IV-2: DESCRIPTION OF FOUR CATEGORIES OF BARRIER.



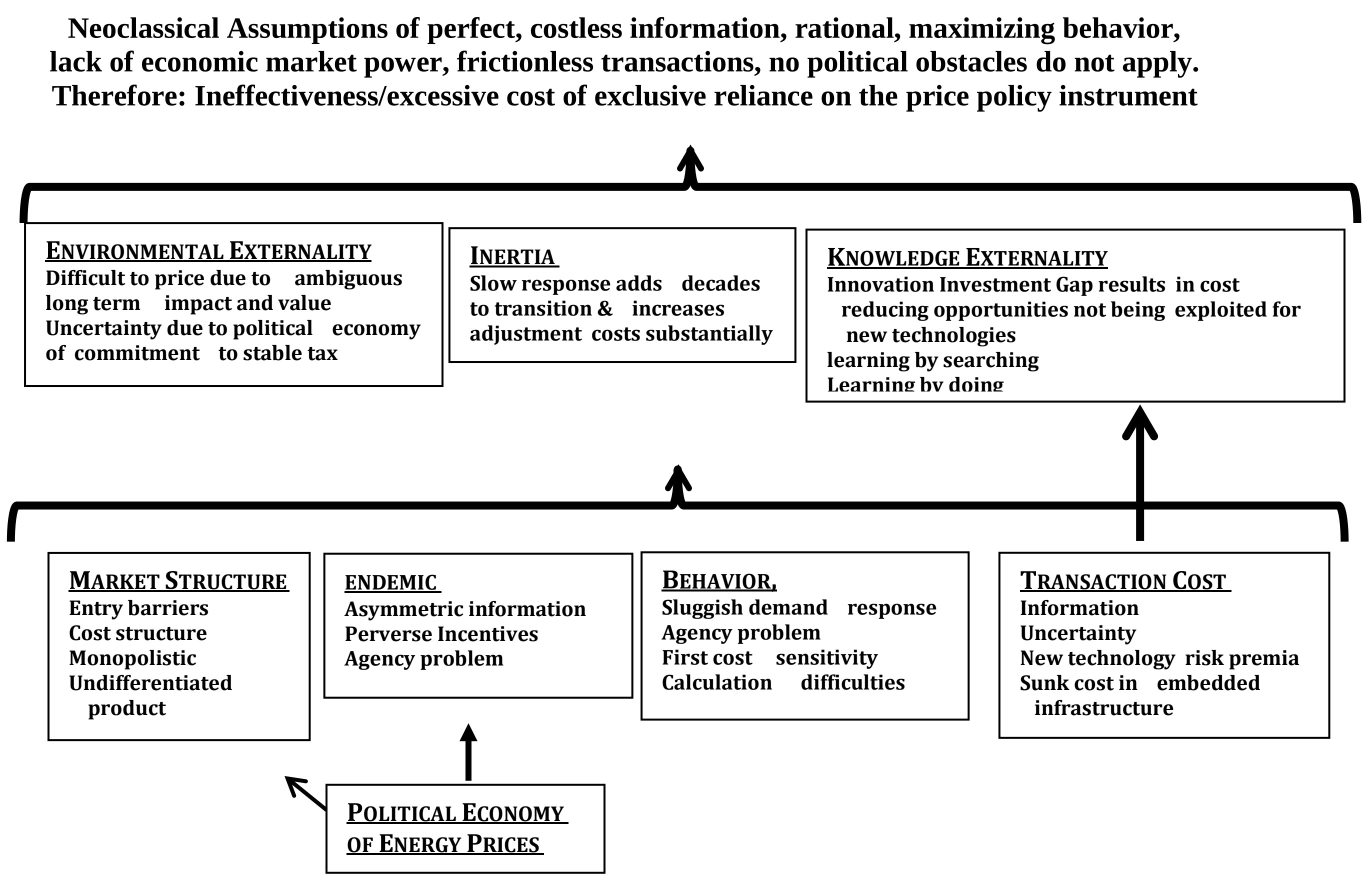
Average score of barriers raised by interviewees.

Barriers	Average score
Employment term limits imposed on managers affect long-term low carbon strategies.	3.00
Staff must demonstrate to their bosses consistency between new recommendations and past methods, entrenching particular paths.	2.90
Lack of financial incentives to stimulate low carbon innovation.	4.00
Long history of a planning-oriented economy can inhibit efficient decision-making.	3.80
Hierarchical systems inhibit flexibility and innovation.	3.50
Isolating low carbon production within the structure of the firm.	2.90
Insufficiently specific policy frame works make implementation difficult.	3.00
Lack of a common definition of low carbon production.	4.00
Uncertainty about government actions.	2.50
Lack of detailed implementation plans and mechanisms to monitor implementation.	3.80
Existence of silos between planning and production.	2.30
Operational staff are often physically separated from planning staff, which isolates them from planning decisions.	2.30
Strong organizational culture of risk aversion.	3.50
Uncertainty about the impacts of climate change may force adaptation instead of mitigation, and a focus on short-term planning.	3.00
Competing priorities inhibit commitment to low carbon production.	2.90
Lack of low carbon technology.	2.90
Uncertainty about the marketplace.	2.90

Source: Liu, Yong, 2014, "Barriers to the adoption of low carbon production: A multiple-case study of Chinese industrial firms," ***Energy Policy,*** **67.**

Figure IV-3 summarizes a recent analysis by energy researchers at Imperial College London that starts at the theoretical level by cataloguing the very restrictive assumptions that are necessary to reach the conclusion that imposing a hefty tax on carbon is the efficient, first-best way to internalize the carbon externality– perfect, costless information, rational, maximizing behavior, lack of economic market power, frictionless transactions, no political obstacles.[83] They point out that in the energy space, there is a great deal of evidence that demonstrates the simple theory is confronted with and contradicted by a complex reality.[84] The incumbent market and institutional structure is riddled with important and concrete problems that ensure the market outcome will fall short of the theoretical optimum.

FIGURE IV-3: THE CHALLENGE OF CLIMATE CHANGE VIEWED AS AN "INNOVATION GAP"



Sources: Gross, Robert, et al., *On Picking Winners: The Need for Targeted Support for Renewable Energy*, Imperial College, October 2012

[83] Gross, et al, 2012, p.11. Temperton, 2012, p. 2,
[84] Gross, et al., 2012, p. 12;

V. Recent Empirial Findings in the Efficiency Gap and Climate Change Literatures

This chapter presents a brief review of recent empirical studies in the two fields that are central to the design of policies to respond to the challenge of climate change, the efficiency gap and climate change. There are over 120 studies, all of which are empirical in nature – either reporting specific new results or reviewing and summarizing empirical results. The vast majority of studies are less than five years old and with one or two exceptions, they are less than ten years old. The studies provide evidence to support the market barrier framing in the previous chapter.

Embedded in the literature reviews for each of the recent studies are citations to earlier empirical studies that provide the context for the more recent research. All of the failures, barriers and imperfections have been supported in the empirical literature, which is why they have been recognized in the conceptual frameworks. Because the Tables in this chapter are long, for ease of presentation, I place them at the end of the section.

A. Summary of Recent Empirical Studies

Table V-1 lists the full array of market failures, barriers and imperfections that cause the underinvestment in energy saving technologies derived from the conceptual discussion above.

The framework used in Table V-1 reconciles the diversity of the literatures reviewed by identifying three schools of analysis (1) traditional neoclassical and industrial organization captures the externalities, market structure (2) new institution economics includes the endemic barriers and transaction cost economics and policy, regulation and political power issues, and (3) behavioral economics. For the efficiency gap literature, Table V-2 provides a description of each of the major studies.

Table V-3 places the recent empirical studies of climate change in the market imperfections and barriers framework. There are strong parallels between the empirical findings in the analysis of the response to climate change and the efficiency gap analysis. One significant difference between the two literatures is that the climate change literature contains a significant number of studies that directly evaluate the impact and efficacy of specific policy instruments. This reflects the fact that climate change as a policy challenge is more urgent, specific and larger than the efficiency gap. For the climate change studies I identify each market imperfection addressed and offer a sample citation to describe it.

B. Summary of Key Market Imperfections In Responding to Climate Change

1. Externalities

The large negative externalities associated with the fossil fuel-based electricity sector are the proximate cause of the need to re-center the sector on alternative resources. The need for change is great and urgent. However, the negative externalities are not the only obstacles that the transformation confronts. Other market barriers and imperfections must be overcome to control the cost and speed the transition to a new electricity system.

There is a very large literature on the externalities associated with energy consumption. Importantly, it goes well beyond the negative national security and environmental externalities, which are frequently noted in energy policy analysis. The central observation on the supply-side is that many of the benefits of alternative generation technology resources or the processes by which their costs would be reduced – e.g. public goods qualities of research and development, learning by doing, network effects – are positive externalities themselves. This means the private sector will underinvest. Long lead times for technology development, increasing returns to scale and network effects make entry difficult.

The macroeconomic effects of energy consumption and energy savings are important externalities of the efficiency gap, as are health and welfare effects. There are two macroeconomic effects that have begun to receive a great deal of attention – multipliers and price effects. The ability to increase macroeconomic activity or, more importantly in the case of climate change, moderate reductions in macroeconomic activity that flow from the need to shift energy resources is an important policy consideration.

Choosing least cost approaches to decarbonization is critically important from the macroeconomic perspective. Reducing energy consumption tends to reduce economic activities that have relatively small multipliers (especially when energy imports are involved as in the transportation sector) and increase economic activities that have large multipliers (including the direct effects of spending on technology and the indirect effect of increased household disposable income).

2. Information

Information plays a very large role in the LBL and RFF efficiency gap analysis. It can be a problem at the societal level since it can be considered a public good that is not produced because the authors of the information cannot capture the social value of information. It is a structural problem because, where it is lacking, even capable, well-motivated individuals cannot make efficient choices and a transaction cost problem where it is costly or difficult to verify.. Where information is asymmetric, individuals can take advantage of the less informed to produce outcomes that are not efficient. It is a problem at the behavioral level where individuals lack the ability to gather and process information.

3. Inertia on the Supply-Side

The inertia that supports the incumbent technology is a central factor.[85] Inertia is the result of several factors that exacerbate the problem of underinvestment in alternatives,[86] including the ability of dominant incumbents to implement practices and promote policies that magnify the barriers to entry,[87] like control of access to the grid or dispatch.[88] A long period in which fossil fuels were dominant and created a large market makes it the focal point of resources and investment and will be the focal point of innovative activity. Since the alternative

[85] De Cian, 2012, p. 6,
[86] Kalkuhl, Edenhofer and Lessmann, 2012, p.340.
[87] They have an advantage in the ability to lobby for policies that favor their interests, Friehe, 2013; Freeman, Anderson, 2013.
[88] Walz, 2007; Walz, Schleich and Ragwitz, 2011.

technologies are at a disadvantage in terms of development and the ability to attract resources, just raising the cost of the dominant fuels does not overcome the inertia and actually allows the gap between the incumbent and alternative technologies to persist or even grow as the entrenched interests use their resource advantage and political power to protect their incumbency.[89]

Dislodging a dominant technology requires overcoming a great deal of physical and institutional inertia that has built up over decades. New technologies face significant barriers to entry that are compounded by the existence of entrenched incumbents. Thus, the inertia that supports the dominant incumbent technology is a central factor. Inertia is the result of several sets of market imperfection – market and institutional factors including market structure, endemic, behavioral and transaction costs issues. Some of the market imperfections exacerbate the problem of underinvestment in knowledge creation, but their impact on inertia is paramount.

4. Market Structure and Transaction Costs

Market structural problems not associated with market power are equally important,[90] including market size, the tendency to invest in incremental innovation focused on the dominant technology, innovative activity[91]and existing skill sets;[92] lack of substitutability between the alternatives, limited spillovers from innovation in the incumbent technology, and the undifferentiated nature of the product makes it hard for new entrants to secure a foothold (niche) from which to build scale and learn-by doing.[93]

Uncertainties about the nature of the market and the value and cost of technology and limitations of technological expertise and information play an important role, increasing the cost and raising the risk of adopting new technologies.

As a result of these factors, the marketplace yields a limited set of choices because producers and consumers operate under a number of constraints. Split incentives flowing from the agency problem are a frequently analyzed issue. When the purchaser of the energy consuming durables and the users are different people, inefficient choices result.

5. Slow Responses on the Demand-side

Consumers and producers are poorly informed, influenced by social pressures and constrained in their ability to make the calculations necessary to arrive at objectively efficient decisions. Consumers and producers apply heuristics that reflect rationality that is bounded by factors like risk and loss aversion. Inattention to energy efficiency is rational, given the magnitude, variability and uncertainty of costs, as well as the multi-attribute nature of energy consuming durables. . The product is a bundle of attributes in which other traits are important and energy costs are hidden costs. The resulting energy expenditures are important components

[89] Acemoglu, et al, 2012, pp. 137.
[90] Robert Gross, et al., 2012; Nicolli and Vona, 2012.
[91] Acemoglu, et al, 2012, pp. 137.
[92] Gross, et al., 2012, p.18.
[93] Kalkuhl, Edenhofer and Lessmann, 2012, p. 10,

of total household spending. Important benefits of energy consuming durables may be "shrouded" in the broader multi-attribute product.

Consumers are influenced by social norms and advertising Consumers respond sluggishly to price increases, so the shifting of the risk of price volatility onto the consumers does not have the hoped for effect in stimulating demand for alternative resources. The undifferentiated nature of the product makes it hard for new entrants to secure a foothold (niche) from which to build scale and learn-by doing.   Energy consuming durables have long lives, and consumers frequently do not make the purchase decision. The agents who make the purchase decisions and consumers are first cost sensitive and have difficulty projecting energy prices and quantities to make lifecycle cost calculations. The demand–side does not receive the attention commensurate with its importance as a source of market failure or its potential impact on the transition to a decarbonized sector.

These factors weaken the ability of price to deliver the first best outcome and trigger the search for second best solutions. Moreover, while "picking winners" is fraught with dangers, setting the right level of the tax is equally difficult and the benefits of overcoming inertia and other barriers to cost reducing innovation are large. A portfolio of policies that includes both carbon taxes and targeted intervention to stimulate innovation, is widely seen as the best approach.

The empirical evidence on consumer rationality in the literature paints a picture that bears little resemblance to the rational maximizer of neoclassical economics. We find a risk averse,[94] procrastinating consumer,[95] who responds to average, not marginal prices,[96] who is heavily influenced by social pressures,[97] with discount rates that vary depending on a number of factors[98]

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[94] See e.g., Arbuthnott, Dolter, 2013, p.7, loss aversion, we choose to procrastinate—rather than accepting a sure loss by admitting a mistake now, we invest in the low-probability hope that our original choice will be successful in the future… A similar causal theory focuses on social rather than financial cost: Admitting failure damages self-esteem and public reputation… A third theoretical explanation for escalation of commitment is associated with ambiguous information for both past outcomes and future probabilities… group cohesion such as loyalty and affiliative feeling between group members increases escalation of commitment. Qui, Colson and Gretus, 2014, p. 216, results show that more risk averse consumers are less likely to adopt energy efficient technologies (except for the case of energy efficient air-conditioners). In addition, the findings provide evidence that households' perceived mobility as measured by the probability of moving within five years, can amplify the negative impact of risk aversion on the adoption of energy efficiency retrofitting technologies.).

[95] See e.g., Lilemo, 2014, The effect of procrastination on intertemporal energy choice behaviours could be even more serious because energy is an abstract, invisible and intangible commodity. This paper uses a web survey to investigate how people's procrastination propensity and environmental awareness affect their heating-energy-saving behaviours. The results indicate that people who state that they have a higher tendency to procrastinate are significantly less likely to have engaged in most of the heating energy-saving activities, especially regarding larger purchases or investments in equipment and the insulation of doors and windows.

[96] See e.g., Ito, 2014, p. 537, I find strong evidence that consumers respond to average price rather than marginal or expected marginal price. This suboptimizing behavior makes nonlinear pricing unsuccessful in achieving its policy goal of energy conservation and critically changes the welfare implications of nonlinear pricing.

[97] See e.g., Axsen, Orlebar and Skippon, 2013, 96, Findings suggest that participant perceptions change in part through social negotiation of meaning, lifestyle and identity. Neglect of social influence processes will underestimate the potential for shifts in consumer preferences regarding emerging pro-environmental technologies.

[98] See e.g., While the sensitivity to a range of socio-economic factors is to be expected, other variation is surprising (e.g. Enzler and Meir, 2014), for example, the time frame Andersson, Henrik, et al., 2013, 437.We explore how WTP per unit risk reduction depends on the time period over which respondents pay and face reduced risk in a

and has difficulty making calculations,[99] not to mention the fact that the most important decision, which energy consuming durable is made by someone else.[100]

Firms suffer similar problems. We find organization structure matters a great deal[101] in routine bound,[102] resource strapped organizations[103] confronted with conflicting incentives[104] and a great deal of uncertainty about market formation for new technologies.[105] Knowledge and skill to implement new technologies is lacking[106] and firms have little incentive to create it because of the difficulty of capturing the full value.[107] Public policy efforts to address these problems have

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theoretical model and by using data from a Swedish contingent valuation survey…. Our theoretical model predicts the effect from the time framing to be negligible, but the empirical estimates from the annual scenario are about 70% higher than estimates from the monthly scenario.

[99] See e.g., Kurani and Turrentine, 2004, p. 1, One effect of limited knowledge is that when consumers buy a vehicle, they do not have the basic building blocks of knowledge to make an economically rational decision. When offered a choice to pay more for better fuel economy, most households were unable to estimate potential savings, particularly over periods of time greater than one month. In the absence of such calculations, many households were overly optimistic about potential fuel savings, wanting and thinking they could recover an investment of several thousand dollars in a couple of years.

[100] See e.g., Davis, 2010, p. 1; Extensive analysis of U.S. and global markets support the conclusion that this is an important impediment to greater energy efficiency of consumer durables. "The results show that, controlling for household income and other household characteristics, renters are significantly less likely to have energy efficient refrigerators, clothes washers and dishwashers." Lutzenheiser, et al., (2001, cited in Blumstein, 2013), p. viii, The commercial building "industry" is in fact a series of linked industries arrayed along a "value chain" or "value stream" where each loosely coupled link contributes value to a material building in process. Each link, while aware of the other links in the process, is a somewhat separate social world with its own logic, language, actors, interests, and regulatory demands. For the most part "upstream" actors constrain the choices and actions of "downstream" actors.

[101] See e.g., Inoue, 2013, 162, our finding shows that the organisational and managerial factors of firms are important in examining environmental R&D.

[102] See e.g., Montvalo, 2007, A11, organization capabilities refer to the firm's endowments and capabilities to carry out innovation… When the knowledge is not present in the firm adoption will depend on the firm's capacity to overcome shill lock-in, and to unlearn and acquire new skills.

[103] See e.g., UNIDO, 2011, p. iii, If an organization has insufficient capital through internal funds, and has difficulty raising additional funds through borrowing or share issues, energy efficient investments may be prevented from going ahead. Investment could also be inhibited by internal capital budgeting procedures, investment appraisal rules and the short-term incentives of energy management staff.

[104] Sardianou, 2007, p. 1417, Decision making process to invest in energy efficiency improvement, like other investments, is a function of the behavior of individual or of various actors within the industrial firm. In this context, managerial attitudes toward energy conservation are also important factors… [E]nergy efficiency measures are often overlooked by management because it is not a core business activity and it is thus not worth much attention.

[105] See e.g., Montvalo, 2007, p. A10,. In the literature on technology management it has been established that adoption or development of new production processes implies the capacity to integrate new knowledge and large organizational change.

[106] See e.g., Horbach, 2007, p. 172, Environmental management tools help to reduce the information deficits to detect cost savings (especially material and energy savings) that are an important driving force of environmental innovation… An environmentally oriented research policy has not only to regard traditional instruments like the improvement of the technological capabilities of a firm but also the coordination with soft environmental policy instruments like the introduction of environmental management systems.

[107] See e.g., de Cian and Massimo, 2011, p. 123, Uncertainty and irreversibility are two features of climate change that contribute to shape the decision making process. Technology cost uncertainty can depress the incentive to invest. The risk of underinvestment is even more severe considering that energy infrastructure has a slow turnover. Capital irreversibility and uncertainty heighten the risk of locking into existing fossil-fuel-based technologies. Additional investments are sunk costs that increase the opportunity cost of acting now… The result

been weak and inconsistent.[108] The supply-side does not escape these factors and it exhibits the added problem of powerful vested interests and institutional structures that are resistant, if not adverse to change.[109]

Given this, it is little wonder that the centerpiece of traditional economic analysis, the discount rate, which is supposed to express the way the utility maximizer maximizes value is a shambles. It is claimed to represent the value people place on efficiency, which is presumed to be correct, but for externalities, which do not enter into the private calculation, or information problems, which frustrate the calculation. The empirical analysis of discount rates shows that this claim suffers from two fundamental flaws. We have no solid basis to answer two basic questions

The market exhibits a high "implicit" discount rate, which I interpret as the result of the many barriers and imperfections that retard investment in efficiency enhancing technology. There are several aspects of the high discount rate that deserve separate attention. There is a low willingness to pay and a low elasticity of demand. In a sense the discount rate is the centerpiece of the market fundamentalist objection to performance standards.

- How big is the discount rate?[110]
- How big should it be?[111]

Estimates of the discount rate vary widely, from zero to well over 100% and the discount rate appears to be influenced by a wide number of personal and situational factors.

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is reinforced when uncertain costs have a large variance, showing that investments decrease with risk. Jamasb and Nicita, (2007, p 8) R&D activity can be subject to three main types of market failure namely indivisibility, uncertainty and externalities.

[108] See e.g., UNIDO, 2011, p. 67, The government does not give financial incentives to improve energy efficiency, Lack of coordination between different government agencies, Lack of enforcement of government regulations, There is a lack of coordination between external organizations; Sardianou, 2007, p. 1402, [B]ureaucratic procedure to get government financial support is a barrier to energy efficiency improvements for the majority (80%) of industries.

[109] See e.g., Fuss and Szolgayosva, 2010, p.2938, We find that the uncertainty associated with the technological progress of renewable energy technologies leads to a postponement of investment. Even the simultaneous inclusion of stochastic fossil fuel prices in the same model does not make renewable energy competitive compared to fossil-fuel-fired technology in the short run based on the data used. This implies that policymakers have to intervene if renewable energy is supposed to get diffused more quickly. Otherwise, old fossil-fuel-fired equipment will be refurbished or replaced by fossil-fuel-fired capacity again, which enforces the lock-in of the current system into unsustainable electricity generation.

[110] See e.g., Bruderer, et al., 2014, 524, Our analyses reveal that on average subjective discount rates are well above market interest rates and moderately stable over a time interval of four years .Income and education are negatively correlated with discount rates. Contrary to expectations, we did not find convincing support for an impact of discount rates on energy saving behavior. Min, 2014, Lia, et al., N.D.; Huecker, 2013.

[111] See e.g., Davidson, 2014, Roemer, 2013, 141, Jacquet, et al., 2013; Grijlava, 2014; Roemer, 2013.

TABLE V-1: EMPIRICAL EVIDENCE SUPPORTING THE EFFICIENCY GAP

TRADITIONAL ECONOMICS & INDUSTRIAL ORGANIZATION

Externalities
- Public goods[1] & Bads[2]
- Basic research
- Network effects
- Information as a public good
- Learning-by-doing & Using[9]

Industry Structure
- Imperfect Competition
  - Concentration[13]
  - Barriers to entry
  - Scale[18]
  - Switching costs[20]
- Technology[23]
  - R&D
  - Investment[25]
- Marketing
  - Bundling: Multi-attribute[26]
  - Substitutes[27]
- Cost-Price
  - Limit impact of price[29]
  - Fragmented Mkt.[30]
  - Limited payback[31]

NEW INSTITUTIONAL ECONOMICS

Endemic Imperfections
- Asymmetric Info[3].
- Agency[5]
- Adverse selection[6]
- Perverse incentives
- Lack of capital[10]

Transaction Cost
- Search and Information
- Imperfect info[14]
  - Availability[16]
  - Accuracy
  - Search cost[21]
- Bargaining
  - Risk & Uncertainty[24]
  - Liability
- Enforcement
- Sunk costs
- Hidden cost[28]

Political Power & Policy
- Power of incumbents to hinder alternatives
- Monopolistic structures and lack of competition
- Importance of institutional support for Alternatives[32]
- Inertia[33]

Regulation
- Price[34]
  - Infrequent
  - Aggregate, Avg.-cost[35]
  - Lack of commitment[36]

BEHAVIORAL ECONOMICS

Motivation & Values
- Non-economic[4]

Influence & Commitment
- Custom[7]
- Social group & status[8]

Perception
- Bounded Vision/Attention[11]
- Prospect[12]

Calculation.
- Bounded rationality[15]
- Limited ability to process info[17]
- Heuristic decision making[19]
- Discounting difficulty[22]

Citations

1. Macroeconomic: Edelstein and Killian, 2009, p. 13, [T]he cumulative effects on real consumption associated with energy price shocks are quantitatively important. We showed that the responses of real consumption aggregates are too large to reflect the effects of unanticipated change in discretionary income alone. Our analysis suggests that the excess response can be attributed to shifts in precautionary savings and to changes in the operating costs of energy using durables.
2. Committee On Health, Environmental, And Other External Costs And Benefits Of Energy Production And Consumption, 2011, p. I, D]espite energy's many benefits, most of which are reflected in energy market prices, the production, distribution, and use of energy also cause negative effects. Beneficial or negative effects that are not reflected in energy market prices are termed "external effects" by economists. In the absence of government intervention, external effects associated with energy production and use are generally not taken into account in decision making. When prices do not adequately reflect them, the monetary value assigned to benefits or adverse effects (referred to as damages) are "hidden" in the sense that government and other decision makers, such as electric utility managers, may not recognize the full costs of their actions. When market failures like this occur, there may be a case for government interventions in the form of regulations, taxes, fees, tradable permits, or other instruments that will motivate such recognition.
3. UNIDO, 2011, p. 19, Asymmetric information exists where the supplier of a good or service holds relevant information, but is unable or unwilling to transfer this information to prospective buyers. The extent to which asymmetric information leads to market failure will depend upon the nature of the good or service…. In contrast to energy commodities, energy efficiency may only be considered a search good when the energy consumption of a product is clearly and unambiguously labelled and when the performance in use is insensitive to installation, operation and maintenance conditions. But for many goods, the information on energy consumption may be missing, ambiguous or hidden, and the search costs will be relatively high. In the absence of standardised

performance measures or rating schemes, it may be difficult to compare the performance of competing products. Taken together, these features tend to make energy efficiency closer to a *credence good* and hence more subject to market failure. Thus, to the extent that energy supply and energy efficiency represent different means of delivering the same level of energy service, the latter is likely to be disadvantaged relative to the former. The result is likely to be overconsumption of energy and under-consumption of energy efficiency.

4. Alcott, 2011, p. 1, Results show that beliefs are both highly noisy, consistent with imperfect information and bounded computational capacity, and systematically biased in manner symptomatic of "MPG illusion;" Alcott and Wozny, 2010.
5. Davis, 2010, p. 1; Extensive analysis of U.S. and global markets support the conclusion that this is an important impediment to greater energy efficiency of consumer durables. "The results show that, controlling for household income and other household characteristics, renters are significantly less likely to have energy efficient refrigerators, clothes washers and dishwashers."
6. UNIDO, 2011, p. 19, In some circumstances, asymmetric information in energy service markets may lead to the adverse selection of energy inefficient goods. Take housing as an example. In a perfect market, the resale value of a house would reflect the discounted value of energy efficiency investments. But asymmetric information at the point of sale tends to prevent this. Buyers have difficulty in recognising the potential energy savings and rarely account for this when making a price offer. Estate agents have greater resources than buyers, but similarly neglect energy efficiency when valuing a house. Since the operating costs of a house affect the ability of a borrower to repay the mortgage, they should be reflected in mortgage qualifications. Again, they are not. In all cases, one party (e.g., the builder or the seller) may have the relevant information, but transaction costs impede the transfer of that information to the potential purchaser. The result may be to discourage house builders from constructing energy efficient houses, or to discourage homeowners from making energy efficiency improvements since they will not be able to capture the additional costs in the sale price.
7. Ozaki and Sevastyanove, 2009.
8. Claudy and O'Dricoll, 2008, p. 11, "A growing body of literature around energy conservation contends that investment into energy efficiency measure is often motivated by "conviction" rather than "economics." Behavioral factors, including attitudes and values, explain a greater amount of variation in proenvironmental behaviour and provide valuable insights for policy makers and analysts."
9. Desroches, 2011, p. 1, Costs and prices generally fall in relations to cumulative production, a phenomenon known as experience and modeled as a fairly robust empirical experience curve… These experience curves… incorporated into recent energy conservation standards… impact on the national modeling can be significant, often increasing the net present value of potential standard levels… These results imply that past energy conservation standards analyses may have undervalued the economic benefits of potential standard levels.
10. UNIDO, 2011, p. iii, If an organization has insufficient capital through internal funds, and has difficulty raising additional funds through borrowing or share issues, energy efficient investments may be prevented from going ahead. Investment could also be inhibited by internal capital budgeting procedures, investment appraisal rules and the short-term incentives of energy management staff.
11. Alcott, 2009, p. 1. "I provide evidence to suggest that at least some of this effect is because consumers' attention is malleable and non-durable." UNIDO, pp. viii, Owing to constraints on time, attention, and the ability to process information, individuals do not make decisions in the manner assumed in economic models. As a consequence, they may neglect opportunities for improving energy efficiency, even when given good information and appropriate incentive consumers do not attempt to maximise their utility or producers their profits.
12. Sardiano, 2007, p. 1417, Decision making process to invest in energy efficiency improvement, like other investments, is a function of the behavior of individual or of various actors within the industrial firm. In this context, managerial attitudes toward energy conservation are also important factors… [E]nergy efficiency measures are often overlooked by management because it is not a core business activity and it is thus not worth much attention.
13. Blumstein, 2013, p. 5, [T]he existence of market power dampens the responsiveness of suppliers of goods or services to consumer demand, as actors in a monopolistic or oligopolistic setting can more or less set prices and quality attributes.
14. Atari, et. al., 2010, p. 1. For a sample of 15 activities, participants underestimated energy use and savings by a factor of 2.8 on average, with small overestimates for lower-energy activities and large, underestimates for high-energy activities." Jessoe and Rapson, 2013, p. 34, "These results confirm the practical importance of one of economics' most ubiquitous assumptions – that decision makers have perfect information. Indeed, the absence of perfect information is likely to cause substantial efficiency loses both in this setting and others in which quantity is also infrequently or partially observed by decision makers." Consumers Union, 2012, p. 8, "this suggests that

many consumers are misinformed about the program requirements.

15. Green, German and Delucchi, 2009, p. 203; “The uncertainty/loss aversion model of consumers’ fuel economy decision making implies that consumers will undervalue expected future fuel savings to roughly the same degree as manufacturers’ perception that consumers demand short payback periods.”
16. UNIDO, 2011, p. iii, Lack of information on energy efficiency opportunities may lead to cost-effective opportunities being missed. In some cases, imperfect information may lead to inefficient products driving efficient products out of the market. Information on: the level and pattern of current energy consumption and comparison with relevant benchmarks; specific opportunities, such as the retrofit of thermal insulation; and the energy consumption of new and refurbished buildings, process plant and purchased equipment, allowing choice between efficient and inefficient options.
17. Atari, et. al., 2010, p. 1. For a sample of 15 activities, participants underestimated energy use and savings by a factor of 2.8 on average, with small overestimates for lower-energy activities and large, underestimates for high-energy activities.”
18. Montvalo, 2007, p. S10, Due to the size of investment and longevity or production processes it is very likely that the diffusion of new processes will occur in an incremental way.
19. Ito, 2010, p. 1, Evidence from laboratory experiments suggests that consumers facing such price schedules may respond to average price as a heuristic. I empirically test this prediction using field data.
20. Sardianou, 2007, p. 1419, Our empirical results also confirm that organizational constraints and human related factors can be thought of as barriers in incorporating the energy saving technology in incorporating the energy saving technology in the existing production process.
21. Sardianou, 2007, p. 1419, Having limited information with regard to energy conservation opportunities and their profitability is considered an obstacle…. Other possible barriers include lack of documentation of energy data.
22. Kurani and Turrentine, 2004, p. 1, One effect of limited knowledge is that when consumers buy a vehicle, they do not have the basic building blocks of knowledge to make an economically rational decision. When offered a choice to pay more for better fuel economy, most households were unable to estimate potential savings, particularly over periods of time greater than one month. In the absence of such calculations, many households were overly optimistic about potential fuel savings, wanting and thinking they could recover an investment of several thousand dollars in a couple of years.
23. Montvalo, 2007, p. A10, Finally, firms face the challenge of technological risk. The gains promised by new technologies have yet to materialize, a situation that contrasts strongly with the perceived reliability of the current, familiar operating process. In the literature on technology management it has been established that adoption or development of new production processes implies the capacity to integrate new knowledge and large organizational change.
24. UNIDO, 2011, p. iii, The short paybacks required for energy efficiency investments may represent a rational response to risk. This could be because energy efficiency investments represent a higher technical or financial risk than other types of investment, or that business and market uncertainty encourages short time horizons.
25. Montvalo, 2007, p. s10, Closely related to these technological opportunities are the firm and sector level capabilities to actually adopt new technologies. It has been reported that insufficient availability of expertise in clear production (eco-design) the current training and clean technology capacity building at the sector level and the insufficient understanding and experience in cleaner production project development and implementation, play a role in the adoption of new cleaner production processes. These factors can be expected to become even more critical at the level of small- and medium sized enterprises..
26. Gabaix and Laibson, 2005, p. 1; “We show that information shrouding flourishes even in highly competitive markets, even in markets with costless advertising, and even when the shrouding generation allocational inefficiencies.” Hosain and Morgan, Brown, Hossain and Morgan
27. Sallee, 2012, “The possibility of rational inattention has two key implications. First, if consumers rationally ignore energy efficiency, this could explain the energy paradox. In equilibrium, firms will underprovide energy efficiency if consumers ignore it. If true, this would qualitatively change the interpretation of empirical work on the energy paradox. Most empirical work tests for the rationality of consumer choice across goods that are actually sold in the market. If rational inattention leads to an inefficiency set of *product offerings* (emphasis added), consumer might choose rationally among goods in equilibrium but a paradox still exists. Second, if consumers are rationally inattentive to energy efficiency, this could provide direct justification for regulatory standards and “no tech policies, such as the Energy Star Label System.” Green, German and Delucchi, 2009, p. 203; This suggests that increasing fuel prices may not be the most effective policy for increasing the application of technologies to increase passenger and light truck fuel economy. This view is supported by the similar levels of technology applied to U.S. and European passenger cars in the 1990s, despite fuel prices roughly three times

higher in Europe. It is also circumstantially supported by the adoption by governments around the world of regulatory standard for light-duty vehicle fuel economy and carbon dioxide emissions.

28. UNIDO, 2011, p. iii, Hidden costs Engineering-economic analyses may fail to account for either the reduction in utility associated with energy efficient technologies, or the additional costs associated with them. As a consequence, the studies may overestimate energy efficiency potential. Examples of hidden costs include overhead costs for management, disruptions to production, staff replacement and training, and the costs associated with gathering, analysing and applying information. General overhead costs of energy management: employing specialist people (e.g., energy manager); energy information systems (including: gathering of energy consumption data; maintaining sub metering systems; analysing data and correcting for influencing factors; identifying faults; etc.); energy auditing; Costs involved in individual technology decisions: i) identifying opportunities; ii) detailed investigation and design; iii) formal investment appraisal; formal procedures for seeking approval of capital expenditures; specification and tendering for capital works to manufacturers and contractors additional staff costs for maintenance; replacement, early retirement, or retraining of staff; disruptions and inconvenience; Loss of utility associated with energy efficient: problems with safety, noise, working conditions, service quality etc. (e.g., lighting levels); extra maintenance, lower reliability.
29. Li, Timmins and von Haefen, 2009, "we are able to decompose the effects of gasoline prices on the evolution of the vehicle fleet into changes arising from the inflow of new vehicles and the outflow of used vehicles. We find that gasoline prices have statistically significant effects on both channels, but their combined effects results in only modest impacts on fleet fuel economy. The short-run and long-run elasticities of fleet fuel economy with respect to gasoline prices are estimated at 0.o22 and 0.204in 2005. "
30. Committee to Assess Fuel Economy, 2010, p. 2, The [Medium and Heavy Duty] truck world is more complicated. There are literally thousands of different configurations of vehicle including bucket trucks, pickup trucks, garbage trucks, delivery vehicles, and long-haul trailers. Their duty cycles vary greatly… the party responsible for the final truck configuration is often not well defined.; Lutzenheiser, et al., (2001, cited in Blumstein, 2013), p. viii, The commercial building "industry" is in fact a series of linked industries arrayed along a "value chain" or "value stream" where each loosely coupled link contributes value to a material building in process. Each link, while aware of the other links in the process, is a somewhat separate social world with its own logic, language, actors, interests, and regulatory demands. For the most part "upstream" actors constrain the choices and actions of "downstream" actors.
31. Sardianou, 2007, p. 1419, The lack of access to capital (76%) and the slow rate of return (74%) of energy savings investments are categorized as barriers.
32. UNIDO, 2011, p. iii, Routines as a response to bounded rationality the use of formal capital budgeting tools within investment decision-making. Other types of rules and routines which may impact on energy efficiency include: operating procedures (such as leaving equipment running or on standby); safety and maintenance procedures; relationships with particular suppliers; design criteria; specification and procurement procedures; equipment replacement routines and so on.
33. Montvalo, 2007, A11, organization capabilities refer to the firm's endowments and capabilities to carry out innovation… When the knowledge is not present in the firm adoption will depend on the firm's capacity to overcome shill lock-in, and to unlearn and acquire new skills. UNIDO, Inertia and the status quo bias: Routines can be surprisingly persistent and entrenched. … This type of problem has been labeled inertia within the energy efficiency literature and identified as a relevant explanatory variable for the efficiency gap.
34. Sardianou, 2007, p. 1419, Uncertainty about future energy prices (62%) is also characterized as a barrier [leading] to the postponement of energy efficiency measures.
35. Ito, 2010, p. 1, I find strong evidence that consumers respond to average price rather than marginal or expected marginal price.
36. UNIDO, 2011, p. 67, The government does not give financial incentives to improve energy efficiency, Lack of coordination between different government agencies, Lack of enforcement of government regulations, There is a lack of coordination between external organizations; Sardianou, 2007, p. 1402, [B]ureaucratic procedure to get government financial support is a barrier to energy efficiency improvements for the majority (80%) of industries.

TABLE V-2: KEY CHARACTERISTICS OF AND FINDINGS OF EMPIRICAL STUDIES ON EFFICIENCY GAP

Author, date	Geller, et al., 2006	Montevallo, 2007	Scleigh & Gruber, 2008	Brown et al., 2008	Sardinaou, 2008
Products	Multiple, aggregate sectors	Clean technologies	Commercial	4 type of GHG emitters	Industrial 19 sectors, 2848 Cos.
Method, period, size	Historic trend, 1973-2000	Review of empirical studies	Econometric. 9 variables	Review of Case studies 27 Expert Interviews	Survey
Scope		Primarily US, EU	Germany	US 15 sectors	Greed
National	US. Japan, Europe, Calif.				
Cross National					
Actors	Regulator		Producer	Producers	Perception of Barrier
Aspect Studied	Policy	Economic barriers	Attitude, Action	Barriers	Barriers
Key Findings	Substantial energy savings	appropriability access to capital lack of expertise Technological factors inertia stock of opportunities lack of capability in firms technology risk Organizational barriers capabilities	Most important factors: Split incentives, Lack of information Policy recommendation Lower transaction cost, Performance stds, Financial incentives Audits, Benchmarks Focus on smaller firms	Iron Triangle of Barriers Incumbent Technology Support Systems Business Risk of Innovation High Transaction Costs Unfavorable Policy Environment	Risk, Lack of knowledge Lack of skill, adjustment costs operating costs, Capital rationing, hurdle rates Culture, Gov't policy

Author, date	UNIDO, 2011 (Sorrell, Mallett & Nye	Jesseo & Rapson, 2013	Allcott & Wozny, 2010	Kok et al., 2010	Li, 2010
Products	Industrial production process		Autos, new and used	Buildings	Appliance
Method, period, size	160 case studies (64 evaluated)	Field Experiment 1150+ subjects	National 1.1 million auto sales	Regression 48 MSAs	Regression
Scope	National Cross National	US	US	US 48 Metro areas	UC California, PG&E sample
Actors	Market outcome	Consumers	Market outcome		Consumer
Aspect Studied	Attitude, Action	Response to information	Willingness to Pay	% Energy Star or LEED	Structural characteristics
Key Findings	7 main barriers: Imperfect information, Hidden costs. Access to capital, Split incentives, Bounded rationality, Risk/uncertainty Inertia	3 st dev. Large reduction with info. $\simeq$ 15%	\$.61/\$1.00 of potential economic gains Efficiency is a shrouded attribute	Accredited professionals local policy increase % of building	agency and information are important factors

Author. Date	Hyland, 2013	Mallaburn, 2013	Liu, 2014	Siderius, 2014	Argonne, 2013a,b	Wasai, 2013
Products	Buildings	Efficiency Programs	Industrial Firms	Digital Devices	Autos	Water heaters
Method, Period	Statistical, 2012	Historical, 1973-2013	Case Study, 2009	Market Data 2000-2013	Review of empirical studies	Sales 2000-2013
Size	240,000	UK	283 firms, 189 Resp.	18 Products		3000+
Scope	Ireland	Policy interventions	China	Global	U.S.	Australia
Actors	Buyers & Sellers	Policy makers	Management	Regulators	Policy makers	Consumers
Aspect	Sales price	Program characteristics	Technology adoption	Speed of change	Market barriers to efficiency	Rebate program
Finding	Efficiency increases price 16% (bottom to top); sales affected 2.5 time more than rentals	Good practices Market barriers addressed Problem of inconsistent support	17 barriers identified Keys barriers: lack of finance; lack of definitions lack of technology Inflexible structure Risk aversion	Policy Window for Stds. varies due to dynamic change	Decade or more for penetration Supply-side focus 5 major types of barriers Vehicle limitation, lack of availability, stds., uncertainty, uniqueness	High discount rate Sig. free riding Rebates induce some change Gas is preferable

Author	Sierchula, 2014	Jenn, 2013	Qui, 2014	Ren, N.D.	Lillemo, 2014	Park, 2014
Product	Elect. Vehicles	Hybrids	Appliances	Electricity	Energy Savings	Smart Grid
Method, period	National Stats, 2012	Econometric 2000-2010	Survey, 2013	Econometric 2004-2012	Econometric, survey	Survey, 2012
Size	30 nations	National sales data	43	1.6 million bills	1000 Internet	300
Scope	X-national	U.S.	U.S.	Canada	U.S.	Korea
Actors	Consumers, Policymakers	Consumers		Consumers	Internet users	Consumers
Aspect Studied	Incentives, other factors	Effect of Incentives	Adoption	Elasticity of demand	Attitudes	Technology acceptance model
Key Findings	Infrastructure is #1 Incentives Local production Incentives not Sufficient	3-20% Large subsidies needed	Risk aversion retards investment Tenure matters	small (-.08/-.13)	Procrastination slows adoption Awareness speeds adoption	Perceived risk equals ease of use Usefulness is 3x higher

Author	Axsen, 2013	Hicks 2014	Anderson, 2013	ITO, 2014	Ohler, 2014	de la Rue, 2014
Product	Workplace Vehicles	LED lighting	Auto safety	Electricity service	Energy Savings	Incentive program
Method, period	Survey, 2010	Survey, 2012	Survey, 2006	Statistical bill analysis 1999-2007	Survey, 2009	Case Study
Size	21	500 Craig's list	920	All bill data	1100	12+ programs
Scope	UK	4 U.S. cities	Sweden	California	US Midwest	X-national
Actors	Users	Policy makers	Willingness to pay time frame	Pricing	Motives, Cost/comfort	Design elements
Aspect Studies	Attitudes	Policy Impact	WTP sensitive to time	Respond to avg. rather	Self-interest >	Target subsidies at
Key Findings	Social Influence Identity	Rebound extend >Intensify (7to1) Price sensitive Lifetime rarely considered Education is important	1 year 70% > 1 month	than marginal price Non-linear pricing is ineffective	concern for commons Combine tools private & public	high efficiency products Holistic approach supply & demand

Author, date	Sierchula, 2014	Giraudet, 2014	Green et al. 2012	Rexhauser, 2014	Maidment, 2014	IEEP, 2013
Products	Elect. Vehicles	Bldg. retrofit	Bldgs.	Innovation>Profitability	Energy use	Energy efficiency
Method, period	National Stats, 2012	Simulation on REC data empirical estimate	Survey, 2008	Statistical analysis, 2008	Statistical meta-analysis	Review of empirical studies
Size	30 nations	Large national data set	313	3600 innovations	36 studies	3-Res. 5-Ind.
Scope	X-national	U.S.	Netherlands	Germany	Global	EU
Actors	Consumers, Policymakers	Policymakers	Policymakers	Policymakers	Policymakers	Policymakers
Aspect Studies	Incentives, other factors	Moral Hazard	Standards	Profitability	Health impact	Cost/benefit ratio macroeconomics
Key Findings	Infrastructure is #1 Incentives Local production Incentives not sufficient	Minimum efficiency performance Std. beats insurance approach	Improves efficiency	Regulation more important than voluntary Improved resource efficiency improves profit	Small but significant impact	Positive jobs C/B ratio varies 3-1 to 8-193

Author, date	Ito, 2011	Ozaki & Sevastyanova, 2011	Noailly, 2012	Mareur, et al., 2013
Products	Appliance	Hybrid Autos	Buildings	Appliances
Method, period, size	Regression	Survey, Jan. 2009, 1200+	Econometric, 9 nations 9 variables	Historical analysis
Scope	Southern CA	US	US	
Actors	Consumer	Consumer	Regulator	Policy makers
Aspect Studied	Price response	Attitude	Attitude, Policy	Cost, impact on features
Key Findings	Consumers respond to average, not marginal prices	Financial benefits are important, Social norms influence consumer behavior Practical, experimental & affective values should be communicated	Regulations significantly stimulate innovation, R&D expenditures slightly increase innovation, Energy price has little effect on innovation	Declining cost no reduction in features

Author, date	Poortinga, 2003	Kurani & Turentine, 2004	Li, et al., 2009	Consumer Fed. , 2010
Products	Energy-saving measures	Autos	Willingness to pay for R&D Expenditures	Autos
Method, period, size	National Poll 455 respondents	Interview, 57 respondents	Contingent Valuation, National Referendum 2000+ respondents, split sample	National Poll 2000
Scope	Netherlands	US	US	US
Actors	Consumers	Consumer Market outcome	Consumers	Consumer
Aspect Studied	Preference for types	Attitudes	Attitudes	Attitudes
Key Findings	Technical > Behavior > Shift in consumption Home > Transport Amount of energy saved is unimportant Environmental concern increases support	Consumers: do not pay much attention to fuel cost have ephemeral knowledge, at best are unable to estimate savings are overly optimistic about savings associate fuel economy with poor quality see vehicle as multi-attribute where fuel economy is not important use crude reference points: loan life, monthly cash flow Notes Importance of	Willingness to pay: $137 per year > Increase R&D spending Reduce dependence on foreign Promote crop based fuels Demographics are important Income Gender Attitudes that matter Importance of energy issues Political ideology	Payback periods tested 3-5 yrs garner majority Lack awareness of US oil resources Information increases support for higher stds. 2/3 want higher mileage

Author, date	Consumer Fed, 2011a	Consumer Fed., 2011b	Consumer Rpts. 2010	Consumer Repts., 2012	Arimura, 2009
Products	Autos	Appliances	Household Energy	Autos	Electricity efficiency programs
Method, period, size	National Poll 1000+	National Poll 1003	National Poll 1536 Home Owners	National Poll 1702 random	Regression ~ 700 utilities, 5,000 obs.
Scope	US	US	US	US	US
Actors	Consumers	Consumer	Consumers	Consumers	Utility-regulator
Aspect Studied	Concerns	Attitudes	Purchases, Attitudes	Concerns in purchase	Cost of saved energy
Key Findings	Great concern about: Gasoline prices (80+%) Mideast oil Dependence (70+%) Strong majority support for stds. 80% support of stds. 60% with 5 yr payback	Payback periods tested 3-5yr garner strong 70+% favorable 70+% support for stds Awareness increases support for stds.	Purchases of Efficient: Bulbs (81%) Energy Star (44%) Windows (29%) Insulation (24% HVAC/Water Heat (21-23%)	Fuel economy (34%) Quality *17%) Safety (16%) Performance (6%) Style (6%) Small cars most popular 2/3 want higher mileage	$0.06/kwh existing states $0.03/kwh new states

Author, date	Freidrich, et al. 2009	Dale et al., 2009	Kiso, 2009	Hwang & Peak, 2010	Weiss, et al., 2010
Products	Utility efficiency programs	RAC, Refrig CAC, Clothes Wash	Autos	Autos, 11 innovations	6 Large Appliances
Method, period, size	Direct cost estimates, 14 states 53 year covered	Historic trend, 1965-2005 Time series/cross sectional	Historic trends 1988-2006	Historic trends 1975-2001	Historic Trends Energy & cost data
Scope	US	US	Japanese Cars sold in US	US	Europe
Actors	Utility-regulator	Regulator Market outcome	Market outcome	Regulators Market outcome	Market Outcome
Aspect Studied	Cost of saved energy	Projected cost increase	Regulation	Regulation	Productivity Growth
Key Findings	Electricity: Avg. $0.025/kwh Range - $0.016-$0.044 Gas: Avg. $0.37/therm Range - $0.27-$0.55	2.1 times cost increase expected due to: Price increase less than expected due to: Technological change, Decreasing mark-ups, Economics of scale	Regulation induces innovation	Projected cost increase 1.48 times actual	faster after policy intervention

Author, date	Wie, Patadia & Kammen, 2010	Desroches, et al., 2011	Woolf, et al., 2011
Products	Electricity Resources	Learning Curves for Appliances	Learning curves for Standard
Method, period, size	Cost data 2010	Energy & cost data Long term series	Energy & cost data Long term series
Scope	US	US	US
Actors	Market Outcome	Market Outcome	Market Outcomes
Aspect Studied	Jobs/Gwh equiv.	Productivity Growth	Productivity growth
Key Findings	Efficiency yields 2 to 3 times as many jobs	faster after policy intervention	

TABLE V-3: MARKET BARRIERS AND IMPERFECTION IN CLIMATE CHANGE ANALYSIS

EXTERNALITIES 54, 59, 64, 67, ZL
Research and Development 20, 22, 23, 48, 52, E
Importance of learning by searching 27, 31, 38, E
Deployment: Importance of learning by doing 27, 10, 31, 38, E
Economics of Scale/returns to scale 6, 38, 41, 47, G
Localization 24, 38, 45, H

ENDEMIC
Perverse incentives:
allocation of fuel price volatility 20, 50, 68, O
Asymmetric information 21, 48, Q

BEHAVIOR
Motivation/willingness to pay 51, ZM
Sluggish demand response 20, 23, W
Agency 18, 8, X
Organizational 58,ZN
Risk Aversion 6, Y
Calculation (17, 47, Z)

MARKET STRUCTURE:
Cost Structures: Long investment cycles, increasing returns to scale, network effects 8, 28, 33, 48, I
Challenge of creating new markets: Undifferentiated product 20, 23, 28, 42, J
Entry Barriers: Capital Cost, access to network 20, 41, 47 48, K
Lack of competition hinders innovation 41, 48, L
Regulatory Risk
Carbon tax level and permanence 21, 30, 40, 44, P

TRANSACTION COST *N, O*
Uncertainty: as a cause of underinvestment 8, 21, 26, 43, 47, R
Fuel price volatility 20, 33, S
High risk premia on new technologies 28, T
Information: Value of information 2, 22, 56, U
Sunk costs and embedded infrastructure 21, 48, V

POLITICAL POWER
Power of incumbents to hinder alternatives 20, 45, ZA
Monopolistic structures and lack of competition *u*, 24, 39 41, 46, 47, ZB
Importance of institutional support for Alternatives 22, 30, ZC
INERTIA:
Cost of Inertia 1, 14, 28, M
Importance of inertia/stock of knowledge 9, 24, 37, 45, N

EFFECTIVE POLICY RESPONSES
Public goods 24, 49, ZC
Institution Building 22, 30, 49, ZE
Research and Development 5, 10, 20, 23, 25, 26, 28, 32, 35, 37, 47, ZF
Capital subsidies Adders, premium prices 6, 41, ZG
Obligations/Consenting 25, 28, 35, 47, M, ZH
Standards 8, 22, ZI
Feed in Tariffs 28, 41, 45, 47, ZJ
Merit order 20, 21, ZK

EVIDENCE ON THE INEFFECTIVENESS OF PRICE/TAX AS POLICY
Price Insufficiency 4, 11, 15, 20, 19, 25, 29, 35, 41, 47, 48 A
Tax: Difficulty of setting and sustaining "optimal" levels 20, 19, 47, B
Tradable permits do not increase innovation (5, 36, C)

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A Walz, Schleich and Ragwitz, 2011, p. 16, Power prices, however, are not found to drive patent activity. Hence power prices alone would likely not be sufficient to spur innovation activities in wind and arguably also other, currently less cost-efficient renewable technologies.

B The stability and long term vision of policy target setting are important policy style variables, which contribute to the legitimacy of technology and provide guidance of search…

C Calel and Dechezloprete, 2012, p. 1. "[M]ore refined estimates that combine matching methods with different-in-difference provide evidence that the EU ETS has not impacted the direction of technological change. This finding appears to be robust to a number of stability and sensitivity checks. While we cannot completely rule out the possibility that the EU ETS has impacted only large companies for which suitable unregulated comparators cannot be found, our findings suggest that the EU ETS so far has had at best a very limited impact on low-carbon technological change.

D Massetti and Nicita, 2010, p. 1The presence of market failures in the R&D sector, as emphasized by Griliches, is confirmed by the evidence, virtually found in all studies, that the social rate of return on R&D expenditure is higher than the corresponding private rate; estimates of the marginal social rate of return on R&D range between 30 and 50 percent and of private return between 7 and 15 percent… When it comes to technologies for carbon emissions reduction, the difference between private and social rate of return to R&D investment arises from a double externality; the presence of both environmental and knowledge externalities. First, without a price on carbon that equates the global and the private cost of emitting GHGs, all low emissions technologies are relatively disadvantaged and the level of investment is therefore sub-optimal. Second, the private return to investment in R&D is lower than the social return of investment due to the incomplete appropriability of knowledge creation, thus pushing further away investment for the socially optimal level.

E Massetti and Nicita, 2010, p. 17, We find that a [carbon] stabilization policy together with an R&D policy targeted at the only energy sector is significantly less costly than the stabilization policy alone. We find that energy R&D does not crowd-out non-energy R&D, and thanks to intersectoral spillovers, the policy induced increase in energy efficiency R&D spills over to the non-energy sector, contributing to knowledge accumulation and the reduction of knowledge externalities.

F Gross, et al., p.18, The phenomenon of "learning by doing", whereby costs for technologies reduces as experience is gained from deployment of the technology creates lock-in. It also creates better, cheaper technologies. The incumbent fossil and nuclear forms of generation have had many decades of technical refinement through experience which have driven their costs down to low levels relative to new, renewable technologies. In part, this was financed by considerable public subsidy… The very same effects that created lock-in to high carbon systems offer the potential to decrease the costs and improve the commercial/consumer attractiveness of new forms of low carbon energy.

G Qui and Anadon, pp. 782, The size of the wind farm is another significant factor in all specifications… indicate that a doubling in wind farm size could lead to price reductions of about 8.9%.

H Qui and Anadon, pp. 782, Localization rate is a significant factor in all specifications… indicate that a doubling of localization rate was associated with reductions in wind electricity price ranging from 10.9% to 11,4%.

I de Cian and Massimo, 2011, p. 123, Uncertainty and irreversibility are two features of climate change that contribute to shape the decision making process. Technology cost uncertainty can depress the incentive to invest. The risk of underinvestment is even more severe considering that energy infrastructure has a slow turnover. Capital irreversibility and uncertainty heighten the risk of locking into existing fossil-fuel-based technologies. Additional investments are sunk costs that increase the opportunity cost of acting now… The result is reinforced when uncertain costs have a large variance, showing that investments decrease with risk. Jamasb and Nicita, (2007, p 8) R&D activity can be subject to three main types of market failure namely indivisibility, uncertainty and externalities.

J Kalkuhl, Edenhofer and Lessmann, 2012, p. 10, The energy sector is highly vulnerable to lock-in because electricity is an almost perfect substitute for consumers. In contrast, many innovations in the manufacturing or entertainment electronics sector provide a new product different from existing ones (e/g/ flat screens vs. CRT monitor). The low substitutability implies a high niched demand and, thus, provokes ongoing learning-by-doing although considerable spillovers exist and market prices are distorted.

K Gross, et al. 2012, p. 18, In the energy sector, such "network externalities" rise for example in the physical structures of large scale high voltage alternating current (AC) power grids themselves (themselves a reminders of early energy planners' desire to locate power stations close to the source of coal) which now provides a cost advantage to large scale centralized station over distributed alternatives.

L Gross, et al., 2012, p. 10, Either policymakers around the world are blind to the logic of economic theory, or there are factors that overwhelm or undermine the theoretical Pigouvian considerations. The rest of this paper discusses the considerations t

M Grimaud and Lafforgue, 2008, p. 1…20,The main results of the paper are the following: i) both a carbon tax and a green research subsidy contribute to climate change mitigation; ii) R&D subsidies have a large impact on the consumption, and then social welfare, as compared to the carbon tax alone; IV) those subsidies allow to spare the earlier generations who are, on the other hand, penalized by a carbon tax….In a second-best world, a carbon tax used alone leads to a higher social cost (with respect to first-best) than a research policy alone;

N Jamasb and Kohler, 2007, p. 9, Information technology and pharmaceuticals, for example, are both characterized by high degrees of innovation, with rapid technological change financed by private investment amounting typically to 10-20% of sector turnover. This is in dramatic contrast with power generation, where a small number of fundamentals technologies have dominated for almost a century and private sector RD&D has fallen sharply with privatization of energy industries to the point where it is under 0.4% of turnover.

O Gross, et al., 2012, p. 14, Capital intensive, zero fuel cost power stations like wind farms, need to cover their long run average costs—namely the cost of capital. They can neither actively affect/set marginal power prices nor respond to power price changes, except to curtail output, which does not save costs (as there are no fuel cost to save), but does lose revenue. However, carbon prices only affect the marginal price of fuel and power. We should therefore expect that an emissions trading scheme will encourage fuel switching from coal to gas, and efficiency first and renewable energy (or indeed nuclear) investment last. This is exactly what we have seen in reality.

P Reuter, et al., 2012, p. 253, If there is uncertainty about the future development of feed-in-tariffs, much higher levels will be needed to make renewable investment attractive for energy companies.

Q Gross, 210, p. 802, "A range of factors that relate to the amount and quality of information about technology costs and risks available to policymakers and market participants are relevant when considering incentives and investment in new technologies: Policymakers may have relatively poor information about costs for emerging technologies. 'Appraisal optimism' (where technology/project developers under estimate the cost of unproven technology/systems) is a common feature in the development of new technologies. When providing cost data to policymakers technology developers or equipment suppliers may also have incentives to up or play down costs and potential according to circumstances. Where new or unproven technologies are being utilized for the first time, information about costs may be limited for all concerned... There may be an 'option value' to potential investors in waiting (delaying investment) where there is poor information and high levels of technology and market risk. The first conclusion is that policymaking in the energy area needs new tools of analysis that can deal with the market risks associated with policy design… In particular, policymakers need to be mindful of the role of revenue risk as well as cost risk in the business case for investment.

R Fuss and Szolgayosva, 2010, p.2938, We find that the uncertainty associated with the technological progress of renewable energy technologies leads to a postponement of investment. Even the simultaneous inclusion of stochastic fossil fuel prices in the same model does not make renewable energy competitive compared to fossil-fuel-fired technology in the short run based on the data used. This implies that policymakers have to intervene if renewable energy is supposed to get diffused more quickly. Otherwise, old fossil-fuel-fired equipment will be refurbished or replaced by fossil-fuel-fired capacity again, which enforces the lock-in of the current system into unsustainable electricity generation.

S Gross, et al., 2012, In short,, whilst carbon pricing can create conditions that make investment in wind more attractive, there are uncertainties associated with wholesale power prices, carbon permit prices, and future political decisions on carbon tax levels. These make wind investment more risky, which drives up the cost of capital investors require higher returns), and discourage investment.

T Gross, Blyth and Heponstall, 2012, p. 802.The first conclusion is that policymaking in the energy area needs new tools of analysis that can deal with the market risks associated with policy design… In particular, policymakers need to be mindful of the role of revenue risk as well as cost risk in the business case for investment.

U Horbach, 2007, p. 172, Environmental management tools help to reduce the information deficits to detect cost savings (especially material and energy savings) that are an important driving force of environmental innovation.

V Weyant, 2011, p. 677, The infrastructure for producing, distributing, and promoting the industries' current products require large investments that have already been incurred.

W Jamasb and Kohler, 2007, Thus, the 'market pull' forces reach deep into the innovation chain…This is in contrast with power generation, where a small number fundamental and private sector RD&D has fallen sharply with privatization of energy industries. technologies have dominated for almost a century and private RD&D has fallen sharply with privatization... In turn, market pull measures are devised to promote technical change by creating demand and developing the market for new technologies.

X Weyant, 2011, p. 675, The situation can develop from several different types of market failure, including poor or asymmetric information available to purchasers, limits on individual's ability to make rational decisions because of time or skill constraints, principle agent incongruities... and lack of financing oppoertunities.

Z Green, 2010, p. 6, The rational economic consumer considers fuel saving over the full life of a vehicle, discounting future fuel savings to present value. This requires the consumer to know how long the vehicle will remain in operation; he distances to be traveled in each future year, the reduction in the rate of fuel consumptions, and the future price of fuel…. The consumer must also estimate the fuel economy that will be achieved in real world driving based on the official estimate. Finally, the consumer must know how to make a discounted present value calculation, or must know how to obtain one… The utility-maximizing rational consumer has fixed preferences, possesses all complete and accurate information about all relevant alternatives, and has all the cognitive skills necessary to evaluate the alternatives. These are strict requirements indeed….

ZA Nicolli and Vona, p. 1, Our empirical results are consistent with predictions of political-economy models of environmental policies as lobbying, income and to a less extent, inequality have expected effects on policy. The brown lobbying power, proxied by entry barriers in the energy sector, has negative influence on the policy indicators even when taking into account endogeneity in its effect. The results are also robust to dynamic model specifications and to the exclusion of groups of countries

ZB Weyant, 2011, p. 677, Further complicating matters, existing companies in energy-related industries --- those that produce energy, those that manufacture the equipment that produces, converts and uses energy, and those that distribute energy – can have substantial incentives to delay the introduction of new technologies. This can happen if their current technologies are more profitable than the new ones that might be (or have been) invented, or if they are in explicitly (oil and gas) or implicitly (electric generation equipment producers and automakers) oligopolistic structured, or if they are imperfectly regulated (electric and gas utilities). The incentive arises partly because the infrastructure for producing, distributing, and promoting the industries' current products require large investments that have already been incurred.

ZC Horbach, 2008, p. 172, An environmentally oriented research policy has not only to regard traditional instruments like the improvement of the technological capabilities of a firm but also the coordination with soft environmental policy instruments like the introduction of environmental management systems.

ZD Johnstone and Haccic, 2010, p.25 "Since innovating in storage technologies is an important complement to innovation in all intermittent renewable generating technologies such a strategy reduces the risk of (not) picking winners. Moreover, the technologies are at a relatively early stage of development, with greater need for support.

ZE Wilson, et al., p. 781, The institutions emphasized in our analytic framework are twofold: the propensity of entrepreneurs to invest in risky innovation activities with uncertain pay-offs; and shared expectation around an innovation's future trajectory. Other important and related institutions include law, markets and public policy. Public resources are invested directly into specific innovation stages, or are used to leverage private sector resources through regulatory or market incentives structured by public policy…. New technologies successfully diffuse as a function of their relative advantage over incumbent technologies. For energy technologies, this can be measured by the difference in cost and performance of energy service provision in terms of quality, versatility, environmental impact and so on. Many of these attributes of relative advantage can be shaped by public policy as well as the other elements of the innovation system.

ZF Walz, Schleich and Ragwitz, 2011, p. 5, The specific advantage of feed-in tariffs is seen in lower transaction costs and reduced risk perception for investors and innovators, which are extremely important especially for new entrants and for financial institutions.

ZH Walz, Schleich and Ragwitz, 2011, p. 16, Our econometric analyses also imply that the existence of targets for renewables/wind and a stable policy support environment are associated with higher patent activity.

ZI de Cian and Massimo, 2012, pp. 1333…15, Against this evidence, regulation such as Emissions Performance Standards (EPS) that set a maximum threshold for the emission intensity of power generation in terms of grams of CO_2 per kilowatt hour could be justified as a way to reduce uncertainty exposure... [W]e have also pointed out that the optimal penetration of renewables is slow, even when facing a given deterministic carbon price.

ZG Rubbeike and Weiss, 2011, Including non-price-based variable increases the fit of the model… the coefficients for grants is positive and highly significant.

ZJ Gross, Blyth and Heptonstall, 2010, 802,The international evidence suggests that in most cases countries with fixed price schemes have been more successful at deploying renewables than those with trading scheme. Whilst the reasons for this are complex and varied it appears likely that investment risk plays an important role.

ZK Gross, Blyth and Heptonstall, 2010, 798,The result is that significant long-run fuel price uncertainty.. cannot usually be hedged through contractual arrangements. Long-run fuel price changes, like time of day rates, are mediated by the current market arrangements but remain fundamental to electricity prices.

ZLMaxim, 2014, 284, Measuring the sustainability of the energy sector has evolved around three main dimensions: environmental, economic and social.

ZMCroson, 2014, 336, This literature has often discussed how traditional policy instruments (like taxes), or traditional methods (like cost-benefit analysis), can be affected by behavioral concerns, including taxes crowding out public good contributions or the impact of hyperbolic discounting or reference dependent preferences on environmental policy. This research which integrates human limitations into environmental economics is refreshing, and shows great promise. Scholars, policy makers and politicians have enthusiastically embraced this research. One reason may be the increasing awareness of environmental problems, and of the evident difficulty in solving these problems using traditional instruments. Another reason may be the low cost of many behavioral interventions. An additional, more concealed, reason may be a general distrust in the market system and classical economics by individuals in these positions.

ZN Inoue, 2013, 162, our finding shows that the organisational and managerial factors of firms are important in examining environmental R&D.

VI. POLICY IMPLICATIONS OF THE MARKET ANALYSIS

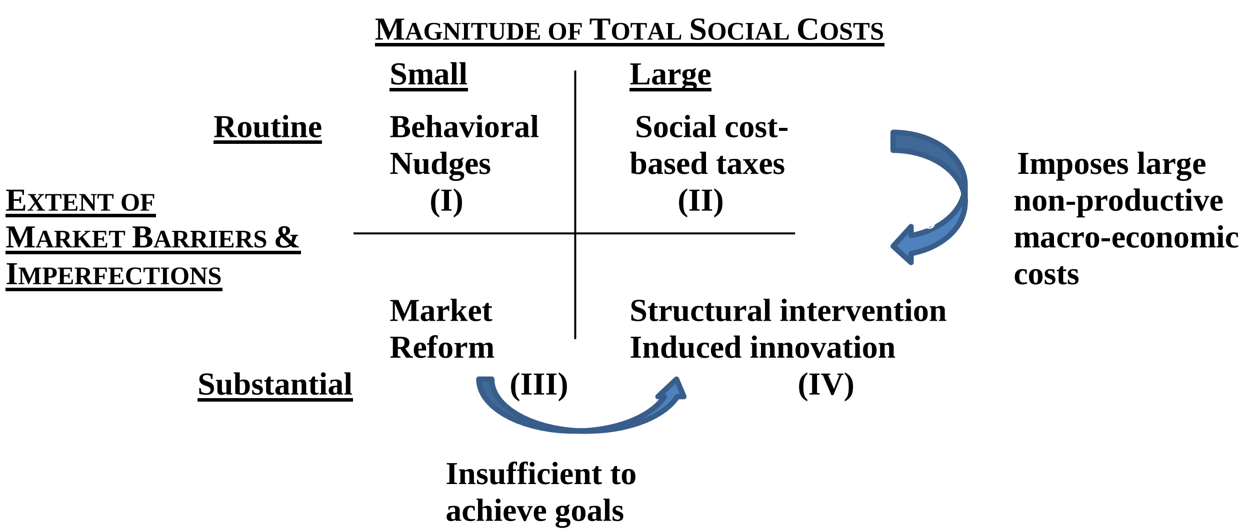
A. The Increasing Urgency and Payoff to Policy Action

The efficiency gap analysis and debate are not about externalities, although the environmental, national security and macroeconomic impacts of energy consumption stimulated interest in the value of reducing consumption, particularly after the oil price shocks and subsequent economic recessions of the 1970s. Although externalities like these attract attention, these are not the underlying cause of the efficiency gap. Because they are externalities, they are not priced into the market transactions, and we would not expect market behavior to reflect their value. The efficiency gap arises from the failure of market transactions to reflect the costs of energy that are reflected in its price.

To the extent that there are externalities associated with energy consumption, they magnify the concern about market barriers and imperfections, if only because they would make efforts to respond to externalities more difficult. If climate change is recognized as an external cost of energy consumption, it magnifies the importance and social cost of failing to address the efficiency gap. This is where the efficiency gap and climate change analyses intersect. Large externalities magnify the impact and importance of other market imperfections, which affect the ability of policy to respond and reduce negative externalities or capture the value of positive externalities.

At a high level, the most important implication of this broadening of the framework to include large externalities is to underscore the need for vigorous policy action to address a problem that is now seen as larger and more complex than it was in the past. It is the combination of substantial market imperfections and large externalities that demonstrates there is an urgent need for vigorous policy action, as suggested by Figure VI-1.

Figure VI-1: Typology of Policy Challenges and Responses



Market failures associated with environmental pollution interact with market failures associated with the innovation and diffusion of new technologies. These combined market failures provide a strong rationale for a portfolio of public policies that foster emissions reduction as well as the

> development and adoption of environmentally beneficial technology. Both theory and empirical evidence suggest that the rate and direction of technological advance is influenced by market and regulatory incentives, and can be cost-effectively harnessed through the use of economic-incentive based policy. In the presence of weak or nonexistent environmental policies, investments in the development and diffusion of new environmentally beneficial technologies are very likely to be less than would be socially desirable. Positive knowledge and adoption spillovers and information problems can further weaken innovation incentives. While environmental technology policy is fraught with difficulties, a long-term view suggests a strategy of experimenting with policy approaches and systematically evaluating their success.[112]

If market imperfections are routine and the social costs of poor market performance are small (cell I), modest policies like behavioral nudges may be an adequate response. If market imperfections are small and costs are large (cell II), then price signals might be sufficient to deal with the externalities. If market imperfections are substantial but costs are small, market reform would be an appropriate response (cell III), since the slow response and long time needed to overcome inertia does not impose substantial costs. If both market imperfections and social costs are large (cell IV), more aggressive interventions are in order.

An analysis by Madrian of the value of bringing behavioral economics into the policy picture provides a useful framework to summarize this argument (see Figure VI-2). He identifies behavior barriers that shift the demand curve to reduce that amount of a good with a positive externality that consumers buy. Behavioral nudges can move consumers closer to the social optimum. In our analysis, we identify market structural and new institutional barriers that drive consumer purchases farther from the optimum. We further identify supply-side market barriers that inhibit investment in and output of the good, moving it away from the optimum. I have constructed the graph to generally reflect the magnitude of effects suggested by the literature.

- Behavioral factors are a modest part of the problem.
- Structural and new institutional factors are at least as important as behavioral and they affect both the supply and the demand sides.
- The supply-side is at least as important and the demand-sdie.
- The externality market failure is a large cause of the underinvestment, although smaller than the market structure, institutional and behavioral

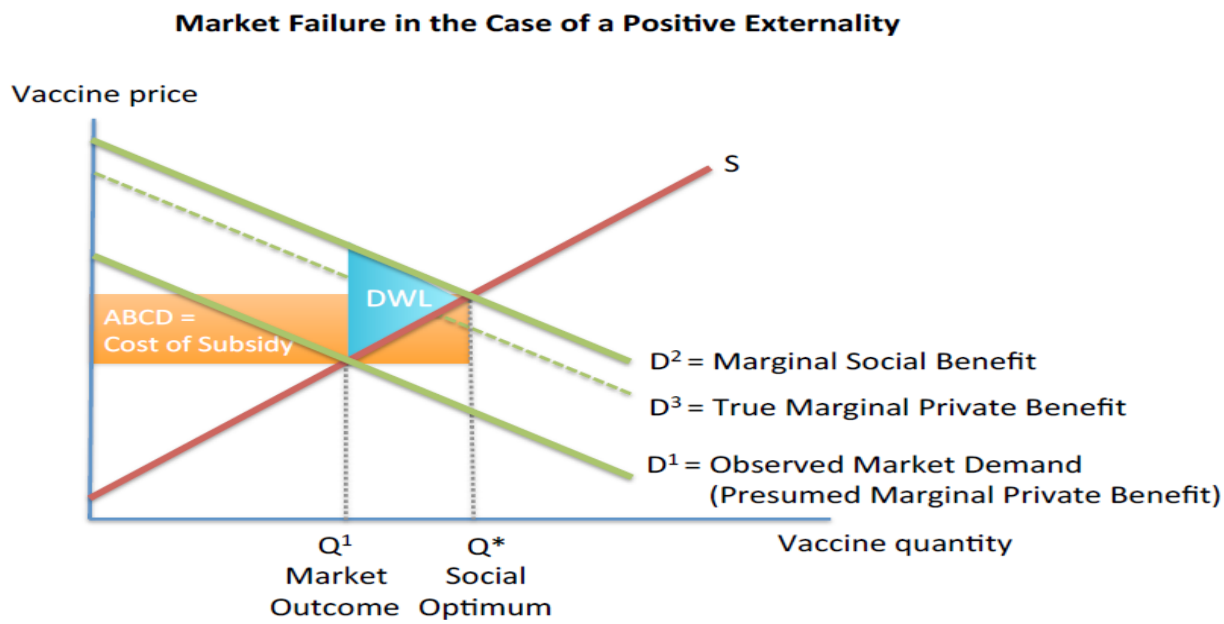
The challenge is to choose policies that reduce the market barriers in an effective (swift, low cost) manner. Given the magnitude and nature of climate change and the extensive nature of market imperfections, reinforced by inertia that must be overcome rapidly, each of the policy approaches has a role to play and an “all of the above” approach is in order, but the structural change is vital because it influences how effective the other policies can be. The sequence is important because addressing severe market failure that have large social costs can impose an extraordinary burden on society. The farther and faster structural change is implemented, the easier it is for the other policies to work.

The findings of this literature can be summarized at the highest level by noting that the presence of the market imperfections means that policies that successfully overcome them yield

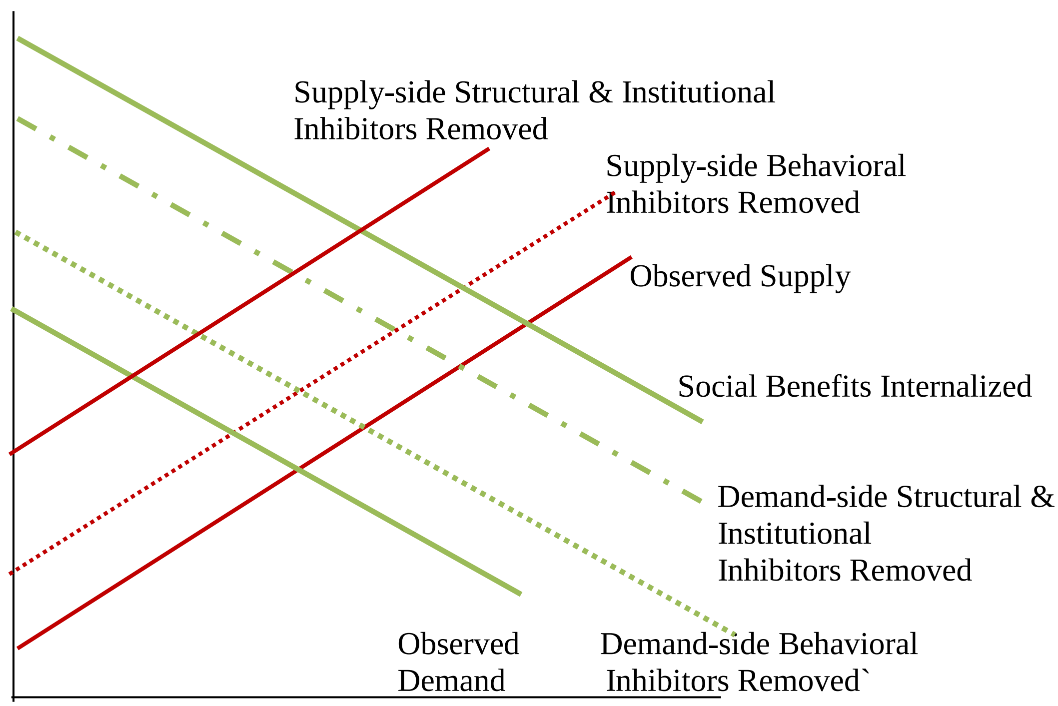
[112] Jaffe, Newell and Stavins, 2005, p. 164.

substantial benefits it terms of reducing the cost and accelerating the transition to a low carbon sector. This was the conclusion drawn in the LBL analysis of the "efficiency gap."

FIGURE VI-2: WELFARE ECONOMICS OF MARKET BARRIERS AND POSITIVE EXTERNALITIES



Treating Decarboniztion as a Positive Externality & Incorporating All Demand and Supply-side sources of Mark Failure



Source: Upper graph from Brigitte C. Madrian, *Applying Insight from Behavioral Economics to Policye Design*, NBER Working Paper, 20318, p. 7.

- A general finding that the social return to R&D is twice as large as the private return appears to hold in the energy technology space.[113]
- Estimates of the speed of innovation suggest a one to two decade delay in the introduction of new technologies, if targeted policies to accelerate the diffusion of innovation are not adopted.[114]
- Targeted financial incentives deliver three times as much monetary support for alternatives.[115]
- Because of the magnitude of the change required, the macroeconomic impacts of policy takes on great significance, with analysis of the macroeconomic savings from a smoother, swifter transition yielding very substantial projected economic savings of at least 50%.[116]

- In the large distance between the current equilibrium and the equilibrium that reflects the removal of all barrier, the figure also reflects the fact that climate change possess two characteristics that set it apart and make it a particularly difficult challenge for traditional neoclassical analysis as it has come to be practices in the U.S. It involves very large impacts[117] and a great deal of uncertainty,[118] stemming in part for the very long time frame of analysis, which raises a host of questions about the discount rate.[119] These characteristics interact to argue for a precautionary principle that

---

[113] Qui, 2012, Massetti and Nicita, 2010.
[114] Dechezlepetre, et al., 2011.
[115] Nordhaus, Shellenberger and Trembath, 2012, calculate that that targeted subsidies yield approximately three times the incentive to invest in low carbon alternatives (compared to coal) as a general carbon tax.
[116] Grubb Chapuis and Duong, 1995, p. 428,
[117] Corradini, et al., 2014, p. 248, Conventional benefit–cost analysis incorporates the normally reasonable assumption that the policy or project under examination is marginal. Among the assumptions this entails is that the policy or project is small, so the underlying growth rate of the economy does not change. However, this assumption may be inappropriate in some important circumstances, including in climate-change and energy policy. Dietz and Hepburn, 2013, 61, we conclude that if there is cause to suspect a project under evaluation is not 'small', in the sense that the range of net benefits might be a significant share of aggregate consumption, then the NPV rule will not suffice. Instead, analysts must fall back on a model, which is capable of evaluating the underlying change in social welfare brought about by the project.
[118] Wouter, Botzen and van den Bergh, 2014, p.1, This paper shows that applying distinct decision or social welfare criteria can result in different optimal policies of climate control, notably if climate change impacts are uncertain. Hwang, Chang, and Tol, 2013, p. 415, Uncertainty plays a significant role in evaluating climate policy, and fat-tailed uncertainty may dominate policy advice. Should we make our utmost effort to prevent the arbitrarily large impacts of climate change under deep uncertainty? In order to answer to this question, we propose a new way of investigating the impact of (fat-tailed) uncertainty on optimal climate policy: the curvature of the optimal carbon tax against the uncertainty. We find that the optimal carbon tax increases as the uncertainty about climate sensitivity increases, but it does not accelerate as implied by Weitzman's Dismal Theorem. We find the same result in a wide variety of sensitivity analyses. These results emphasize the importance of balancing the costs of climate change against its benefits, also under deep uncertainty.
[119] Davidson, 2014, p. 40, Most people share the moral intuition that we ought to refrain from harming others, and ought to compensate them if we were unable to prevent harm. To regain a reflective equilibrium between such deontological intuitions and economic theory there is a need to accept different discount rates for different situations: a zero consumption discount rate in the case of cost–benefit analysis of measures to prevent wrongful harm to future generations, and standard discounting in all other cases. Applying a zero consumption discount rate means that future generations are automatically largely compensated for climate damage that remains unmitigated. Roemer, 2013, 141, that every individual, no matter when born, has an equal right to well-being. That justification

supports greater reduction in emissions[120] and the adoption of overlapping policy instruments.[121]

The literatures reviewed above contain a number of evaluations of the efficacy of specific policy instruments in both the efficiency gap context and the climate change context. One of the clearest conclusions that can be derived from these assessments is that performance standards – appliance efficiency standards, auto fuel economy standards, building codes and emission standards – are seen as very attractive policy options because they are effective and address many important barriers. Table VI-1 identifies the market barriers and imperfections that can be addressed by a well-designed standard.

My review of the climate change literature shows that it is a policy challenge to which performance standards are ideally suited.

- Significant market barriers and imperfections exist.
- Social (externalities) and transition costs are substantial.
- The need to overcome inertia is great and urgent.
- Dynamic conditions make the sector ripe for a transformation that will allow goals to be achieved at a far lower cost than static analysis suggests.

Achieving these benefits requires policies that address the market imperfections and barriers on both the supply and demand sides of the market.

B. Performance Standards as a Policy Response to Market Imperfections, Barriers and Failures

Performance standards should be among the first assets added to the policy portfolio. They are a structural intervention that address more barriers and are more effective in overcoming them and more likely to achieve their goals. The ability of standards to address the market failure problems goes beyond their ability to address the barriers to investment in efficiency enhancing technologies that focus on consumer behavioral and transaction cost economics. Standards can address the behavioral and transaction cost problems that afflict the supply-side of the market, as well as some of the structural problems.[122] This evaluation of the important role of performance standards is supported by the recent evaluations.

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is that future generations may not exist. In an earlier article published here, I explained this view, and criticized economists who deviate from it: the practical aspect of this deviation is to choose discount rates which are far too high, thus relegating future generations to lower utility than they a priori have a right to.

[120] Aldred, 2013, p. 132, When decisions are taken in conditions of Keynesian or Knightian uncertainty, and when there is a threat of serious or irreversible environmental damage, the Precautionary Principle is often recommended to guide decision-making. However, the Precautionary Principle has been widely criticised. In response to these criticisms, a qualitative version of the Precautionary Principle is developed which draws its normative content from a blend of formal decision theory and political philosophy. It is argued that precautionary action can be justified by some flexible combination of uncertainty and incommensurability. The 'greater' the uncertainty, the 'less' incommensurability is required to justify precautionary action, and vice versa. Throughout the paper, the arguments are explored using the example of climate change decision problems.

[121] Lecuyer and Quirion, 2013.

[122] See e.g., de Cian and Massimo, 2012, pp. 1333…15, Against this evidence, regulation such as Emissions

Resources for the Future identifies standards conceptually as one of the two main policies to address the behavioral market barriers and imperfections, with labelling being the other policy identified. Analysts at LBL offered a broader view of the impact of performance standards on market.

> In some cases the direct regulation of equipment performance might side-step problems of asymmetric information, transaction costs and bounded rationality, obviating the need for individual consumers to make unguided choices between alternative technologies.[123]
>
> Subjective uncertainty, however, may stem from the fact that precise estimates of energy prices and equipment performance are costly to obtain from the perspective of individual consumers. If the costs of gathering information were pooled across individuals, substantial economies of scale should be achieved which could reduce the uncertainties associated with certain technologies.
>
> The informational requirements that must be met to identify an efficient tax regime, however, are particularly onerous. The government must know not only the level of consumer expectations but also the specific way in which they are formed, and this information must be effectively conveyed to manufacturers through the structure of the tax. In practice, such information may be very difficult to obtain reducing the efficacy of tax instruments.
>
> Such limitations suggest a potential role for the direct regulation of equipment performance. Energy efficiency standards led to demonstrable improvement in the fuel economy of automobiles in the 1970s and early 1980s. State and local governments set requirements concerning the thermal performance of building elements. [124]

Detailed evaluations of policies in practice, suggest that standards are more effective than labels and address other barriers. For example, the European study summarized in Table VI-1 identifies over half a dozen ways in which performance standards address barriers. The barriers addressed include transaction costs, economic uncertainties, lack of technical skill, barriers to technology deployment, inappropriate evaluation of cost efficiency, insufficient and incorrect information on energy features, operational risks, and bounded rationality constraints. Similarly, in the McKinsey analysis discussed above, the combination of building codes and appliance standards.

Tables VI-2 and IV-3 give other examples of the broad potential for performance standards to address market imperfection and barriers. Mechanisms that reduce barriers include information and capacity building by stimulating the demand side, creation and promotion of a stable market, establishment of a methodology for calculating the energy performance of a

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> Performance Standards (EPS) that set a maximum threshold for the emission intensity of power generation in terms of grams of CO2 per kilowatt hour could be justified as a way to reduce uncertainty exposure... [W]e have also pointed out that the optimal penetration of renewables is slow, even when facing a given deterministic carbon price.

Cooper, 2009b, p . 64

[123] Howarth and Sanstad, p. 108.

[124] Howarth and Anderson, p. 265

TABLE VI-1: EVALUATION OF 20 POLICIES

Policy Type	Policy Instrument	Target	Achieved
Regulation	Building performance standards	2	4
	Building regulations	2	1
	Efficiency commitment	2	2
	Mandatory target on consumption	2	2
	Top runner	2	2
	Labelling of appliances	2	2
	Obligation on management	1	1
Financial	Soft loans	2	3
	Investment deductions	1	1
Information	Local advice	1	1
	Energy audits public	2	4
	Energy audits private	2	2
	Network	1	1
	Industry concepts	1	1
	Individual advice service	1	1
	Eco-driving	2	3
	FEMP	2	2
Voluntary	Efficiency agreements	2	2
	ACEA	2	2
Procurement	Energy	1	1
	BELOK	1	4

Source: Mirjam Harmeling, Lara Nilsson, and Robert Harmsen, 2008, "Theory-based Policy Evaluation of 20 Energy Efficiency Instruments, *Energy Efficiency,* 1, p.48. 2=Quantitative 4=Achieved or overachieved

TABLE VI-2: POLICY INSTRUMENT FOR REDUCING GREENHOUSE GASSES

	Energy/CO2 Effectiveness	Cost Effectiveness	# of Barriers	Economic	Market Failure	Hidden Cost	Culture Political
Appliance standards	H	H	3	Y	Y	Y	
Energy efficiency obligations	H	H	2	Y	Y		
DSM	H	H	2	Y	Y		
Tax exemptions/ reductions	H	H	2	Y	Y		
EPC/ESCO	H	M/H	3	Y	Y		
Building codes	H	M	3	Y	Y	Y	
Coop. Procurement	H	M	2	Y	Y		
Public leadership programs	M/H	H/M	4	Y	Y	Y	
Labeling and certification	M/H	H/M	3	Y			Y
Procurement.	M/H	H/M	3	Y	Y	Y	
Energy certificates	M/H	H/M	1	Y	Y		
Voluntary and negotiated	M/H	M	2			Y	Y
Mandatory audit requirement	H & variable	M	1				Y
Public benefit charges	M	H	2	Y	Y		
Capital subsidies,	H	L	2	Y	Y		
Detailed disclosure	M	M	2			Y	Y
Education and information	L/M	M/H	2			Y	Y
Taxation (on CO2 or fuels)	L/M	L	1	Y			
Kyoto Protocol flexible	L	L	1		Y		

Source: Sonja Koeppel, Diana Urge-Vorsatz and Veronika Czako, 2007, *Evaluating Policy Instruments for Reducing Greenhouse Gas Emissions from Buildings – Developed and Developing Countries,* Assessment of Policy Instruments for Reducing Greenhouse Gas Emission from Buildings
H= high, M=medium, L=low

TABLE VI-3: ASSESSMENT OF POLICY INSTRUMENTS IN PLACE IN THE EUROPEAN UNION

POLICY EVALUATION CRITERIA / POLICY APPROACH	Importance of main barrier the policy instrument addresses	Impact/ expected impact of policy instrument	Increased impact by further broadening or strengthening	Policy for specific barrier/ tackles several barriers	Clear/ appropriate to target/ barrier	Compatible with other instruments	Compatible with MS/ appropriate as EU instrument
Directive on energy end-use efficiency and energy services	5	5	3	4	3	3	4
Energy performance of buildings directive	4	5	4	2	4	3	5
EPBD-related CEN mandate to develop a set of standards	3	4	4	2	4	3	4
Eco-design directive	3	3	4	2	3	4	4
Eco-label regulation	3	2	3	3	5	3	3
Energy labeling directive	2	3	4	3	4	4	4
Environmental technology verification	2	3	na	2	3	2	3
'Intelligent energy Europe" programme	2	2	na	3	3	1	4
Structural, Cohesion Funds & European Investment Bank	3	2	2	2	3	1	3
Energy taxation	1	1	2	1	3	1	1

Source: Andreas Uihlein and Peter Eder, 2009, *Toward Additional Policies to Improve the Environmental Performance of Buildings,* European Commission, Joint Research Centre, Institute for Prospective Technological Studies, Table 9.

building, standards on calculation of energy need for heating and cooling, creation of a functioning efficiency supply market, ensure that qualification, accreditation and certification schemes are available, along with reliable monitoring and diagnostics procedures.

Standards also allow the level to be raised as technology develops. Burtraw and Woerman offered a vigorous defense of well-designed performance standards applying an institutional analysis to the acid rain program, citing the recent update of the fuel economy standards as an example.

> Compared to the unintended consequences and complexities of regulation, setting prices to equal the social cost of environmental damages appears simple. Since Pigou (1920), this economic idea has made a large intellectual contribution, yet it has rarely been adopted in environmental policy. One reason that is sometimes offered for the limited influence of environmental prices in environmental policy is the multitude of market failures that prevent a single price from solving the problem…Vested economic interest in the status quo helps to explain institutional inertia and reluctance to change. In any context, a change in the rules will create losers who will act to obstruct such a change, and we invoke this explanation at some points. However, we have a more general case in mind where institutions may have strong justifications as solutions to historic problems and serve as watchtowers that protect the precedents of values of previous social decisions. By design or evolution, they affect how change will occur….
>
> The flaw of the SO2 cap-and-trade program was its inability to adapt to new information that benefits were substantially greater than anticipated and that costs were substantially less. Emissions trading policy for CO2 in the United States would likely face many of the same issues as SO2 emissions trading including the inability to update the policy over time…
>
> The third factor is the actual mechanism of the Clean Air Act. In 2007 the U.S. Supreme Court affirmed the authority of the EPA to regulate greenhouse gasses under the Clean Air Act. Under threat of private lawsuits against the agency, EPA initiated an investigation culminating in a formal finding that greenhouse gas emissions endangered human health and the environment. Under pressure from subsequent lawsuits EPA initiated regulations. Tighter vehicle emissions standards that took effect in 2011 implement a 5% per year improvement in the vehicle fleet resulting in an average miles per gallon of 35.5 in 2016. A second set of standards will take effect in 2017 and will require efficiency improvements to reach 54.5 miles per gallon by 2025. Preconstruction (design) permitting of new and modified sources for greenhouse gas emissions is also now in effect…
>
> Differences in institutional structure between a cap-and-trade policy and the Clean Air Act regime cause the regulatory systems to vary in two important ways in how they would react to these changes. One way is the ability to update the emission cap or regulation. If secular or regulatory changes occur that make achieving emissions reductions cheaper and if the cap or regulation is set to approximately equalize marginal costs and marginal benefits, then the availability of cheaper reductions suggests that the cap level or regulation should be tightened to achieve additional reductions. As we have argued, this is unlikely to occur in a timely manner. The Clean Air Act regime, however, requires the EPA to regularly update regulations to ensure new information such as new market conditions or scientific information (depending on the relevant portion of the act) is assimilated into the stringency of the regulation. A second way is the natural ability of the regulatory mechanism to react to these changing market conditions. Detailed simulation modeling of these institutional differences described in the next section indicates the Clean Air Act regime is projected to yield greater permanent domestic emissions

reductions than would have occurred under the Waxman–Markey legislation.[125]

A recent description of standards in the diffusion framework underscore this point. Standards are seen as playing different roles at different points in the diffusions process (see Figure VI-3).

> The graph illustrates a cycle of market transformation, which begins with inefficient models being regulated out of the market through minimum energy performance standards (MEPS). Next fleet efficiency is raised using incentive programs. Incentives programs target HE technologies with the best efficiency rating identified by the labeling program. They raise the efficiency ceiling through a combination of upstream, midstream and downstream programs that address specific market barriers. Incentives increase demand, and thus market penetration, for early-stage HE technologies, leading to economies of scale for manufacturers. Economies of scale, and the learning effects engendered by increased demand, streamline production and decrease the costs of production. The efficiency gains achieved through the incentive program can then be cemented by implementing standards that are more ambitious, resulting in a continuous cycle of improvement. This cycle can be repeated indefinitely as innovation produces more and more efficient technologies. Other market interventions, such as most-efficient awards, energy-efficient procurement or awareness programs can help complement this cycle to further accelerate the diffusion rate.[126]

Burtraw and Woerman focus on the ability of a standard setting process to evaluate the development of costs therefore shift the target to capture more benefits. De la Rue du Can emphasize qualitative adjustment in the target of the standards. The suggestion that policy in general and standards in particular need to monitor the changing terrain and adapt is evident in the literature in a number of ways.

- Cost (which tend to fall with economics of scale and learning)[127]
- Value (the optimization principle, which may change over time).[128]
- The nature of uncertainty (which can influence the optimization principle)[129]

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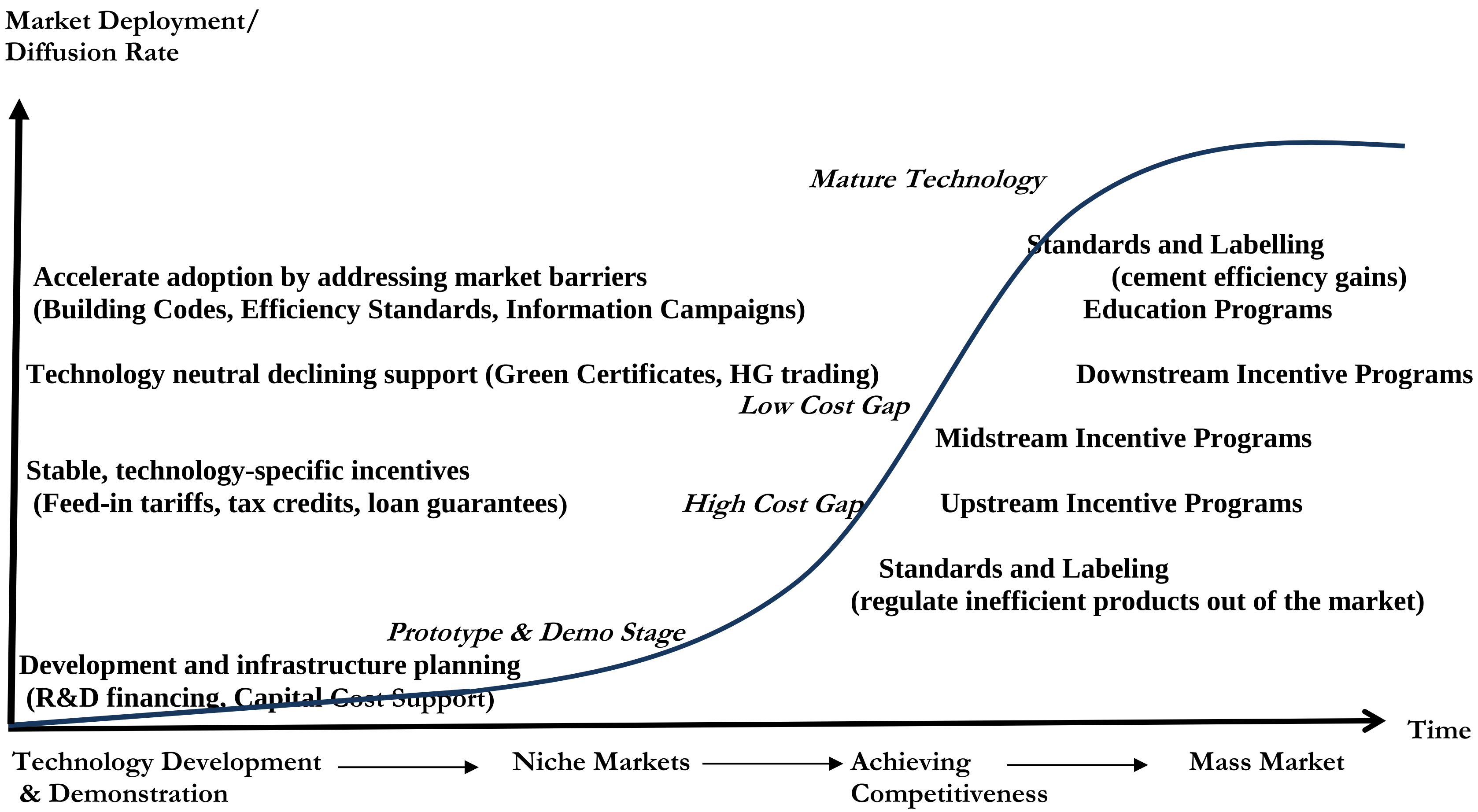
[125] Burtraw and Woerman, 2013,
[126] de la Rue du Can, et al., 2014,
[127] The cost data discussed above and referred to by Burtraw and Woemer provides ample evidence. The driving force for declining cost was the freedom to chose least cost approaches which did not involve he big, high tech solutions that regulators anticipated but relied on small knowledge and substitution (Grover, David, 2013, p. 123,This paper investigates the extent to which ‘advanced’ knowledge and technology played a role in the SO2 compliance process in electric power plants under the US SO2 cap and trade program. It investigates the hypothesis that advanced knowledge and technology dedicated to pollution abatement played a minor role in that process while relatively unadvanced forms of knowledge and technology played the main role… While there are clearly limits to how far this unadvanced knowledge and technology finding can be generalised to GHG emission control, the specific aspects of the SO2 case that might be broadly informative of the response to GHG emissions are elaborated. In any case, the paper shows how ‘innovation’ in pollution control can be inexpensive and effective without involving very much advanced knowledge and technology for pollution control. (Finn Granderson, 2013).
[128] Optimization principles vary based on the value chosen and the assumptions made (e.g., Admirall, 2013, Lejanoa and Stikols, 2013.
[129] See e.g. Aldred, 2013.

FIGURE VI-3: TAILORING SUPPORT TO MEET NEEDS ALONG THE INNOVATION CHAIN, IMPACT OF INTERVENTIONS ON HIGHLY-EFFICIENT (HE) TECHNOLOGY DIFFUSION RATE



Sources: Entries above the curve, International Energy Agency, *Energy Technology Perspective, 2014: Harnessing Electricity's Potential,* 2014, p. 55. Entries below the curve, Stephane de la Rue du Can, et al., "Design of incentive programs for accelerating penetration of energy-efficient appliances," *Energy Policy*, Energy Policy, 72, 2014, p. 59.

- The Dynamic nature of the market (which can diminish the ability to set proper standards).[130]
- Need for and development of and adjust to complementary policies (which interact with standards)[131]

Table VI-4 summarizes the evaluation of energy performance standards. The upper part of the table describes the broad range of market barriers and imperfection that can be addressed by well-crafted performance standards. However, while the empirical research this broad view of evolving standards and the need to take behavioral factors[132] and the interaction between identifies the characteristics of the standard that are necessary to ensure they are effective and efficient. They must really command, but not control, thereby unleashing the forces of innovation and competition in the market economy.

[130] For example, some products/markets (deploy technology faster than regulation can be adjusted, in which case it can become a hindrance rather than a help (e.g. Siderius, 2013).

[131] With shifting target that affects many of the new resources including technology specific adjustment, for example niche markets (e.g. Green, Skerlos and Winebrake, 2013, arguing for niche market targeting of electric vehicles, p. 62, This article argues that policies intending to give PEVs a foothold in the market should not focus on mainstream consumers and should instead focus on niche markets—specifically car sharing and postal fleets—and early adopters including green consumers. Two arguments can be made in support of eliminating the mainstream market bias of current policies toward a policy of cultivating niche markets. The first is efficiency: so far PEV policies featuring a mainstream market bias have proven to be inefficient and costly. The second is effectiveness: it is becoming increasingly evident that PEV policies would be more effective in achieving potential societal benefits if they focused on early adopters and niche markets using such approaches as strategic niche management, accessible loans and financing, and appropriately targeted incentives. PEV policies focused on early adopters and niche markets would create complementary system effects that will lead to increased PEV market penetration and realization of intended societal benefits.), solar (e.g. Zheng and Kammen, 2013, p. 159, To strengthen the industry we find that a policy shift is needed to balance the excitement and focus on market forces with a larger commitment to research and development funding), as well as the characteristics of the standard, maturity of the standard (e.g. Inoue, 2013), Smart Meters (e.g. Green, Skerlos and James, 2014, wind (e.g. Ketterer, 2014, p. 270, The results show that variable wind power reduces the price level but increases its volatility. This paper's results also indicate that regulatory change has stabilised the wholesale price. The electricity price volatility has decreased in Germany after a modification of the marketing mechanism of renewable electricity. This gives confidence that further adjustments to regulation and policy may foster a better integration of renewables into the power system.

[132] Gram-Hanssen, 2013, p. 447, Through the presentation of these different projects and examples, it is shown how user behaviour is at least as important as the efficiency of technology when explaining households' energy consumption in Denmark. In relation to energy policy, it is argued that it is not a question of technology efficiency or behaviour, as both have to be included in future policy if energy demand is actually to be reduced. Furthermore, it is also argued that not only individual behaviour is relevant, but also a broader perspective on collectively shared low carbon practices has to be promoted. Estiri, 43, p. 178, Results demonstrate that the direct impact of household characteristics on residential energy consumption is significantly smaller than the corresponding impact from the buildings. However, accounting for the indirect impact of household characteristics on energy consumption, through choice of the housing unit characteristics, the total impact of households on energy consumption is just slightly smaller than that of buildings. Outcomes of this paper call for smart policies to incorporate housing choice processes in managing residential energy consumption.

TABLE VI-4: FACTORS UNDERLYING THE SUCCESS OF PERFORMANCE STANDARDS

Causes of Market Failure Potentially Addressed by Standards

Traditional Economics & Industrial Organization	New Institutional Economics	Behavioral Economics
SOCIETAL FAILURES Externalities Information	**ENDEMIC FLAWS** Agency Asymmetric Information Moral Hazard	**BEHAVIORAL FACTORS** Motivation Calculation/ Discounting
STRUCTURAL PROBLEMS Scale Bundling Cost Structure Product Cycle Availability	**TRANSACTION COSTS** Sunk Costs Risk Uncertainty Imperfect Information	

Characteristics the Promote Efficiency and Effectiveness of Standards

Encourage entrepreneurial experimentation

- Technology neutrality
- Pro-competitive
- Allow flexibility

Emphasize least cost and risk aware approaches which encourage consideration of

- all externalities and the recognition of subsidies
- lead time, scale, capital at risk and use of portfolio approaches

Take a long-term, total social cost view, which allows policy makers to

- consider cost trends (including the pattern of pay offs to social investment),
- ignore sunk costs,
- steadily raise the target, and
- explore fundamental transformation of infrastructure (physical and institutional

standards and complementary policies into account.[133] Therefore, the lower part of the table Therefore, the lower part of the table identifies the characteristics of the standard that are necessary to ensure they are effective and efficient. They must really command, but not control, thereby unleashing the forces of innovation and competition in the market economy.

C. THE REGULATORY POLICY FRAMEWORK DRIVES THE EMPIRICAL ANALYSIS

Having declared greenhouse gasses to be pollutants, concluded that the emissions of these pollutant endangers the public health and safety, and issued a performance standard for top regulate the emissions of these pollutants from new sources, the EPA is required to adopt measures that reduce the emission of these pollutant from existing sources. EPA's interpretation of its statutory obligations sets the framework for empirical analysis of the necessary and permissible measures.[134]

> Once EPA has elected to set an NSPS for new sources in a given source category, section 111(d) calls for regulation of existing sources…
>
> Section 111(d) requires regulation of existing sources in specific circumstances. Specifically, where EPA establishes a NSPS for new sources in a source category, a section 111(d) standard is required for existing sources in the regulated source category…
>
> Section 111(d) guidelines, like NSPS standards, must reflect the emission reduction achievable through the application of BESR.

Thus, the reduction of emission of pollutants from new and existing are evaluated according to the same basic criteria,

> reflect the degree of emission limitation achievable through the application of the best system of emission reduction which (taking into account the cost of achieving such reduction and any non-air quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated…." In determining BSER, EPA typically

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[133] Giraudet and Houde, 2014, p. 3024, p. 1, Moral hazard problems are consistent with homeowners investing with implied discount rates in the 15-35% range. Finally, we find that minimum quality standards outperform energy-savings insurance. Guerra-Santin, and Itard, 2012, 269, The results showed that energy reductions are seen in. dwellings built after the introduction of energy performance regulations. However, results suggest that to effectively reduce energy consumption, the tightening of the EPC in not enough. Policies aimed at controlling the construction quality and changing occupant behaviour are also necessary to achieve further energy reductions. Mallaburn and Eyre, 2014, p. 36, Most rapid improvements in energy efficiency result from programmes with a carefully managed combination of government intervention (which is generally regulation-led) and market support…. Energy efficiency requires capital investment, and lack of up-front capital is an important barrier in all sectors… However, unlike other policies, energy efficiency policy does create a return on the investment, which, with creative policy design, can be used to offset the cost. Some policies are very effective in doing this. Technology standards and labelling schemes are good examples, such as EU energy labelling and minimum performance standards for domestic goods and the government's Energy Technology List for industrial process equipment eligible for accelerated capital allowances. The evidence is that, with good policy design, end-user costs are negative as long as the energy saving benefits exceed the costs and the market is given time to adjust. The early energy efficiency programmes focused on technologies. But developments in social and behavioural science show that policies need to address the demand-side as well: energy efficiency is about people as well as products.

[134] EPA, 2014d.

> conducts a technology review that identifies what emission reduction systems exist and how much they reduce air pollution in practice. This allows EPA to identify potential emission limits. Next, EPA evaluates each limit in conjunction with costs, secondary air benefits (or disbenefits) resulting from energy requirements, and non-air quality impacts such as solid waste generation. EPA also evaluates the opportunities to promote the development and use of pollution control technology.
>
> While such a standard is based on the effectiveness of one or more specific technological systems of emissions control, unless certain conditions are met, EPA may not prescribe a particular technological system that must be used to comply with a NSPS. Rather, sources remain free to elect whatever combination of measures will achieve equivalent or greater control of emissions.

However the rules governing standards for existing sources must be implemented by the states and take into account the challenge of "retrofitting" existing facilities.

> Instead of giving EPA direct authority to set national standards, section 111(d) provides that EPA shall establish a procedure for states to issue performance standards for existing sources in that source category. ..
>
> Section 111(d) guidelines, like NSPS standards, must reflect the emission reduction achievable through the application of BESR. However, both the statute and EPA's regulations implementing section 111(d) recognize that existing sources may not always have the capability to achieve the same levels of control at reasonable cost as new sources. The statute and EPA's regulations in 40 CFR 60.24 permit states and EPA to set less stringent standards or longer compliance schedules for existing sources when warranted, considering cost of control, useful life of the facilities, location or process design at a particular facility, physical impossibility of installing necessary control equipment…

Thus, as EPA understands its authority, in order to set a standard, the EPA must define a Best System of Emission Reduction by evaluating the options available in terms of their

- effectiveness with respect to reducing emissions,
- efficiency with respect to cost,
- impact with respect to a broad range of economic and non-economic considerations, and
- feasibility with respect to implementation.

EPA may not prescribe a particular technological system that must be used under section 111 and for existing facilities (111d), rather:

- it must delegate the implementation authority to the states, and
- recognize that existing sources may not always have the capability to achieve the same levels of control at reasonable cost as new sources.

PART II.
EMPIRICAL EVALUATION OF LOW CARBON RESOURCES AND EPA'S ANALYSIS IN THE CONTEXT OF A BEST SYSTEM OF EMISSIONS REDUCTION

VII. THE COST OF LOW CARBON RESOURCES

A. INTRODUCTION TO PART II

1. Outline

This part begins in Chapter VII with estimates of the cost of low carbon resources. The cost of generating electricity can be translated into a cost to reduce carbon emissions by making an assumption about which emitting resource is being displaced, but the cornerstone of the economic analysis is the estimate of resource cost of meeting the need for electricity. This Chapter examines the full range of costs for over a dozen and a half technologies, using the cost of nuclear power as a focal point of the analysis.

In Chapter VIII I turn to the analysis of other economic and non-economic characteristics of the resources, which is required under Section 111 rulemaking. I cover the economic traits, such as the size and speed to market of the alternatives, which are important for their attractiveness of resources as financial investments and their ability to shoulder the burden of meeting the challenge of climate change. I also consider their macroeconomic impact and broader environmental footprints of the resources. The analysis is generally qualitative, although I offer a quantitative assessment in the conclusion. Both the quantitative and qualitative approaches support a simple and important conclusion, the attractiveness of the alternatives based on their resource economics is very similar to the attractiveness of the alternatives on the basis of other economic and non-economic characteristics. The sequence in which resources should be acquired is the same

Chapter IX examines the broader question of the transformation of the electricity system from the 20th century, passive, load-following central station model to the 21st century active supply and demand management model. The analysis examines the conditions for a transformation and the impact that such a transformation would have on achieving the goals of the proposed rule.

Chapter X discusses three flaws in the EPA analysis that are revealed by the analytic framework developed in Part I and the empirical analysis of Part II – the underestimation of the role of renewables in a "Best Method System," the overestimation of the cost of efficiency and underestimation of it potential, the mishandling of the suggested nuclear subsidy.

As noted in the Purpose and Recommendations Chapter, my goal is to show that the adopting a performance standard to reduce greenhouse emission from existing sources in the electricity sector or reason and urgent. The fact that the benefits far exceed the costs argues not only that the EPA should adopt the proposed approach, but that the level of reductions could be set much higher and should be raised, if not in the current rulemaking then in future rulemakings, to ensure that the endangerment of the public health and welfare is reduced in accordance with the Clean Air Act.

2. The Role of Nuclear Power

While I consider this wide range of options, in this Chapter I use nuclear as a focal point of analysis for several reasons.

First, nuclear power is the only resource that the EPA explicitly suggested the states consider subsidizing. Showing that nuclear power is one of the more expensive options highlights the critical mistake the EPA made in favoring nuclear power, a mistake that needs to be corrected in the final rule.

Second, nuclear power is a useful focal point for the economic analysis because of the ongoing transformation of the electricity sector. The recognition of the massive external costs of fossil fuel consumption compels a transition to alternative fuels. The search for low carbon alternatives has triggered a second transition – a transition away from base load facilities. In a low carbon sector, the 20th century load-following central station approach to meeting the need for electricity will be much more costly than a decentralized approach. While nuclear power can claim to make a contribution to carbon reduction, it is not only one of the most costly ways to do so, it is also one of the least flexible of the current central station generation technologies. Nuclear power is an obstacle to the transformation of the electricity sector because of its inherent techno-economic characteristics. More importantly, recognizing the untenable economic condition of nuclear power, nuclear utilities and advocates have launched efforts to receive subsidies and undermine the alternatives.

Third, either of the above two observations would make it possible to argue that nuclear power does not belong in a Best System of Emissions reduction certainly does not warrant special treatment and subsidies.

Fourth, the analysis of nuclear costs and the potential subsidy are so flawed and nonsensical that they may fail to pass muster under the administrative procedures act. The states can consider nuclear power in spite of its burdensome economic characteristics, but the EPA mistakenly tied the fate of the rule to economics of nuclear power.

B. LEVELIZED COST

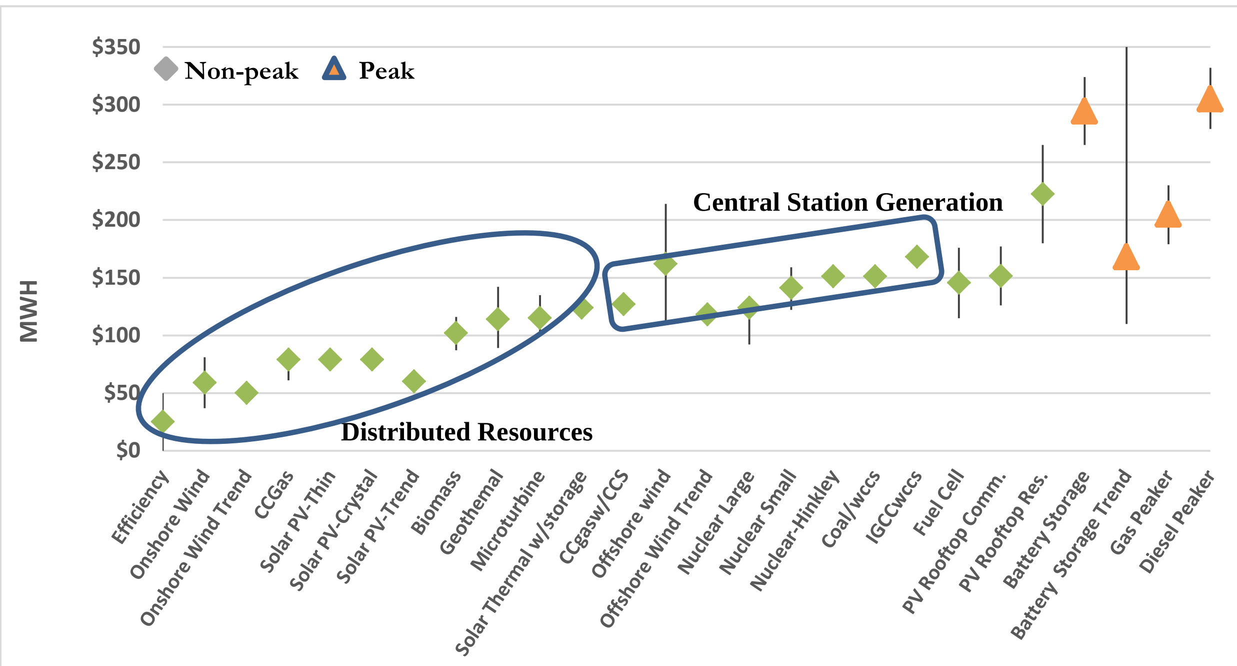
I begin the analysis with estimates of the levelized cost of a number of alternatives. While factors other than levelized cost are considered in making resources acquisition decisions, it has been the foundation for resource selection for decades. Figure VII-1 combines the results of the two most recent estimates of levelized cost of electricity from Lazard. Needless to say, there are many such estimates available. I choose Lazard as a single source for this discussion to preserve consistency in assumptions and because I believe the Lazard analysis is superior to most others and provides the basis for important and useful observations.

- From the outset, the Lazard analysis included efficiency, which is the least cost resource by far. None of the other major studies of electricity resources do so.
- The analysis was among the first of the comprehensive analyses to note the strong downward trend in the cost of solar and to begin arguing that solar was cost competitive in some major markets and for peak power. Many have joined Lazard in projecting that solar will be broadly cost competitive with natural gas by the middle of the second decade of the 21st century.
- The analysis always included estimates for coal with carbon capture and

storage and has recently added an estimate for the cost of natural gas with carbon capture and storage.

- The most recent analysis adds important storage technologies, utility scale solar with storage and utility scale battery storage. The most recent analysis presents a cost trend for storage that is similar to the trends from other sources.
- The current analysis presents "unsubsidized" costs strictly for generation (no transmission, system integration, or waste disposal and decommissioning).
- The analysis always included peaking capacity costs and, in a recent analysis it added a cross national comparison of technologies that might displace gas as the peaker resource.

FIGURE VII-1: LEVELIZED COST (LCOE) OF LOW CARBON OPTIONS WITH TRENDS



Source: ***Lazard's Levelized Cost of Energy Analysis – Version 8.0, Version 7.0.***

I have included trend projections for solar, wind and storage (from Lazard). I use Lazard at the point estimate and an upper bound from the Brattle Group and lower bound from Navigant.[135] I have included two other estimates of nuclear costs because Lazard continues to use a construction period of just under six years, when the U.S. average was ten and the reactors currently under construction are well past six. One is the current official cost of the cost of the Hinkley reactor, which provides an estimate that reflects the higher cost projections of the current technologies. The second additional nuclear cost estimate is my estimate of the long run cost of Small Modular Reactors, which have recently received a lot of attention. To compare

[135] Chang, et.al. 2014. Jaffee, 2014.

apples-to-apples and do mid-term analysis, I highlight the midpoint, unsubidized cost projection and compare it to the other mid-points unsubsidized. I also present the range.

Figure VII-1 delivers a message that has been clear to energy analysts for quite some time. There are a large number of alternatives that are likely to be considerably less costly than nuclear, even in a low carbon environment. It also reminds us that reducing peaks is a very valuable undertaking, since peaking power is so costly. When fossil fuels were inexpensive (in part because of the failure to internalize their negative externalities) it made sense to build base load facilities and let the price run up at the peak. As the cost of fossil fuels has risen, the cost of reducing peaks has declined and the ability to manage supply and demand increased that is no longer the economically efficient approach. This is the reason that storage, which had not been a focal point of investment and innovation, is now such a hotbed of activity.

One can go technology-by-technology, region-by-region and even plant-by-plant, which, in theory, is what the EPA will let the state do. Using the mid-points yields exactly the same rank ordering of the options as standing the ranges side-by-side. The ranges for efficiency, and wind, overlap as the lowest cost resources. The ranges for gas and Solar PV with the cost trend overlap as the next least costly options. In the context of the nuclear debate, when we look at ranges, nuclear cannot compete with efficiency, wind, gas, biomass, solar PV anyplace in the U.S. It is barely competitive with gas with CCS, geothermal, microturbines, and solar thermal with storage. Storage is projected to be the least cost peaking power, just 10 percent more costly than the higher nuclear projections.[136]

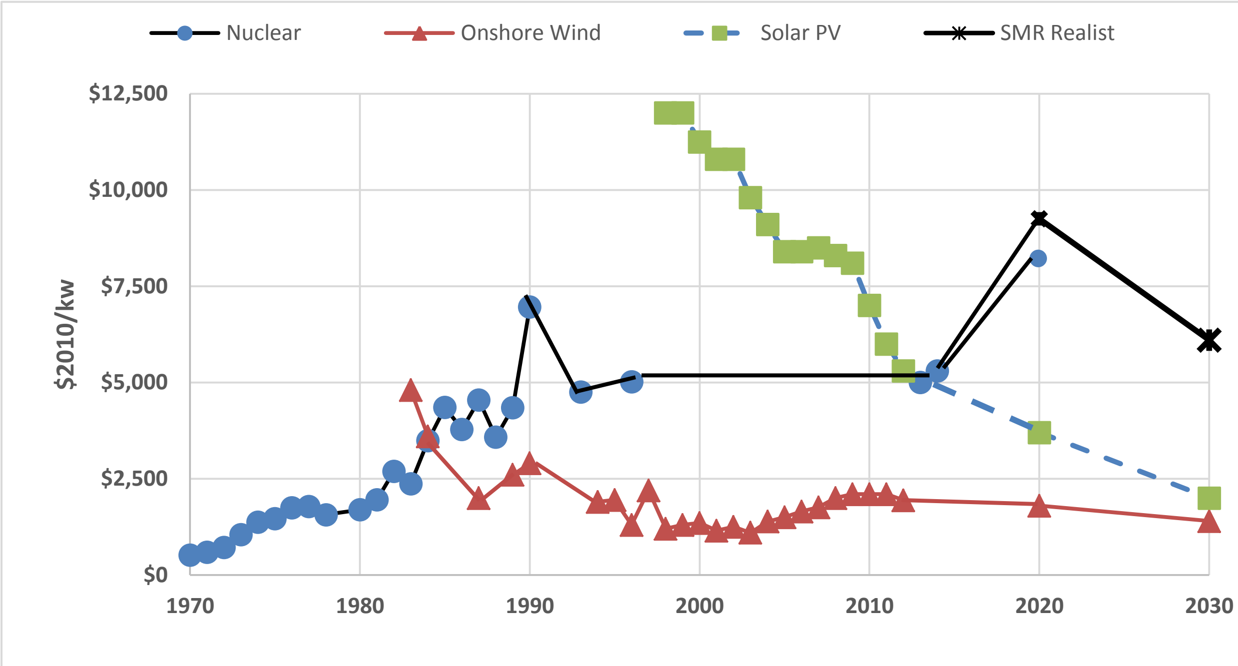
C. KEY COST TRENDS

The economic characteristics of the set of mid-term options reflects dramatic technological and economic developments over the course of the past two decades. Figure VII-2 shows long term cost trends for three of the most frequently discussed supply-side options – nuclear, wind and solar.

For wind, utilization has increased dramatically – achieving capacity factors above 50 percent in some cases, with costs per kilowatt hour plummeting as the result of increasing tower height, longer and larger blades, better gearbox reliability, material optimization, more efficient computer programming.[137] Solar costs have been falling because of economies of scale in production and reduced utilization of key component materials, increasing cell efficiency, other system cost savings and streamlining of siting, all of which have lowered the cost of capital.[138] Figure VII-3 decomposes the long term declining cost trend for solar into two key components, economies of scale and innovation. Each of these two factors has made a substantial contribution to declining cost and both are likely to continue to do so.[139]

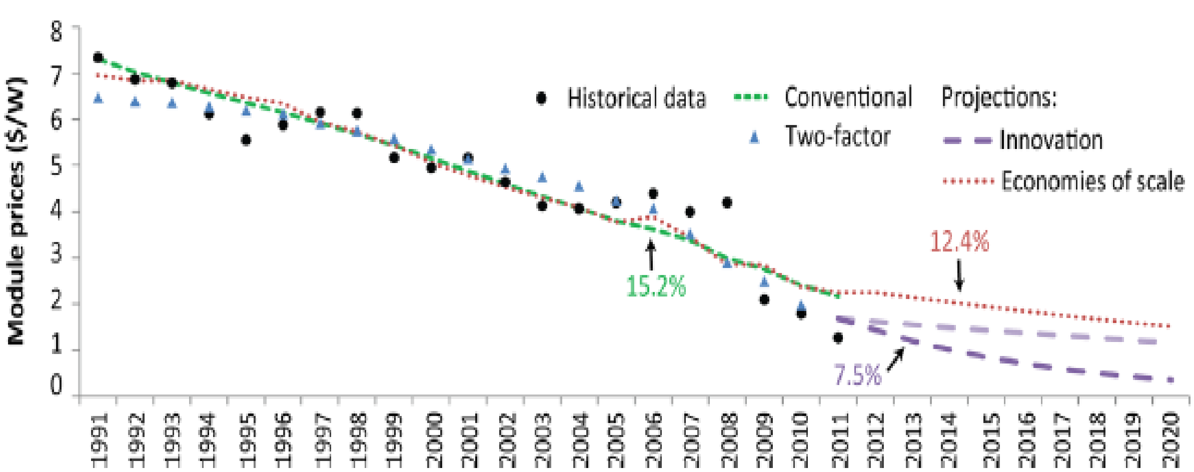
[136] Lyons, 2014, By 2018 the cost of ViZn Energy's 4-hour storage solution in is essentially identical to that of a conventional simple cycle peaker. Given the added benefits of installing storage in distribution, by 2018 storage is a clear winner compared to a typical mid-range cost for a conventional simple cycle CT.
[137] Eggers, Cole and Davis, 2013, p. 3.
[138] Eggers, Cole and Davis, 2013, p. 11.
[139] Zheng, Cheng and Daniel M. Kammen, 2014.

FIGURE VII-2: OVERNIGHT COST TRENDS: NUCLEAR, WIND AND SOLAR



Sources: Galen Barbose, Naïm Darghouth, Samantha Weaver, and Ryan Wiser, 2013, *Tracking the Sun VI: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012,* Lawrence Berkeley National Laboratory, July; Ryan Wiser, Mark Bolinger, 2013, *2012 Wind Technologies Market Report,* U.S. Department of Energy, August; Mark Cooper, 2014, Small Modular Reactors and the Future of Nuclear Power in the United States," *Energy Research & Social Science,* 3.

FIGURE VII-3: THE EFFECT OF ECONOMIES OF SCALE AND INNOVATION IN THE C-SI PV LEARNING CURVE



Zheng, Chengn and Daniel M. Kammen, 2014, "An innovation-focused roadmap for a sustainable global photovoltaic industry," *Energy Policy*, 67, 163

The economic competitiveness of these generation resources reflects technological and economic progress. Over the course of fifty years of commercial nuclear power in the U.S., construction costs have risen substantially and persistently and there are no indications that this pattern will change any time soon. The cost of small modular reactors, which have been touted as the next big thing to save nuclear power, are likely to be much higher than the renewables and investment in SMRs has collapsed, with both Westinghouse and B&W, the two largest firms pursuing the technology in the U.S., throttling way back on investment. Wind already has much lower overnight costs than nuclear and solar soon will. The projections for the cost of new nuclear reactors have been rising steadily for over a decade.

While other factors affect the cost of power, construction costs are the key factors that affect the EPA analysis and the key factors in the current debate, particularly for the major, non-fossil fuel generation sources, which are very capital intensive. Fossil fuels with carbon capture and storage technology added are also capital intensive, which reinforces the importance of construction costs. Output, determined by capacity factors and facility life, also plays a role, but there is general agreement on these factors. Analysis of the levelized cost of electricity generally include a common set of assumption about output and the factors that affect it.

While there can be important local conditions, like the richness of the resource of wind and solar, that affect the estimates of costs power from alternatives, the broad technology cost trends tend to be global, because technology is exportable. Moreover, cost trends can be affected by local policies because specific economic processes can accelerate trends (see Figure VI-4).

The comparison between the U.S. and Germany, after Germany made a strong commitment to increase reliance on renewables and decrease reliance on nuclear is a case in point, as shown in the upper graph of Figure VII-4. Cost trends for renewables in South Africa exhibit a similar pattern, with declines in the U.S. much smaller than South Africa.

Rapid declines in storage costs reinforce the importance of the rapid declines in renewable costs, as low cost storage dramatically boost the effective load factor of renewables. Lazard's estimate of a rapid decline in storage costs is consistent with other estimates, as shown in Figure VII-5.

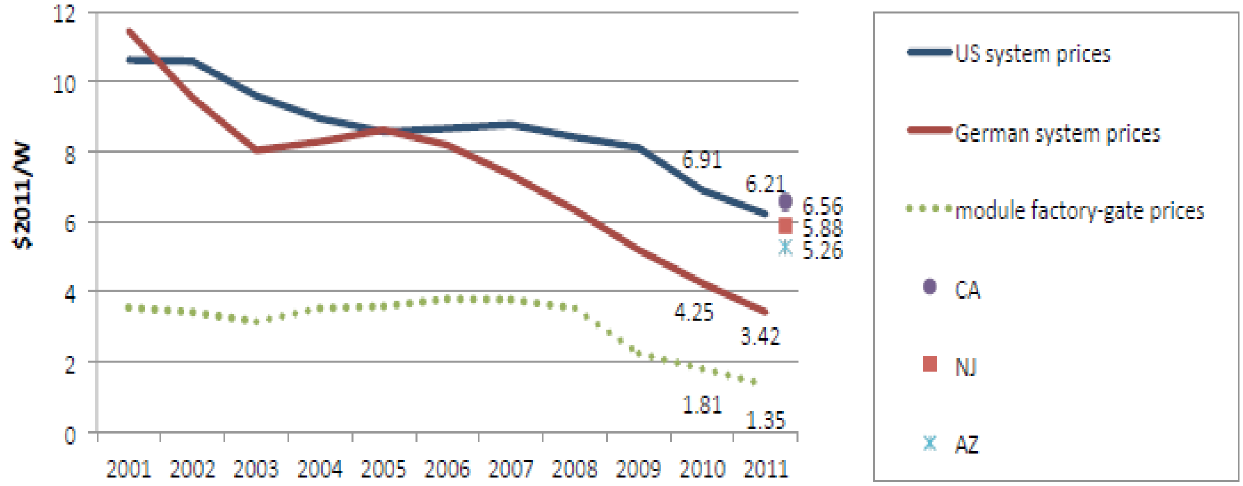
D. Operating Costs and Merit Order Dispatch

A second key component of the cost of electricity is operating costs. Operating cost tend to make up a large part of the total cost of fossil fuels, since fuel costs are high, but a much smaller part of renewables and nuclear. Nevertheless, operating costs are important for the capital intensive low carbon resources and the importance of operating costs is magnified by the role they play in determining which facilities, among those that are available, are called on to supply power. The merit order effect is an important factor in the economic problems that ageing reactors have encountered.

The 20th century electricity industry relied on baseload facilities that had to run constantly to meet off-peak demand and chose to meet higher levels of demand (shoulder and peak), not by storing electricity itself, but by storing potential electricity in the form of raw energy (primarily fossil fuels like natural gas and diesel, but also a small amount of water pumped above a generator). The scarcity rents necessary to pay the capital cost of baseload facilities were created

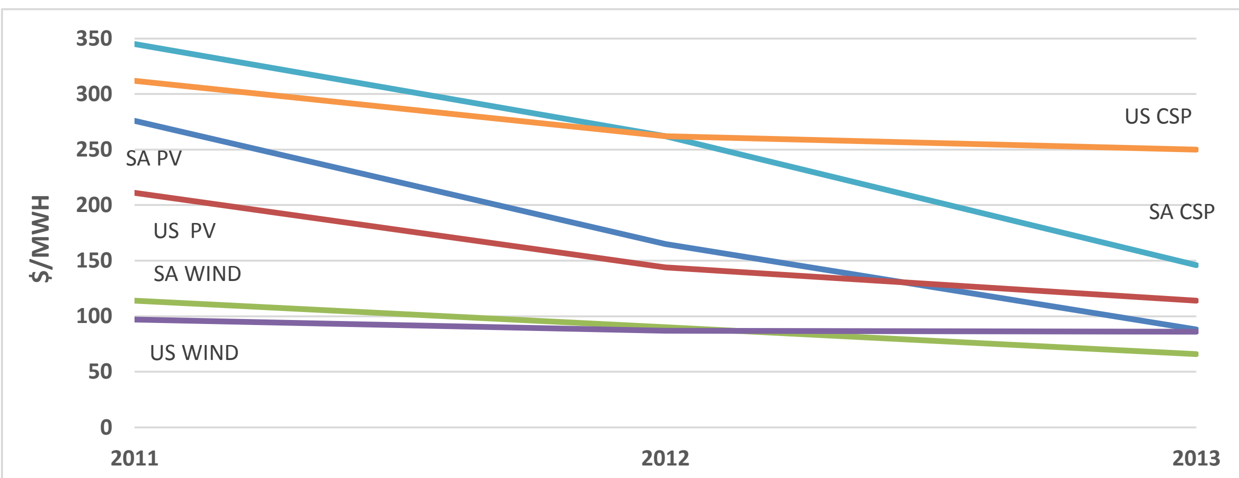
FIGURE VII-4: CROSS NATIONAL COMPARISONS OF SOLAR COST TRENDS

Median Installed Price of Customer-Owned PV Systems ≤10 kW: U.S. v. Germany



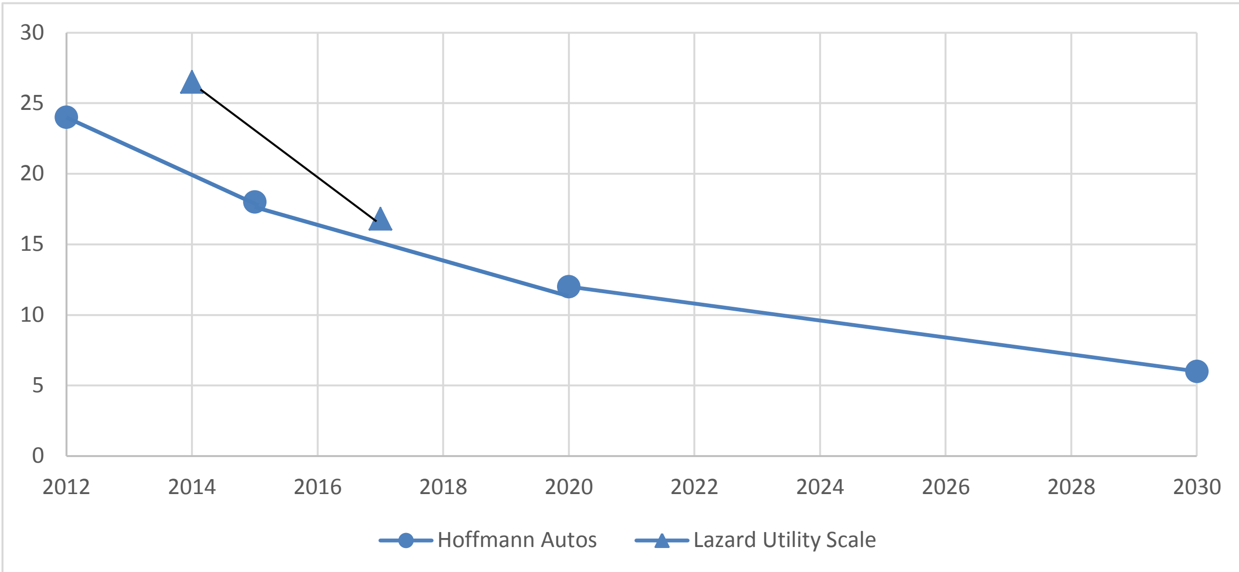
Source: Joachim Seel, Galen Barbose, and Ryan Wiser, *Why Are Residential PV Prices in Germany So Much Lower Than in the United States?*, February 2013, U.S. Department of Energy, SunSpot, p. 9.

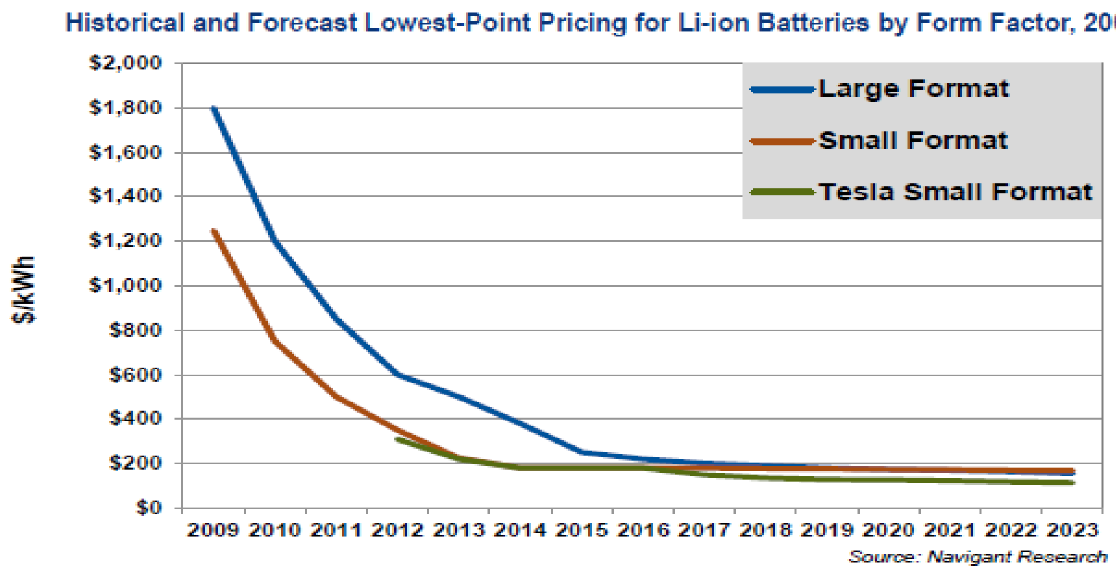
South Africa Bid Prices v. U.S. EIA Cost Projections



Source: David Richard Walwyn and Alan Colin Brent, "Renewable energy gathers steam in South Africa," *Renewable and Sustainable Energy Reviews,* 41 (2015)

FIGURE VI-5: COST OF BATTERIES, CENTS/KWH





Source: ***Lazard's Levelized Cost of Energy Analysis – Version 8.0,*** **Wilfred Hoffman, as reported in Fuhs, Michael, 2014, "Forecast 2030: stored electricity at $0.05/kWh,"** ***PV World,*** **September 29.**
Jaffee, 2014, p. 8.

by allowing peak prices to skyrocket or setting of prices far above marginal cost.[140]

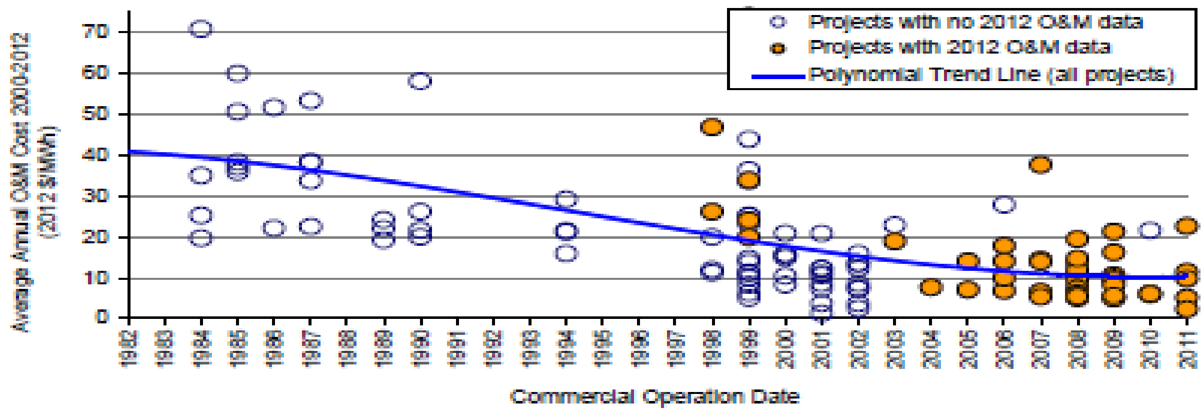
[140] Amer and Amer, 1984, describe a situation of scarcity that applies well to the peak load problem, noting that "when the supply is exceptionally small – its price will be exceptionally high, and it will be said to have *scarcity value"* (p. 416) and links it to the definition of *quasi-rent*, defined as "a return on capital or labor whose supply is temporarily or permanently fixed, so called to distinguish it from a *real rent*, the return on land (whose supply is always fixed). Pearce, 1984, p. 395, applies the concept of absolute scarcity to fossil fuels.

Over the past two decades it has become much more costly to meet peak demand in the old way. First, diesel became expensive. Second, the social costs of fossil fuels have been recognized. Third, carbon emissions have become a major concern. The search for low carbon alternatives to replace coal has unleashed a wave of innovation that is not only dramatically lowering the cost of alternatives but also leads to the use of resources that are likely to be dispatched on-peak because they have low operating costs. As these resources come on line, they shift the supply-curve, putting downward pressure on the market clearing price and the rents available for capital recovery.

As shown in Figure VII-6, the trends in operating costs are similar to the trends in construction costs. In contrast to the increasing operating costs of nuclear reactors, operating costs for wind have been declining. In the mid-1990s nuclear reactors would have been

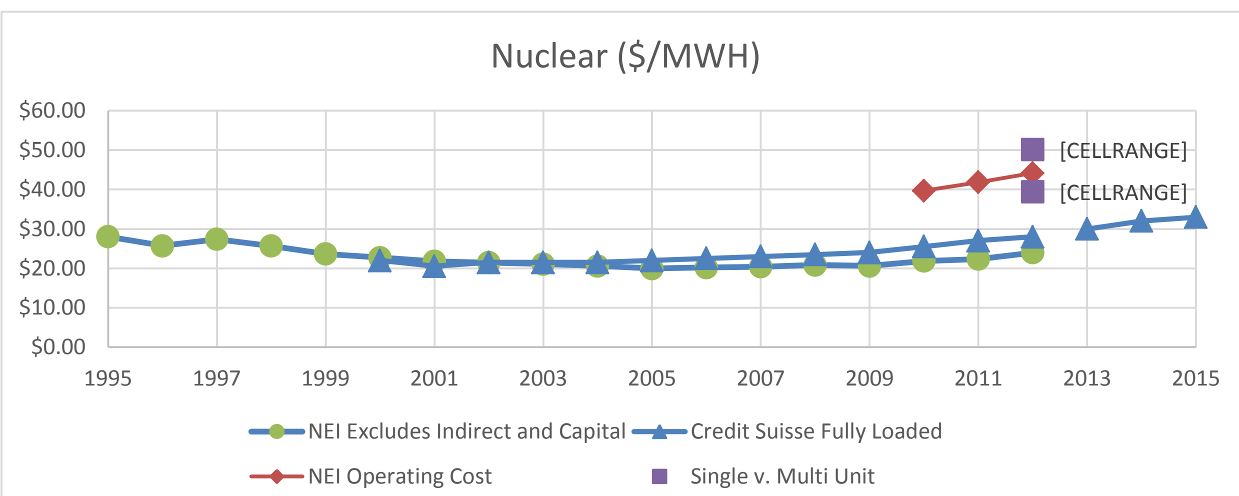
FIGURE VII-6: AVERAGE O&M COASTS ($/MWH)

Wind



Source: Berkeley Lab; seven data points suppressed to protect confidentiality

Nuclear



Source: NEI Operating Cost (Nuclear Street News Team. "NEI Lays Out the State of Nuclear Power." Nuclearstreet.com. February 26, 2014); NEI Excludes Indirect (Nuclear Energy Institute, Operating Costs, http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Costs-Fuel,-Operation,-Waste-Disposal-Life-Cycle/US-Electricity-Production-Costs-and-Components); Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013, p. 9.

dispatched before wind with a substantial operating cost advantage. Two decades later, wind has a substantial advantage, which is likely to grow in the years ahead. Wind operating costs have fallen twice as fast as overnight costs. Thus, it is not coal or gas or subsidies that is giving aging nuclear reactors heartburn, it is the superior economics of wind and efficiency combined with the increasing operating costs of aging nuclear reactors that has made the aging reactors uneconomic.

Figure VII-7, taken from a recent analysis by a group advocating for nuclear power, shows how the addition of wind lowers the market clearing price, which is undermining the economics of aging nuclear reactors. In the "merit order effect," an effect that has been documented in every nation where the use of wind has increased,"[141] wind backs inefficient natural gas plants out of the supply needed to clear the market at the peak, which lowers the market clearing price. The upper graph shows the current situation as lamented by the nuclear industry. The downward pressure on market clearing prices have led to a number of years of losses at the aging high cost nuclear reactors.

The lower graph shows the potential impact of the continuing deployment of low cost renewables. They squeeze out more fossil fuels. Efficiency lowers demand and demand management makes demand more responsive at the peak. The market clears at a lower price.

E. The Cost of Saved Energy

1. Engineering Estimates and Evaluations

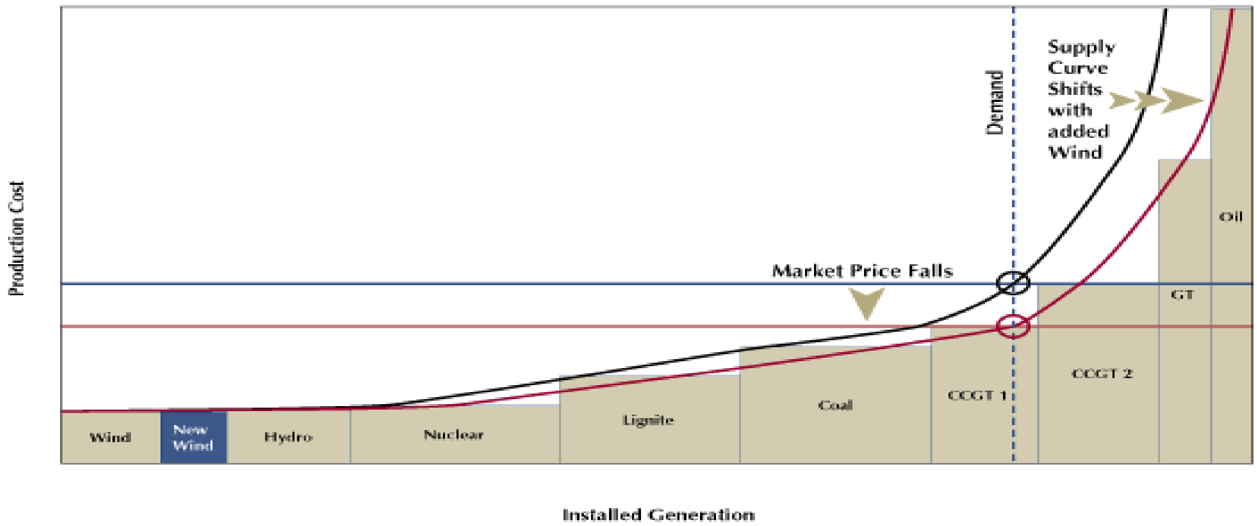
In the above analysis of cost, efficiency is the least cost resource that anchors the supply-curve of low carbon alternatives with a substantial potential to make a major contribution to carbon reduction (in the range of 20% to 30% of current demand in the near term). Yet, as noted, most analyses of levelized cost of resources focus on generation alternatives and do not include efficiency. The cost of efficiency deserves more attention.

The engineering economic analyses that provided the initial evidence for the efficiency gap showed that saving energy was significantly less costly than consuming it. *Ex ante* analyses indicated that there would be substantial net benefits from including technologies to reduce energy consumption in consumer durables. As these policies to spur investment in and deployment of energy savings technologies were implemented, *ex post* analyses were conducted to ascertain whether the *ex ante* expectations were borne out. Those analyses strongly support the *ex ante* engineering analyses, as shown in Figure VII-8.

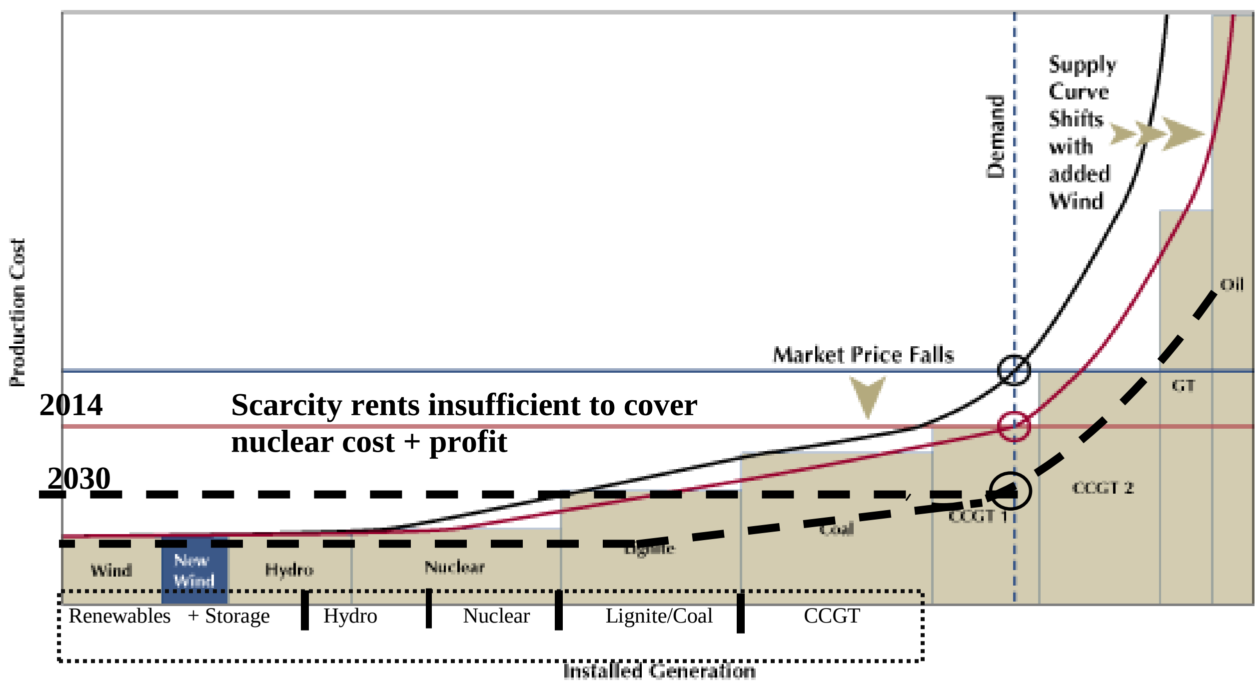
[141] The impact of the Merit Order Effect has been documented in a number of nations in which renewables have shown strong growth in recent years, demonstrating not only that market clearing prices are lowered, but also that they are lowered by an amount that is larger than any subsidies the resources receive. The result is a net benefit to consumers. See for example, United States, Fagan, et. al. 2012, Caperton, 2012, Charles River Associates, 2012; Canada, Ben Amora, 2014; Australia, McConnell, 2013, MacGill, 2013, Melbourne Institute, 2013; Ireland, Mahoney, and Denny, 2011; Denmark, Munksgaard, 2011; Germany, Sensfuss, Ragwitx and Genoese, 2008; Spain, de Miera, 2008; United Kingdom, Green, and Vasilakos, 2011. A separate effect that lowers the market clearing price is the fact that renewables tend to lower the level of concentration of supply, reducing the exercise of market power, Misir, 2012, Twomey, and 2010), Wirl, 2014, Mountain, 2012.

FIGURE VII-7:THE MERIT ORDER EFFECT OF ADDING NEW WIND CAPACITY ON PEAK PRICES

Current Wholesale Market



Continuing Deployment of Wind, Efficiency and Supply-Demand Management



Source: Doug Vine and Timothy Juliant, 2014, *Climate Solutions: The Role of Nuclear Power,* Center for Climate and Energy Solutions, April, p. 6, with authors additions.

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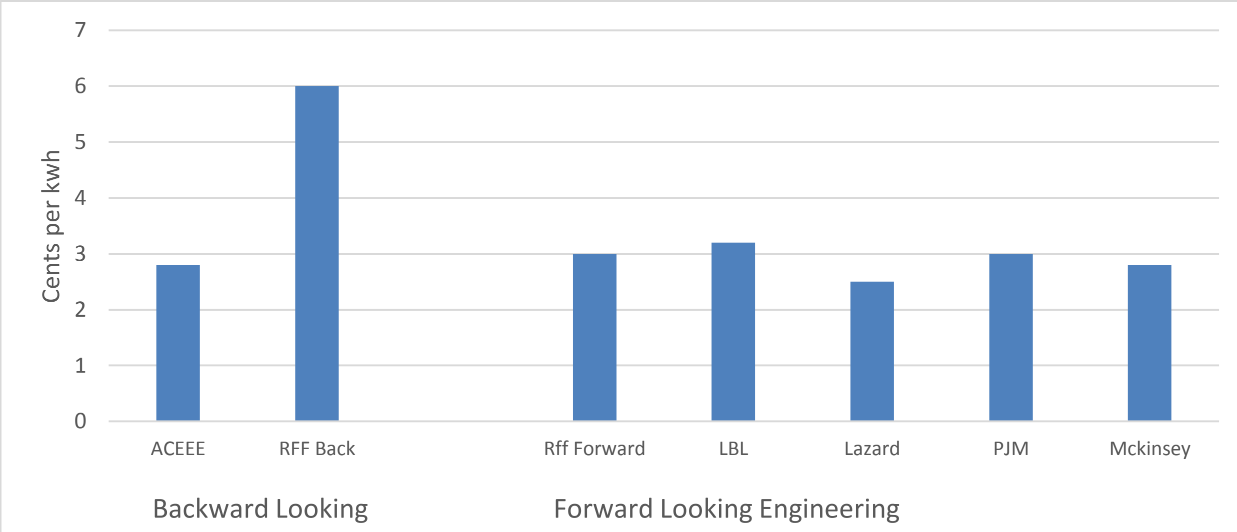
FIGURE VII-8: THE COST OF SAVED ELECTRICITY



Source: Kenji Takahasi and David Nichols, "Sustainability and Costs of Increasing Efficiency Impact: Evidence from Experience to Date," ***ACEEE Summer Study on Energy Efficient Buildings*** **(Washington, D.C., 2008), p. 8-363, McKinsey Global Energy and Material,** ***Unlocking Energy Efficiency in the U.S. Economy*** **(McKinsey & Company, 2009); National Research Council of the National Academies,** ***America's Energy Future: Technology and Transformation, Summary Edition*** **(Washington, D.C.: 2009). The NRC relies on a study by Lawrence Berkeley Laboratory for its assessment (Richard Brown, Sam Borgeson, Jon Koomey and Peter Biermayer,** ***U.S. Building-Sector Energy Efficiency Potential*** **(Lawrence Berkeley National Laboratory, September 2008).**

Several efforts to look back at achieved costs reach similar conclusions, including estimates from Resources for the Future and the U.S. Department of Energy. The forward looking estimates from research institutions like Lawrence Berkeley labs and McKinsey and Company are similar. In fact, utilities and Wall Street analysts use similar estimates

The most intense and detailed studies were conducted by utilities subject to regulation. Figure VII-9 shows the results of analyses of the cost of efficiency in sixteen states over various periods covering the last twenty years. The data points are the annual average results obtained in various years at various levels of energy savings. The graph demonstrates two points that are important for the current analysis.

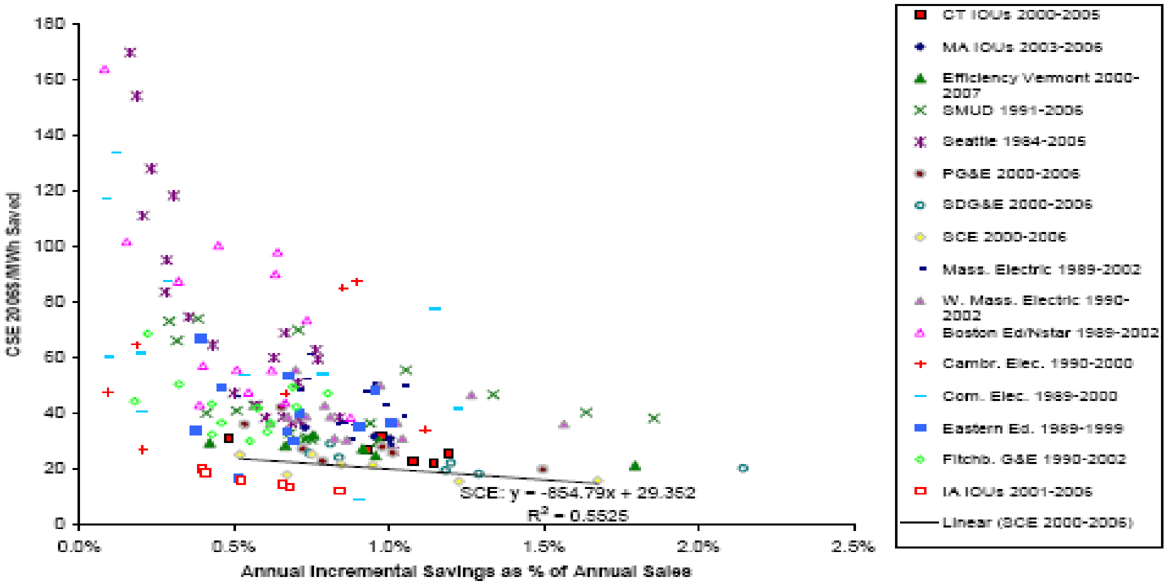
- First, the vast majority of costs fall in the range of $20/MWH to $50/MWH (i.e. 2 to 5 Cents/kwh). The average is about $27/MWH.
- Second, the higher the level of energy savings, the lower the level of costs. There is certainly no suggestion that costs will rise at high levels of efficiency.

While the aggregate data in Figure VII-9 appear to suggest a very strong downward trend, the data for individual utilities suggest a moderate downward trend. Exhibit III-1 shows the trend line for one individual utility. The trend is very slightly negative. The authors suggest that declining costs for higher levels of efficiency can be explained by economies of scale, learning and synergies in technologies.[142] As utilities do more of the cost effective measures, costs

[142] Kenji Takahasi and David Nichols, "Sustainability and Costs of Increasing Efficiency Impact: Evidence from

decline. Also, if technical potential is much higher than achievable savings, economies of scale and scope and learning could pull more measures in and lower costs. This explanation introduces an important area of analysis in the "energy gap" debate – learning curves. While there is a large literature on this subject, one aspect of it plays an important role in evaluating the EPA Clean Power Rule analysis.

FIGURE VII-9: UTILITY COST OF SAVED ENERGY (2006$/MWH) VS. INCREMENTAL ANNUAL SAVINGS AS A % OF SALES



Source: Kenji Takahasi and David Nichols, "Sustainability and Costs of Increasing Efficiency Impact: Evidence from Experience to Date," ***ACEEE Summer Study on Energy Efficient Buildings*** **(Washington, D.C., 2008), p. 8-363.**

2. Overestimation of the Cost of Standards

Policies to reduce the efficiency gap, like performance standards, will improve market performance. By overcoming barriers and imperfections, well-designed performance standards will stimulate investment and innovation in new energy efficient technologies. A natural outcome of this process will be to lower not only the level of energy consumption, but also the cost of doing so. The efficiency gap literature addresses the question of how "learning curves" will affect the costs of new technologies as they are deployed.[143] The recent focus on the supply-side and innovation underlies the observation above that aggressive policies to stimulate innovation and direct technological change can speed the transition and lower the ultimate costs.

In the efficiency gap area, the issue of declining costs driven by technological change has received significant examination as a natural extension of the effort to project technology costs. One of the strongest findings of the empirical literature is to support the theoretical expectation that technological innovation will drive down the cost of improving energy efficiency and

Experience to Date," *ACEE Summer Study on Energy Efficient Buildings* (Washington, D.C., 2008), p. 8-367.
[143] The issue was made explicit in the appliance efficiency standards proceeding.

reducing greenhouse gas emissions. A comprehensive review of *Technology Learning in the Energy Sector* found that energy efficiency technologies are particularly sensitive to learning effects and policy.

> For demand-side technologies the experience curve approach also seems applicable to measure autonomous energy efficiency improvements. Interestingly, we do find strong indications that in this case, policy can bend down (at least temporarily) the experience curve and increase the speed with which energy efficiency improvements are implemented.[144]

The findings on learning curve analysis are extremely important because decisions to implement policies that promote efficiency and induce technological change are subject to intensive, *ex ante* cost-benefit analysis. Analyses that fail to take into account the powerful process of technological innovation that lowers costs will overestimate costs, undervalue innovation, and perpetuate the market failure. Detailed analysis of major consumer durables including vehicles, air conditioners, and refrigerators find that technological change and pricing strategies of producers lowers the cost of increasing efficiency in response to standards.

> 1. For the past several decades, the retail price of appliances has been steadily falling while efficiency has been increasing.
>
> 2. Past retail price predictions made by the DOE analysis of efficiency standards, assuming constant price over time, have tended to overestimate retail prices.
>
> 3. The average incremental price to increase appliance efficiency has declined over time. DOE technical support documents have typically overestimated the incremental price and retail prices.
>
> 4. Changes in retail markups and economies of scale in production of more efficient appliances may have contributed to declines in prices of efficiency appliances.[145]
>
> The more specific point here is that, while regulatory compliance costs have been substantial and influential, they have not played a significant role in the pricing of vehicles. …
>
> As with any new products or technologies, with time and experience, engineers learn to design the products to use less space, operate more efficiently, use less material, and facilitate manufacturing. They also learn to build factories in ways that reduce manufacturing cost. This has been the experience with semiconductors, computers, cellphones, DVD players, microwave ovens – and also catalytic converters.
>
> Experience curves, sometimes referred to as "learning curves," are a useful analytical construct for understanding the magnitude of these improvements. Analysts have long observed that products show a consistent pattern of cost reduction with increases in cumulative production volume. …
>
> In the case of emissions, learning improvements have been so substantial, as indicated earlier, that emission control costs per vehicle (for gasoline internal combustion engine vehicles) are no greater, and possibly less, than they were in the early 1980s, when emission reductions were far

---

[144] Junginger, et al., 2008, p. 12; Kiso, 2009, find for Japanese automobiles that "fuel economy improvement accelerated after regulations were introduced, implying induced innovation in fuel economy technology."
[145] Dale, et. al., 2009, p. 1.

less.[146]

A comparative study of European, Japanese and American auto makers prepared in 2006, before the recent reform and reinvigoration of the U.S. fuel economy program, found that standards had an effect on technological innovation. The U.S. had lagged because of the long period of dormancy of the U.S. standards program and the fact that the U.S. automakers did not compete in the world market for sales, (i.e. it did not export vehicles to Europe or Japan, where efficiency was improving).

> The European car industry is highly dynamic and innovative. Its R&D expenditures are well above average in Europe's manufacturing sector. Among the most important drivers of innovation are consumer demand (for comfort, safety and fuel economy), international competition, and environmental objectives and regulations… One element of success of technology forcing is to build on one or more existing technologies that have not yet been proven (commercially) in the area of application. For improvements in the fuel economy of cars, many technological options are potentially available… With respect to innovation, the EU and Japanese policy instruments perform better than the US CAFE program. This is not surprising, given the large gap between the stringency of fuel-efficiency standards in Europe and Japan on the one hand and the US on the other….
>
> One of the reasons for the persistence of this difference is that the US is not a significant exporter of cars to the European and Japanese markets.[147]

Figure VII-10, shows the systematic overestimation by regulators of the cost of efficiency improving regulations in consumer durables. The cost for household appliance regulations was overestimated by over 100% and the costs for automobiles were overestimated by about 50 percent. The estimates of the cost from industry were even father off the mark, running three times higher for auto technologies.[148] Broader studies of the cost of environmental regulation find a similar phenomenon, with overestimates of cost outnumbering underestimates by almost five to one with industry numbers being a "serious overestimate."[149]

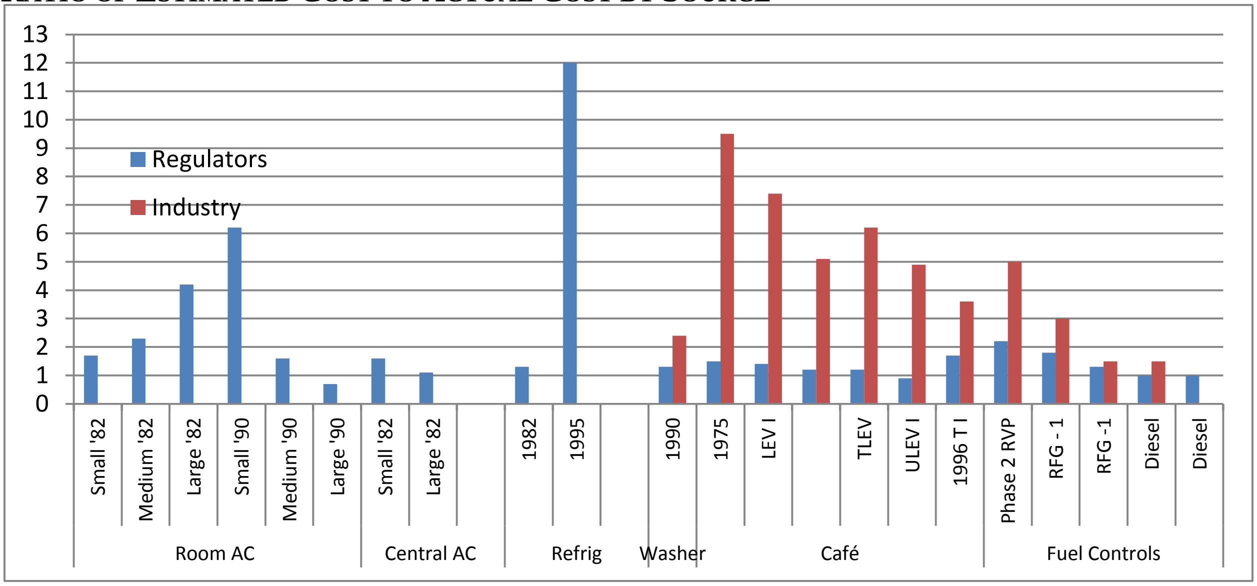
While the very high estimates of compliance costs offered by the auto manufacturers can be readily dismissed as self-interested political efforts to avoid regulation, they can also be seen as a worst case scenario in which the manufacturers take the most irrational approach to compliance under an assumption that there is no possibility of technological progress or strategic response. Consistent with the empirical record on cost a simulation of the cost of the 2008 increase in fuel economy standards found that a technologically static response was 3 times more costly than a technologically astute response.

> We perform counterfactual simulation of firms' pricing and medium-run design responses to the reformed CAFE regulation. Results indicate that compliant firms rely primarily on changes to vehicle design to meet the CAFE standards, with a smaller contribution coming from pricing strategies designed to shift demand toward more fuel-efficient vehicles... Importantly, estimated costs to producers of complying with the regulation are three times larger when we fail to

[146] Sperling, et al., 2004, p.p. 10-15.
[147] Kok, 2006,
[148] Hwang, and Peak, 2006.
[149] Harrington, 2006, p. 3.

account for tradeoffs between fuel economy and other vehicle attributes.[150]

FIGURE VII-10: THE PROJECTED COSTS OF REGULATION EXCEED THE ACTUAL COSTS: RATIO OF ESTIMATED COST TO ACTUAL COST BY SOURCE

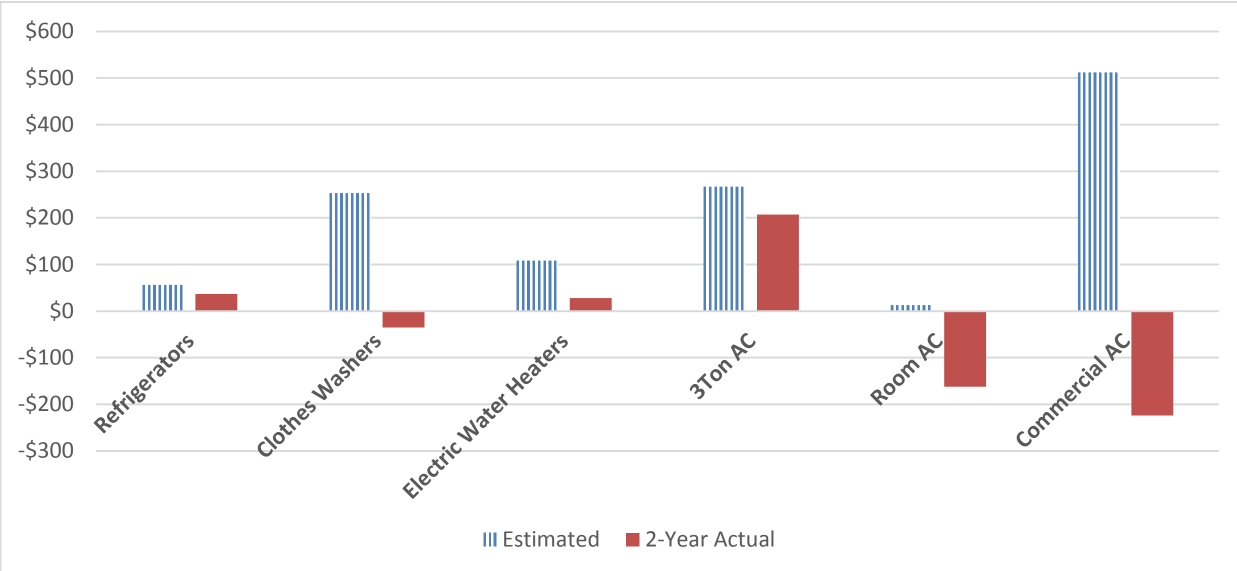


Sources: Winston Harrington, Richard Morgenstern and Peter Nelson, "On the Accuracy of Regulatory Cost Estimates," *Journal of Policy Analysis and Management* 19(2) 2000, *How Accurate Are Regulatory Costs Estimates?,* Resources for the Future, March 5, 2010; ; Winston Harrington, *Grading Estimates of the Benefits and Costs of Federal Regulation: A Review of Reviews,* Resources for the Future, 2006; Roland Hwang and Matt Peak, *Innovation and Regulation in the Automobile Sector: Lessons Learned and Implications for California's CO_2 Standard,* Natural Resources Defense Council, April 2006; Larry Dale, et al., "Retrospective Evaluation of Appliance Price Trends," *Energy Policy* 37, 2009.

A recent analysis of major appliance standards adopted after the start of the century shows a similar and even stronger pattern (see Figure VII-11). Estimated cost increases are far too high. There may be a number of factors that produce this result, beyond an upward bias in the original estimate and learning in the implementation, including pricing and marketing strategies. Sperling et al, 2004, emphasized the adaptation of producers in the analysis of auto fuel economy standards.

[150] Whitefoot, et al., 2012, pp. 1…5.

FIGURE VII-11: ESTIMATED AND ACTUAL COST INCREASES ASSOCIATED WITH RECENT STANDARDS FOR MAJOR APPLIANCES



Source: Steven Nadel and Andrew Delaski, *Appliance Stnadards: Comparing Predicted and Observed Prices,* American Council for an Energy Efficient Economy and Appliance Standards Awareness Project, July 2013 Institute for European Environmental Policy (IEEP), *Review Of Costs And Benefits Of Energy Savings: Task 1 Report 'Energy Savings 2030,:* May 2013, p. 9.

VIII. OTHER ECONOMIC AND NON-ECONOMIC CHARACTERISTICS OF LOW CARBON RESOURCE

While cost is the focal point of resource selection, other economic and non-economic characteristics enter into and can influence the decision about which resource should be included in the portfolio of low carbon resources.

A. INVESTMENT RISK

One set of economic considerations that is playing an increasingly important role are the factors that expose investors to risk. In an uncertain world, where prices are volatile, the size of projects, time to market and sunk capital costs become an important consideration. These concerns are reinforced by the urgency of dealing with the challenge of climate change.

The Lazard analysis provides estimates for key characteristics of deploying various low carbon technologies that have played an important part in the ongoing debate of resource selection, although they have not entered into the EPA analysis. Small, quick to market, nimble assets are considered much more attractive investments. As shown in Figures VIII-1, there is a sharp distinction between the central station resources and the decentralized resources.

Central station, base load facilities in general and nuclear reactor construction and operation are at a disadvantage compared to the alternatives which are more flexible and better able to meet small load increases more quickly and would be easier to finance. The importance of climate change and niche applications is magnified. The slowing of growth in demand, caused in the short term by the severe global recession and reinforced in the long term by improvements in energy efficiency magnify the importance of small size and flexibility.

The investment risk aspect of resource acquisition is increasingly dealt with by applying a portfolio approach to decision making. The key concepts are to reduce the overall risk of the portfolio by including assets that have different levels of risk, particularly when the risks are not positively correlated. Figure VIII-2 illustrates the concept from a publication targeted at energy regulators.

The assumption is that there is a risk/cost tradeoff that defines an efficient frontier. Investors want to be on the efficient frontier, where risk and reward are balanced. They can improve their expected returns if they can increase their reward without increasing their risk, or they can lower their risk without reducing their reward. In the financial literature, risk is measured by the standard deviation of the reward. In applying this framework to the evaluation of generation options, analysts frequently measure reward as kilowatts per dollar (a measure of economic efficiency). This is the inverse of cost. Indeed, they use efficiency and cost interchangeably.[151] Options that would move the portfolio toward the efficient frontier should be adopted since they embody lower cost and/or risk.[152]

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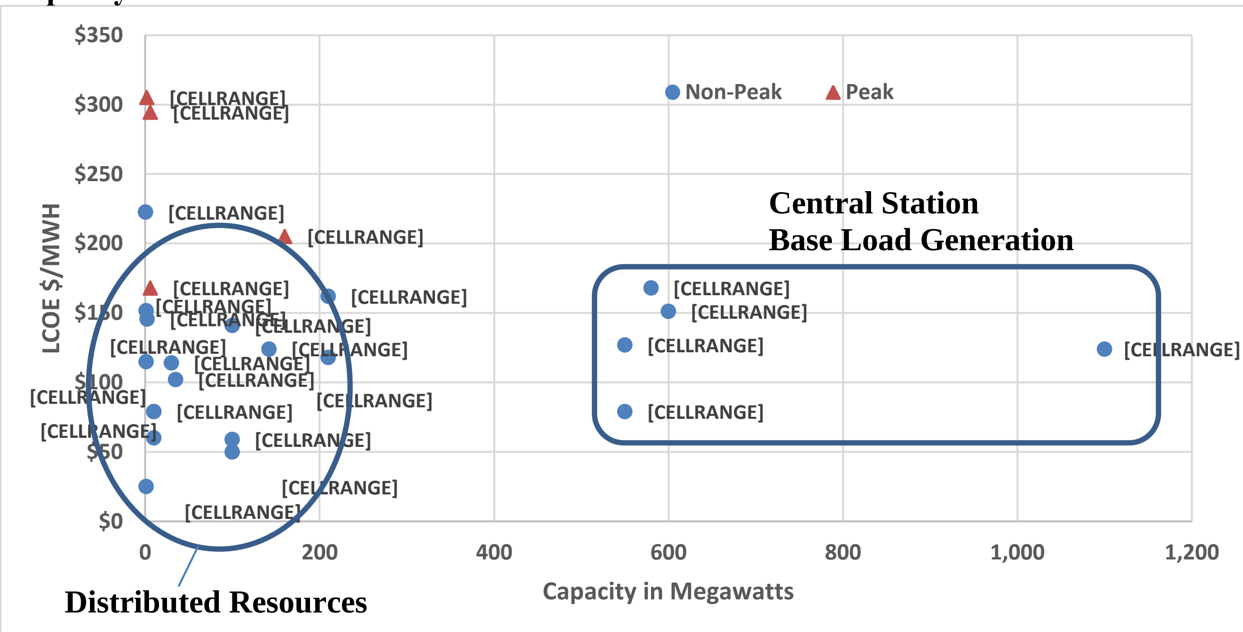
[151] Jansen Beurskens, and Tiburg, 2006, p. 13 argue for a risk-cost frontier.

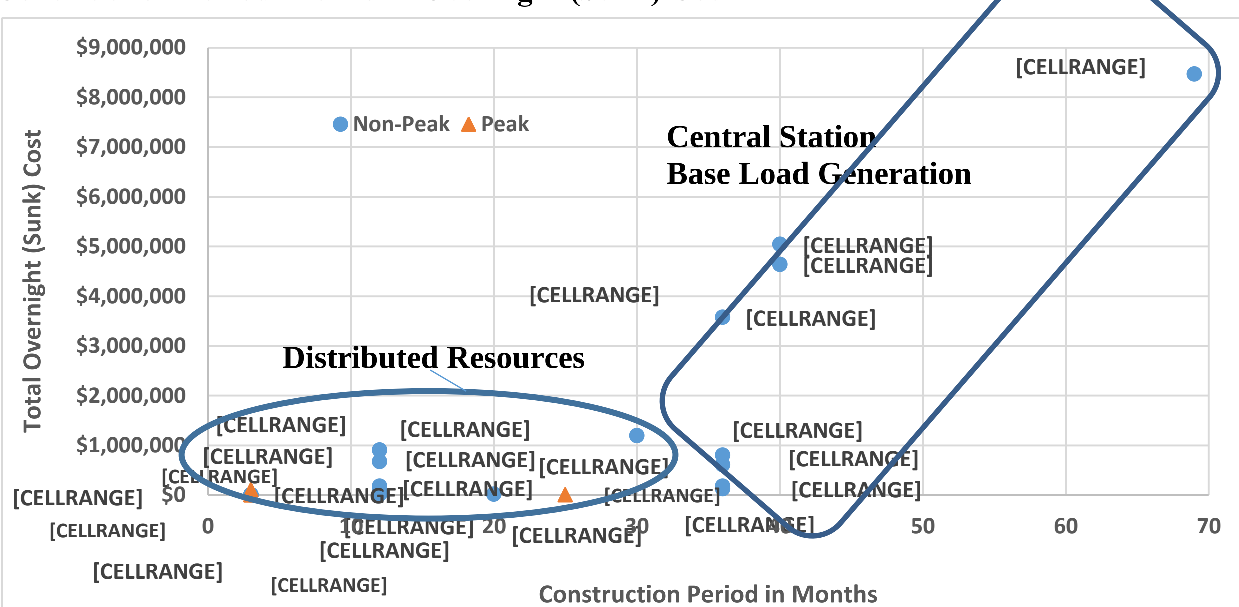
[152] Jansen Beurskens, and Tiburg, 2006, Appendix, p. 59, “”the question of whether a tool could be develop for gauging the impact of incremental technology deployment… the use of a (sort of) Sharpe ratio, showing the tangent of the direction a certain portfolio at (or to the right of) the efficient frontier would move into by

FIGURE VIII-1: COST, CAPACITY AND CONSTRUCTION PERIODS OF LOW CARBON RESOURCES

Capacity and Levelized Cost



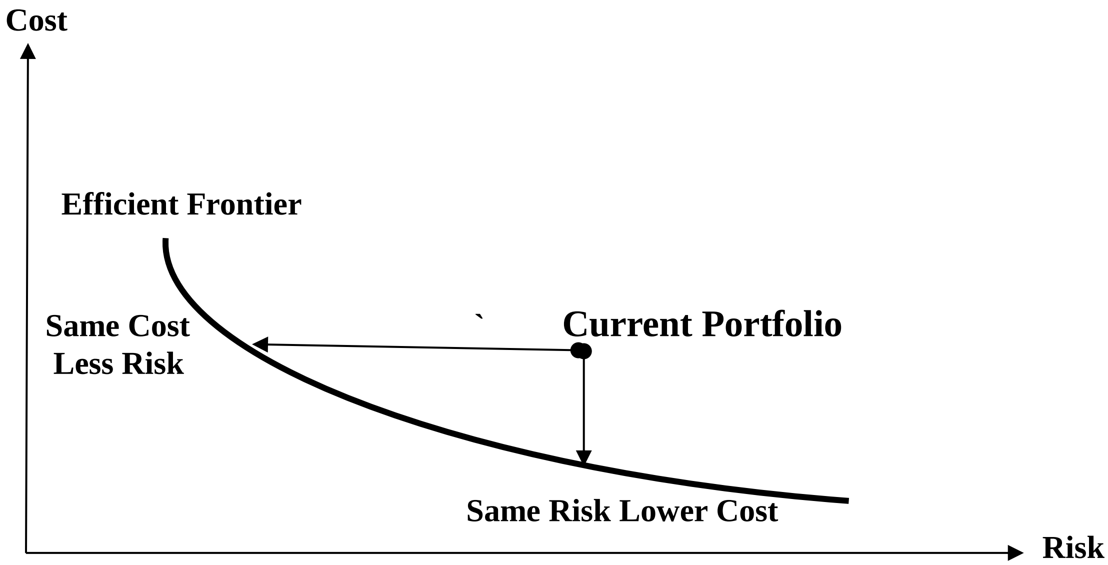
Construction Period and Total Overnight (Sunk) Cost



Source: ***Lazard's Levelized Cost of Energy Analysis – Version 8.0,***

incremental use of a certain technology."

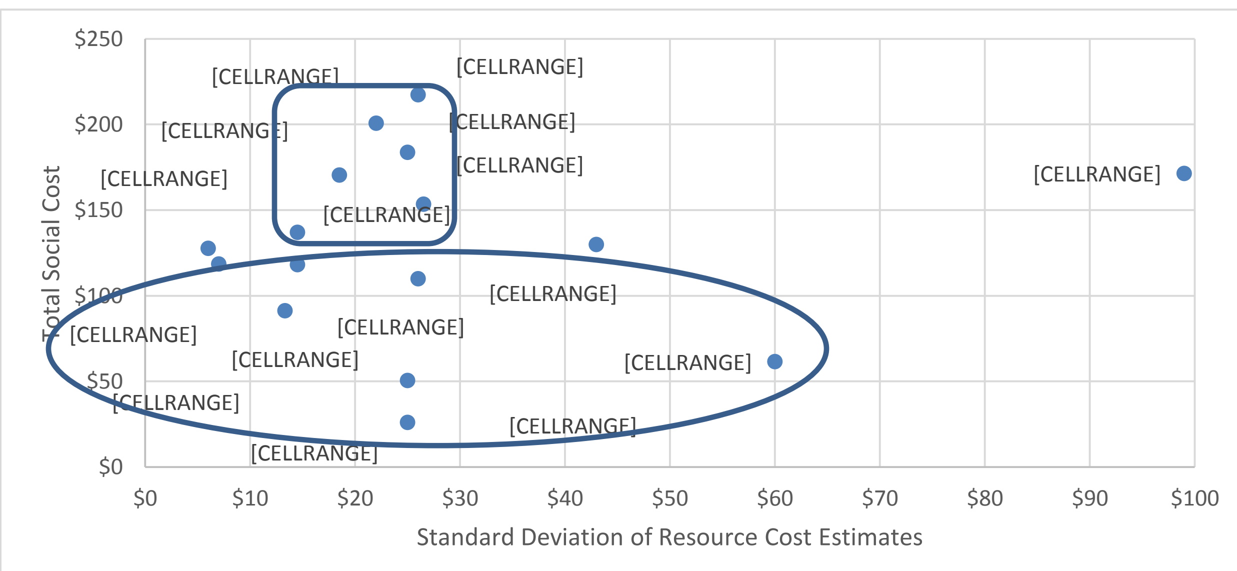
FIGURE VIII-2: RISK/COST REWARD



Source: Ken Costello, *Making the Most of Alternative Generation Technologies: A Perspective on Fuel Diversity*, (NRRI, March (2005), p. 12.

Figure VIII-3 shows the risk/cost array based on the levelized cost estimates from Figure VII-1 above. I base the standard deviation on the full range of costs include not only the basic cases, but all scenarios in Lazard in the full analysis. This is the data that is then used to identify the risk frontier and the optimum portfolio. In building a portfolio, one considers both cost and risk, since adding an asset who cost volatility is negatively correlated with the other assets in the portfolio can lower the overall risk (and therefore the expected price) even though it has a higher price.

FIGURE VIII-3: RISK/COST ARRAY BASED ON LAZARD

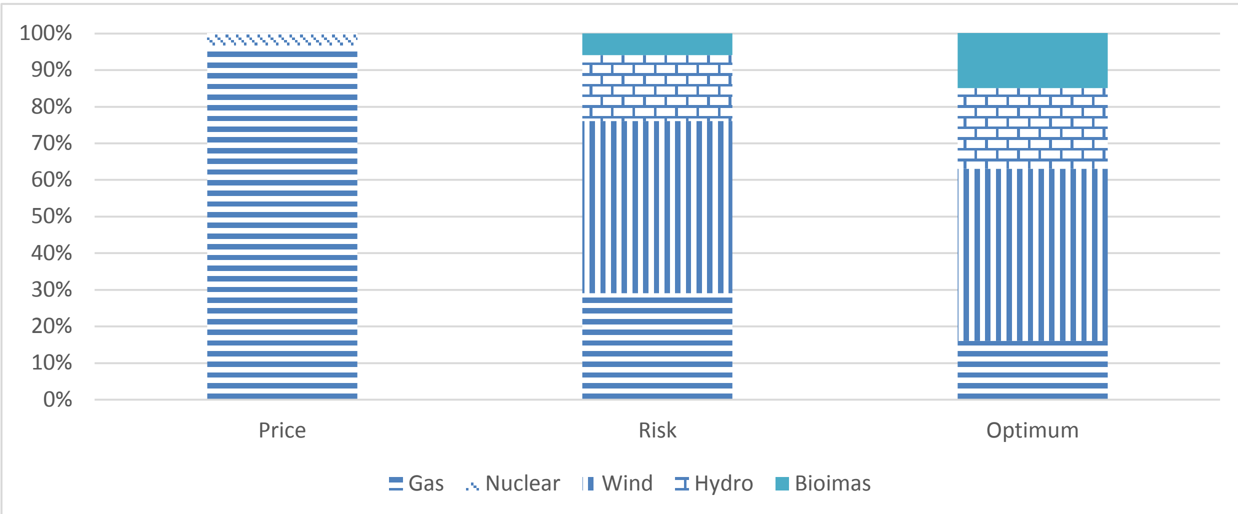


Source: See Figure VII-1 and accompanying discussion.

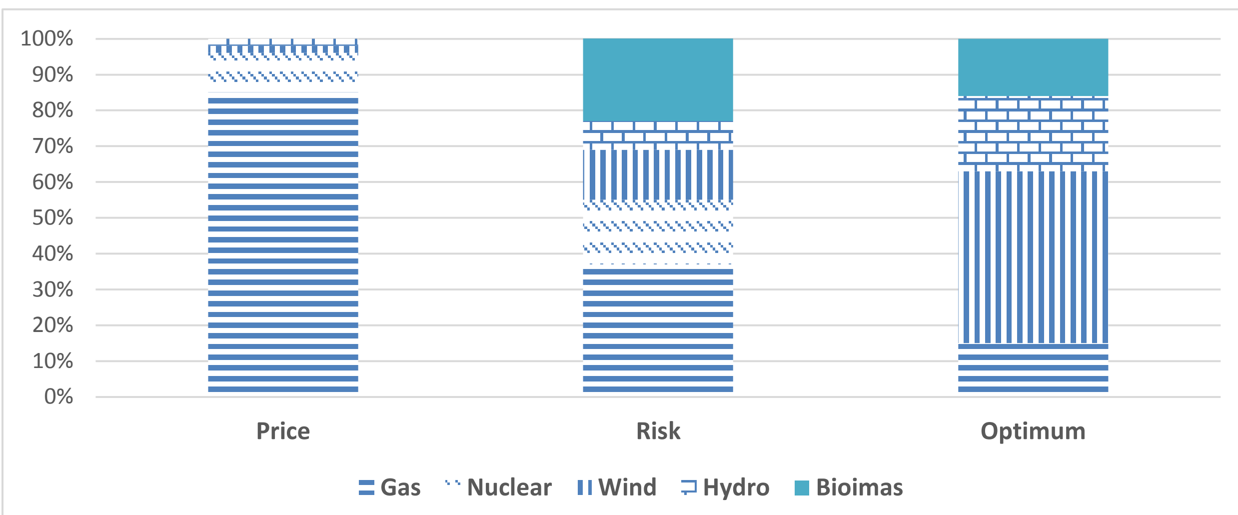
A recent study in the *Electricity Journal* using the portfolio approach can be used to shed important light on many of the issues being hotly debated in response to the EPA's proposed Clean Power Rule (see Figure VIII-4). Jason Rauch, a utility analyst at the Maine PUC, applies a mean-variance portfolio approach to identify the optimal portfolio of generation resources in New England.

FIGURE VIII-4: PORT FOLIO HOLDINGS WITH DIFFERENT MINIMIZATION GOALS

Base Case



Zero Carbon Case



Source: Jason Rauch, "Price and Risk Reduction Opportunities in the New England Electricity Generation Portfolio," ***Electricity Journal***

In that approach, which I have advocated and applied to national analyses of the U.S. and UK,[153] the cost (levelized cost of energy) and risk (variability of cost as measured by the standard deviation of the levelized cost) are given equal weight. The expected value (cost) of the portfolio reflects the cost and risk of each resource and the extent to which the costs covary. The risk of the portfolio can be reduced by including resources whose price are negatively correlated.

The purpose of the paper is to show that taking risk into account is important to arrive at optimal decisions and to demonstrate a rigorous, methodology that can be easily implemented by public utility commissions. This is a purpose I fully support. Here I want to move beyond that laudable goal and draw some policy conclusions that address some big questions in the ongoing debate about EPA's proposed Clean Power Rule – How much nuclear belongs in the portfolio? How does carbon regulation affect the attractiveness of the alternatives? How much gas is needed? How large are the cost increases?

The makeup of the optimal portfolio is clear

- Nuclear is not included in any optimal portfolio.
- Gas is 15% to 16% in the optimal portfolio.
- Wind accounts for 34-48%, depending on the cost of integration.
- Hydro is in the range of 21% to 34% (hydro is up, when wind is down)
- If the decision maker ignores risk and carbon mitigation, the preferred portfolio is 96% gas, but if the decision maker considers **risk or carbon mitigation**, the gas share is reduced by five-sixths.

Carbon regulation has little impact on the mix of generation in the optimal risk-adjusted price portfolio. The optimum resource mix is roughly the same in both the base case and the zero carbon case.

- The cost increase resulting from a long term zero carbon policy (i.e. gas with carbon capture replacing unabated gas), is relatively small.
- This is generally consistent with EPA's analysis of its Clean Power Rule, which yields a low cost (but leaves a lot of carbon emissions, but the very low cost of a zero carbon sector in New England reflects the absence of coal fired

However, once one moves to decarbonize the electricity sector, optimal portfolio analysis becomes particularly important.

- An approach to zero carbon emissions that is not risk aware increases the expected cost by just under 20%.
- An optimal portfolio strategy keeps it under 13%.
- Controlling the cost of integrating large shares of wind is important, as it can add 2 to 4% to the cost of the optimal portfolio.

B. NON-ENERGY BENEFITS

[153] Cooper, 2013f.

A second aspect of regulatory cost-benefit analysis that has begun to receive increased attention in the formal review of specific regulation involves non-energy benefits of energy efficiency technologies. While the economic externalities of energy consumption originally entered the policy arena through the study of the negative recessionary impact of oil price shocks,[154] the positive impact of energy efficiency is becoming widely recognized and consistently modeled.[155] A recent analysis prepared for the OECD/IEA catalogued the varied positive impacts of energy efficiency, identifying over a dozen specific impacts (see Table VIII-1).

TABLE VIII-1: SUMMARY OF OUTCOMES FROM IMPROVEMENT IN ENERGY EFFICIENCY

Area of impact & Specific Benefits	Time Frame		Level of Effect			Country context		Energy Impact	Effects
	Short	Long	Ind.	Nat.	Intl.	Energy Mix	Devel-opment	savings	Rebound
Economic									
Provider Benefit & Infrastructure	x	x	x	x		x	x	x	-
Energy Prices	x	x		x	x	x	x	x	+
Public Budgets		x		x	x	x	x	x	+
Energy Security		x		x		x	x	x	-
Macro-economic effects		x		x			x		+
Social									
Health	x		x	x			x		+
Affordability	x		x				x	x	+
Access		x	x	x			x		+
Development	x			x	x	x	x		+
Job Creation	x		x	x			x		+
Asset Values	x		x	x					-
Disposable Income	x		x	x			x		+
Productivity	x		x	x			x		+
Environment									
GHG Emissions	x			x	x	x	x	x	-
Resource Mgmt.			x	x	x	x	x	x	-
Air/Water Pollutants			x	x		x	x	x	-

Sources: Lisa Ryan and Nina Campbell, *Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements* (International Energy Agency, Insight Series 2012), p. 25.

An evaluation of the non-energy benefits of whole house retrofits produces a similar, long list of benefits (see Table VIII-2). The magnitude of these potential gains is difficult to estimate, but they are likely to be substantial. Direct estimates of the non-economic benefit have been estimated at between 50% and 300% of the underlying energy bill savings.

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[154] Hamilton, 2009, Warr Ayers and Williams, 2009; Belke, Dreger and de Haan, 2010;

[155] In addition to the recent U.S. analysis by U.S. EPA/NHTSA, 2011, see Howland, et. al., 2009, and New York State Energy Research & Development Authority, 2011, for individual states; Homes and Mohanty (2012) and Cambridge Centre for Climate Mitigation Research (2006), and Ryan and Campbell, 2012 for a general global review.

TABLE VIII-2: NON-ENERGY BENEFITS FROM WHOLE HOUSE RETROFITS

Benefit Type	Specific Benefit
Financial (other than energy cost savings)	Water and waste bill savings
	Reduced repaid and maintenance
	Increased resale value
	Improved durability
Comfort	Improved airflow
	Reduced drafts and temperature swings
	Better humidity control
Aesthetic	More attractive windows/ appliances
	Less dust
	Reduced mold and water damage
	Protection of furnishings
	Dimmable lighting
Health & Safety	Improved respiratory health
	Reduced allergic reactions
	Lower fire/accident risk (from gas equipment)

Benefit Type	Specific Benefit
Noise Reduction	Quieter equipment
	Less external noise intrusion
Education-related	Reduced transaction costs (knowing what to look for when purchasing equipment; ease of locating products)
	Persistence of savings
	Greater understanding of home operation
Convenience	Automatic thermostat controls]
	Easier filter changes
	Faster hot water delivery
	Less dusting and vacuuming
Other	Greater control over energy use/bills
	Reduced sick days
	Ease of selling home
	Enhanced pride
	Improved sense of environmental responsibility
	Enhanced peace of mind/responsibility for family well-being

Source: Jennifer Thorne Amann, 2006, *Valuation of Non-Energy Benefits to Determine Cost-Effectiveness of Whole-House Retrofit Programs: A Literature Review,* American Council for an Energy Efficient Economy, p. 8.

These discussions of the non-energy benefits are framed in terms of the benefits to the individual. As shown in Table VIII-3, there are also significant benefits to utilities and society at large. In fact, in the current economic environment, the significant potential benefit in the macroeconomic multiplier effect of reduced energy expenditures takes on special importance. Expenditures are shifted from purchasing energy to purchasing technology, which has a larger multiplier. The decrease in energy expenditures is substantially larger than the increase in technology costs, resulting in an increase in the disposable income of individuals to spend on other things.

1. Macroeconomic Impact

The macroeconomic impact of energy policy has taken on great significance in the current round of decision making for two reasons.

- With the economy mired in recession, every policy is evaluated for its ability to stimulate growth and create jobs.
- Because climate policy requires a dramatic shift in economic activity, its impact on growth and job is extremely important.

TABLE VIII-3: BENEFITS OF EFFICIENCY TO UTILITIES, CONSUMERS AND SOCIETY

Benefits to the Utility

1. Production capacity cost savings
2. Production energy cost savings
3. Avoided costs of compliance with existing environmental regulations
4. Avoided costs of compliance with future environmental regulations
5. Transmission capacity cost savings
6. Distribution capacity savings
7. Avoided line losses
8. Minimizing reserve requirements
9. Decreased risk
10. Displacement of renewable resource obligations
11. Reduced credit and collection costs
12. Demand-Response Induced Price Effect (DRIPE)
13. Other utility benefits

Benefits to Participants

14. Reduced future energy bills
15. Operation and maintenance cost savings
16. Participant health impacts
17. Increased employee productivity
18. Effect on property values
19. Improved comfort

Benefits to Society

20. Public health and welfare benefits
21. Air quality impacts
22. Water quality and quantity impacts
23. Decrease in coal ash ponds and coal combustion residuals
24. Improved economic development and employment effects
25. Decreased societal risk and increased energy security
26. Benefits for low-income customers

Source: Lazar, Jim and Ken Colburn, 2013, *Recognizing the Full Value of Energy Efficiency (What's Under the Feel-Good Frosting of the World's Most Valuable Layer Cake of Benefits),* September, p. 2

a. GDP Multiplier

Assessing the macroeconomic impact of policy choice generally relies on complex models of the economy. Economically beneficial energy efficiency investments yield net savings; the reduction in energy costs exceeds the increase in technology costs. Such investments have three economic effects from the point of view of the economy.

- The inclusion of energy efficient technologies in energy using durables increases the output of the firms that produce the technology.

- To the extent that the energy using products are consumer durables, they increase the disposable income that households have to do other things, such as buy other goods and services.
- To the extent that the energy using products are utilized as inputs in the production of other goods and service, like trucks used to deliver packages or vegetables, they lower the cost of those goods and services. In competitive markets, those costs are passed on to the consumer in the form of lower prices. This also increases the disposable income of the household to buy other goods and services.

The increase in economic activity resulting from spending on new technology and the increase in consumer disposable income flows through the economy, raising the income of the producers of the additional products that are purchased and increasing employment.

> Higher vehicle costs are projected to reduce household consumption slightly in the first few years of the rule implementation. Over time, fuel savings increase and the price of world oil decreases, which leads to lower prices economy-wide. As a result, household consumption increases over the long term.
>
> The fuel savings and lower world oil prices that result from this rule lead to lower prices economy-wide, even when the impact of higher vehicle costs are factored into this analysis. Lower prices allow for additional purchase of investment goods, which, in turn, lead to a larger capital stock. These price reductions also allow higher levels of government spending while improving U.S. competitiveness thus promoting increased exports relative to the growth driven increase in imports. As a result, GDP is expected to increase as a result of this rule.[156]

For example, in the recent regulatory proceeding that finalized the long-term fuel economy standard of 54.5 miles per gallon for 2025, the standard was projected to increase the size of the economy by over $100 billion, in 2010 dollars. This indirect benefit was equal to the direct consumer pocketbook benefit of the standard. Figure VIII-4 shows the relationship between the net pocketbook savings, increases in consumption and increases in GDP. Although the figure was estimated using standard econometric models of the economy, it was not included in the final published cost benefit analysis.[157]

b. Jobs

Another popular measure is to estimate jobs per dollar invested. As shown in Figure VIII-6, in the electricity space, a comparative analysis of efficiency compared to generation found that efficiency created twice as many jobs per dollar spent on nuclear power and 50% more jobs than coal and gas generation.[158]

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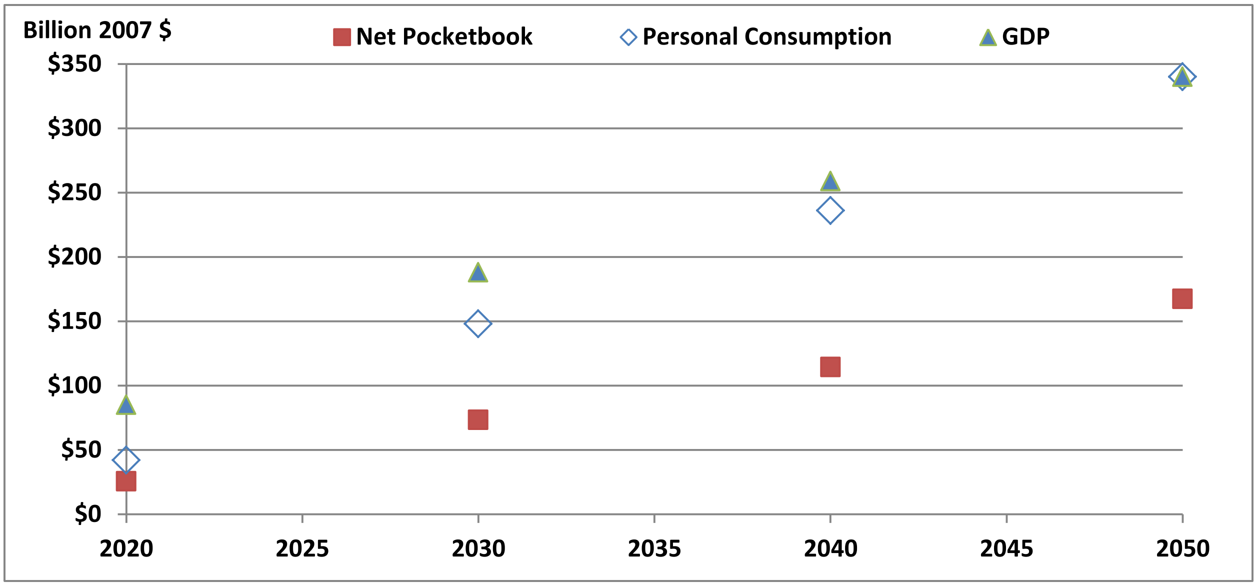
[156] U.S. EPA, 2010, pp. 3-4.
[157] CFA, 2012, pp. 53-54.
[158] Wei, Patadia and Kammen, 2010; Anair, and Hall, 2010; Gold, et al., 2011; Roland-Holst, 2008. The macroeconomic analysis shines a spotlight on the rebound effect, there tendency for some of the cost savings resulting from efficiency investments to be spent on additional consumption of goods and service, including more of the services provided by the more efficient durable equipment There is some rebound, but there is no backfire. Using more efficient durables that lower the energy bill and increase disposable income will result in some direct

FIGURE VIII-5: IMPACTS OF THE 2012-2016 CORPORATE AVERAGE FUEL ECONOMY RULE: SAVINGS AND INCREASE S IN ECONOMIC ACTIVITY



Source: U.S. Environmental Protection Agency, Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency, Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average: Regulatory Impact Analysis, EPA-420-R-10-009, April 2010, Table 6-18, Docket EPA-HQ-OAR-2009-0472, *Memorandum: Economy Wide Impacts of Greenhouse Gas Tailpipe Standards,* March 4, 2012, Tables 1 and 2.

These large increases in economic activity lead to increases in employment. The effect is magnified by the fact that the non-energy sectors of the economy are substantially more labor intensive than energy production. As shown in Figure VIII-7, the energy sector is less than half as labor intensive as the rest of the economy. This effect is compounded where energy is imported (as in the U.S. transportation sector). As consumers substitute away from energy, the goods and services they purchase stimulate economic and disproportionately large job growth.

These efforts to model the ec4onomic impact of energy efficiency have proliferated with different models[159] being applied to different geographic units, including states[160] and nations.[161] The results differ across studies because the models are different, the impact varies according to the size of the geographic unit studied and because the assumptions about the level and cost of energy savings differ. These differences are not an indication that the approach is wrong. On

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increase in the use of the specific device that is more efficient and will allow more consumption of other goods and services. This shift of economic activity is, unequivocally welfare enhancing. The magnitude of the rebound is likely to be much smaller than the initial reduction in energy consumption that triggered the rebound. Thus, while policymakers need to take the rebound effect into account when designing energy consumption and/or carbon abatement policies, the rebound effect is not a reason to pass over policies that promote energy efficiency. Given the advantages of efficiency in terms of resource costs, macroeconomic benefits and non-energy benefits, the rebound effect does not alter the conclusion the efficiency should be considered the “first fuel” (IEA. 2014).

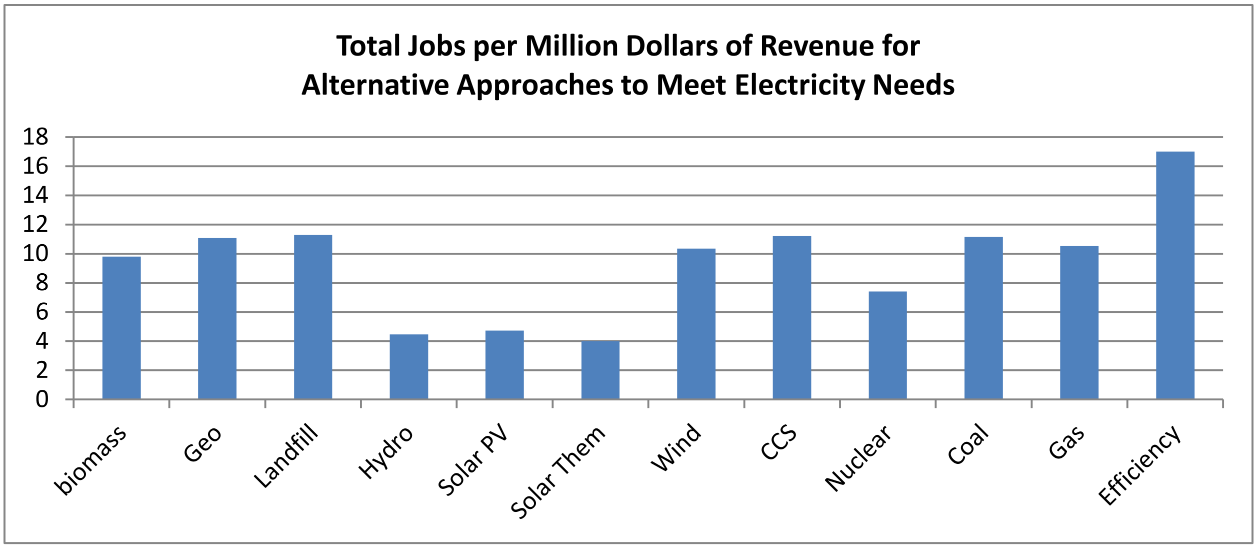
[159] For example, EPA, 2010, IGEM; Gold, 2011, IMPLAN, Howland and Murrow and NYSERDA 2011, REMI),

[160] For example, New York (NYSERDA, 2011), New England (Howland and Murrow), California (Roland Holst, 2008)

[161] For example, U.S. (Gold,, 2011, EPA, 2010, Warr, Ayres and Williams, 2009) and UK (Cambridge Center, 2006). Warr, Ayres and Williams, 2009, note recent studies on Asian economies, Korea, Canada and Spain,

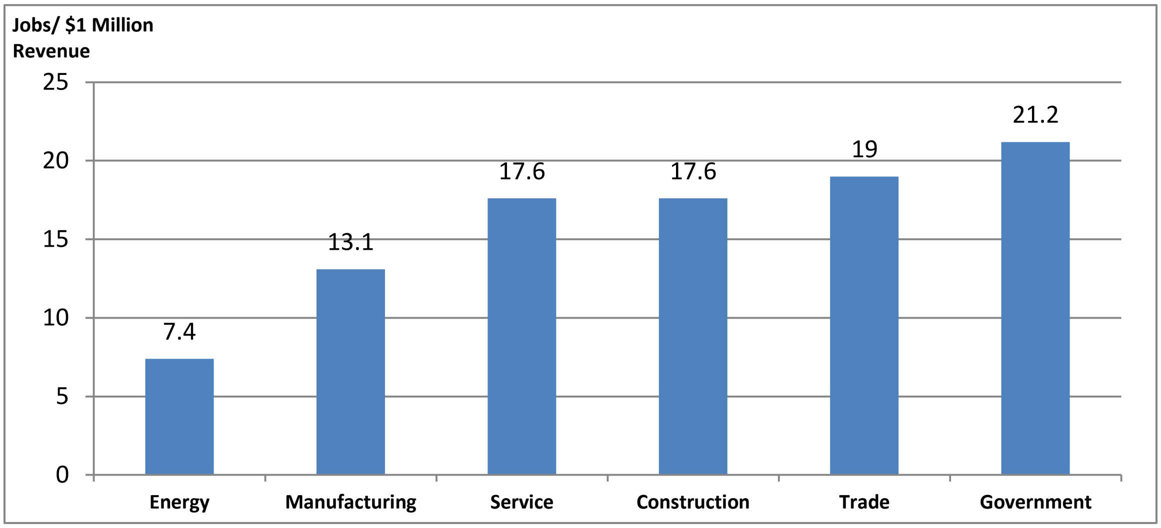
the contrary, all of the analyses conclude that there will be increases in economic activity and employment. Given that there are different regions and different policies being evaluated, we should expect different results.

FIGURE VIII-6: JOB CREATION BY ALTERNATIVE APPROACHES TO MEET ELECTRICITY NEEDS



Sources: Direct jobs: Max Wei, Shana Patadia and Daniel Kammen, :Putting Renewables and Energy Efficiency to work: How Many Jobs can the Clean energy Industry Generate in the US?", *Energy Policy,* 38(2010); Total Jobs: Rachel Gold, et al, *Appliance and Equipment Efficiency Standards: A Money Maker and Job Creator,* (American Council for an Energy-Efficient Economy, January 2010); Lazard, *Levelized Cost of Energy Analysis – Version 3.0,* June 2009.

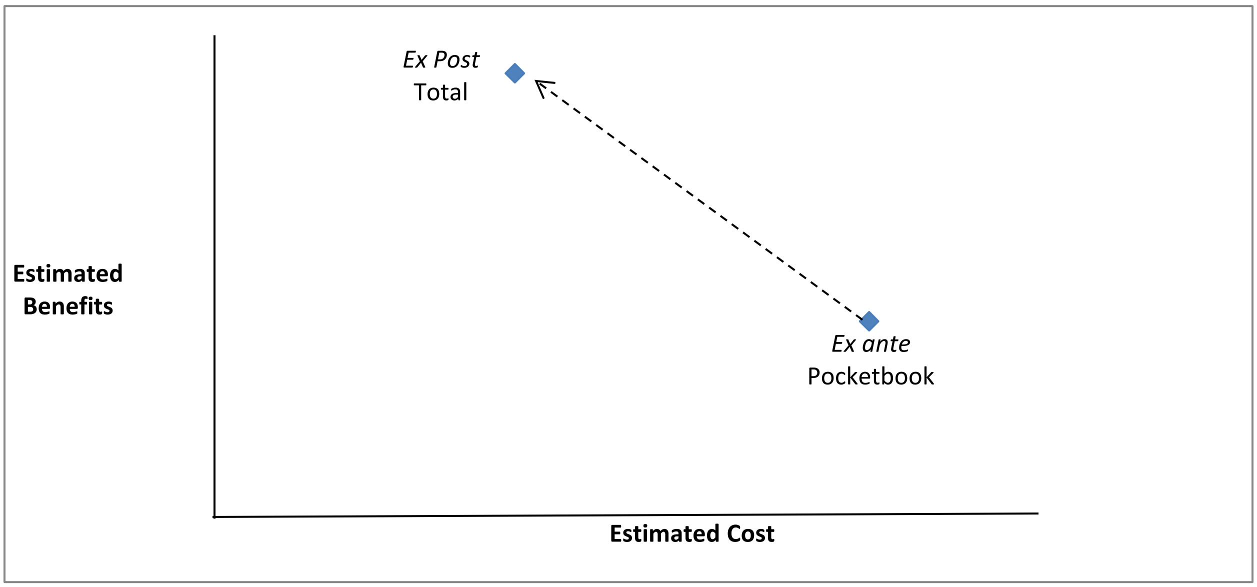
FIGURE VIII-7: LABOR INTENSITY OF KEY ECONOMIC SECTOR IN THE U.S.



Source: Rachel Gold, et al., *Appliance and Equipment Efficiency Standards: A Money Maker and Job Creator,* American Council for an Energy Efficient Economy, January 2011, p. 9, based on the IMPLAN Model, 2009.

Taken together, the overestimation of costs and underestimation of benefits lead to a substantial and systematic underestimation of the net benefits of efficiency gains, as shown conceptually in Figure VIII-8. Because the impact of the efficiency improvements depends on the size of the improvement and the type of consumer durable being studied, the sector in which it occurs and the region being analyzed, one cannot offer a single, simple estimate. Exhibit III-7 is drawn to reflect the likely order of magnitude impact of the underestimation of the benefits of the recent fuel economy standards. The *ex ante* calculation of costs and benefits is likely to underestimate the benefit/cost ratio by a factor of at least two because of the failure to reflect the macroeconomic benefits and cost reducing trends, both of which are positive externalities of the adoption of performance standards.

FIGURE VIII-8: CONCEPTUALIZATION OF THE IMPACT OF UNDERESTIMATION OF BENEFITS AND OVERESTIMATION OF COST ON THE EVALUATION OF BENEFIT/COST RATIOS



C. ENVIRONMENTAL IMPACTS AND SUSTAINABILITY

Once one moves into the broader realm of non-economic goals of the electricity system, nuclear power fares very poorly. Nuclear power has significant disadvantages in terms of security, [162] and proliferation risks[163] and continues to suffer from unique environmental problems.[164] Based on a non-commodity, local source of power, renewables have a large advantage in macroeconomic impacts.[165] As a result, in multi-attribute rankings and evaluations,

[162] Johansonn, 2014.
[163] Katarzyna, et al., 2009, 187,
[164] Stein, 2013; Rabl and Rabl, 2013,
[165] Llera, 2013; Santiago, et al., 2014. Islam, Mekhilef and Saidur, 2013; Pleßmann, Guido, et al., 2014, Branker and Pearce, 2010; Black, Geoffrey, et al., 2014, p. 141,.

the main renewables (wind, solar, hydro) and efficiency are much more highly rated[166] and have consistently been so for decades.[167]

Figure VIII-9 shows the results of several evaluations of energy resources. The top graph shows the average ranking of resources based on studies that generally took place before the focus on climate change became prominent. The lower graph plots those earlier results against a recent ranking. It sets coal as the base (equal to 1) and then calculates the ratio of the other resources compared to coal, with lower scores meaning more preferable rankings. We have also included efficiency at the raking from the earlier studies, in the bottom graph. The sharp break between efficiency and renewables as attractive resources and the conventional (fossil fuels and nuclear) is readily apparent in both sets of rankings, which have a strong correlation (r=.86).

> Evaluation criteria: evaluation of each technology was based on the application of four primary criteria:
>
> - Financial (FC): financial value of the technology and return on investment.
> - Technical (TC): characteristics of the technology as a power source and its production capabilities.
> - Environmental (EN): impact of power plant on local and regional environment, as well as human health.
>
> Social/Economic/Political (SEP): impact on local economy and communities, as well as congruence with over all national policies.
>
> The results indicate that wind, solar, hydropower and geothermal provide significantly more overall benefits than the rest even when the weights of the primary criteria clusters are adjusted during sensitivity analysis. The only non- renewable sources that appear in three of the 20 top rank positions are gas and oil, while the rest are populated with renewable energy technologies. These results have implications for policy development and for decision makers in the public and private sectors. One conclusion is that financial incentives for solar, wind, hydropower and geothermal are sound and should be expanded. Conversely, subsidies for non-renewable sources could be diminished.[168]

The analysis of New England discussed above in the examination of risk showed that the resources mix was similar in the analysis of the base case and the zero carbon case. This discussion of factors other than the levelized cost suggests that on every dimension – risk related characteristics, non-energy, economic impacts, and non-carbon environmental impacts – efficiency and renewables are the preferred option.

Figure VIII-10 presents two quantifications of environmental and health impacts that support that conclusion. Efficiency, wind and solar are the most attractive options by far. Fossil fuels become less attractive. Nuclear power is barely competitive with fossil fuels with carbon capture and storage.

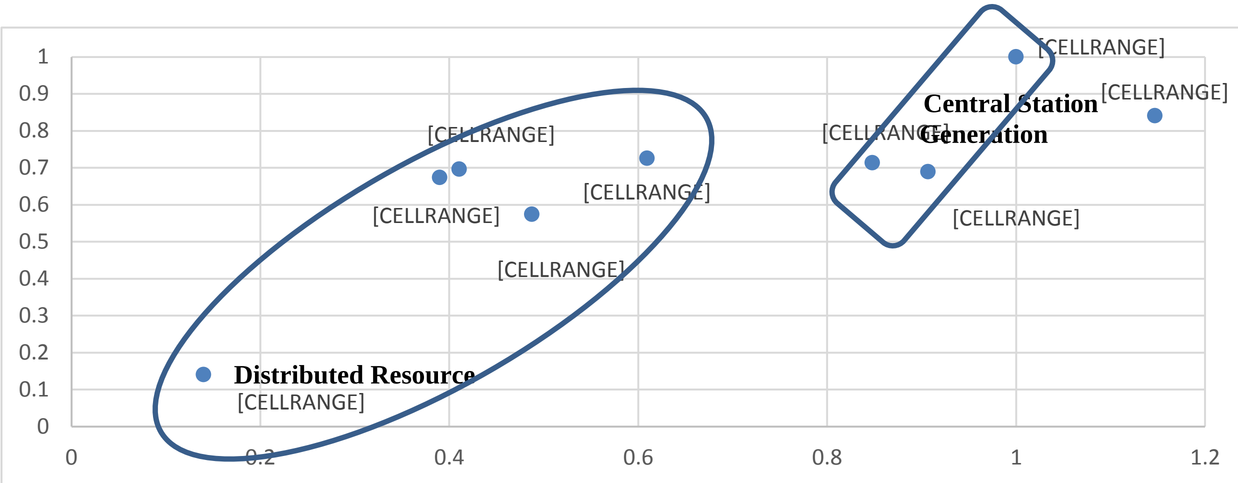
---

[166] Stein, 213, Karakosta, et al., 2013, Verbruggen, Laes and Lemmens, 2014.

[167] U.S. Congressional Office of Technology Assessment, 1994, evaluating Ottinger, Richard ET. al., 1990, Chernik, Paul and Emily Caverhill, 1989, Hohmeyer, Olive, 1988 and Shuman, Michael and Ralph Cavanagh, 1982.

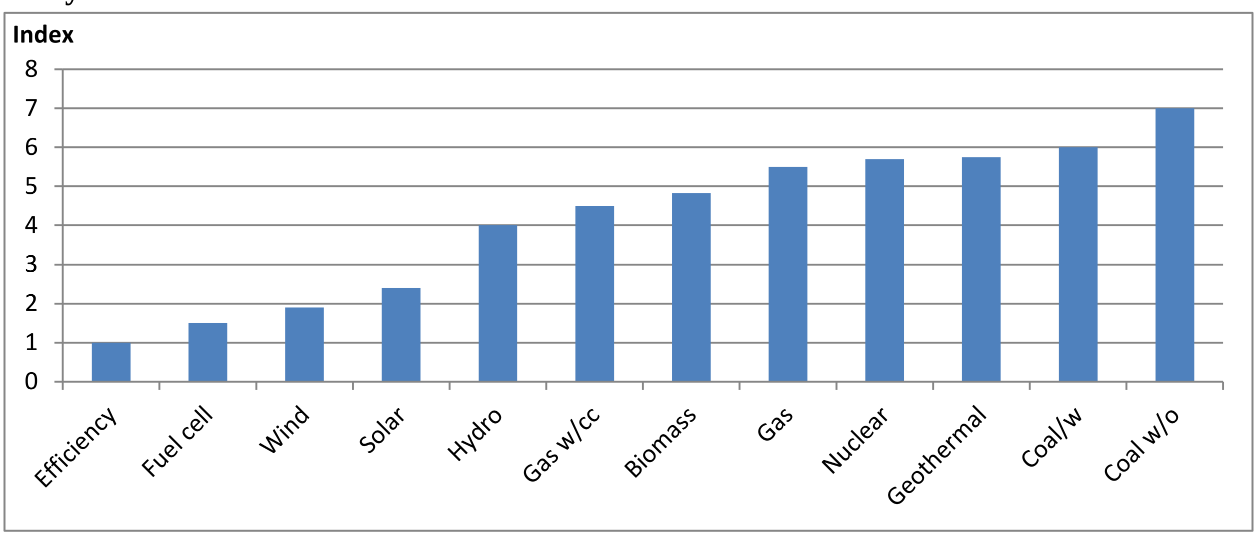
[168] Stein, 213, 646… 640.

FIGURE VIII-9: RECENT SUSTAINABILITY RANKINGS (COAL=1, LOWER SCORES ARE BETTER)



Sources: Eric W., Stein, 2013, "A comprehensive multi-criteria model to rank electric energy production technologies," *Renewable and Sustainable Energy Reviews*, 22; Alexandru Maxim , "Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis," *Energy Policy,* 65: 2014, figure 2.

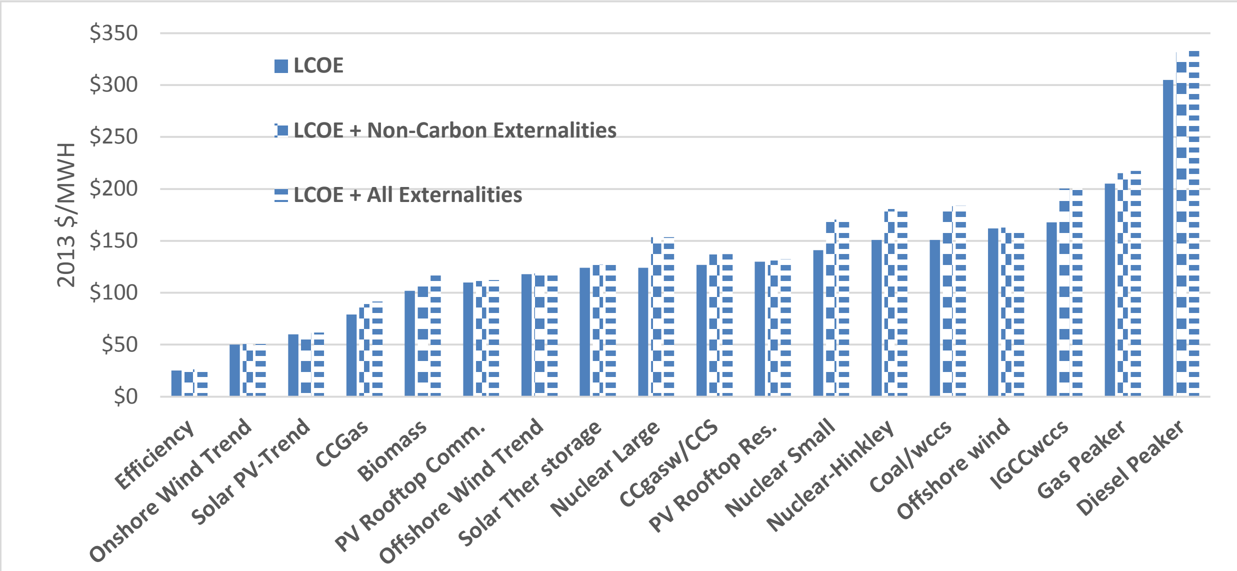
Early Studies



Source: Wilson B. Goddard, *A Comparative Study of the Total Environmental Costs Associated with Electrical Generation Systems* (G&GE Applied Research, 1997); *U.S* Congressional Office of Technology Assessment, *Studies of the Environmental Costs of Electricity* (Washington, D.C. September 1994), evaluating Richard Ottinger, et. al., Pace University Center for Environmental Legal Studies, *Environmental Costs of Electricity* (New York,: Oceana, 1990), Paul Chernik and Emily Caverhill, "the Valuation of Externalities from Energy Production, Delivery and Use (Fall 1989); Olave Hohmeyer, *Social Costs of Energy Consumption: External Effects of Electricity Generation in the Federal Republic of Germany* (Berlin: Springer-Verlag, 1988);Michael Shuman and Ralph Cavanagh, *A Model of Conservation and Electric Power Plan for the Pacific Northwest: Appendix 2: Environmental Costs* (Seattle, WA: Northwest Conservation Act coalition, November 1982).

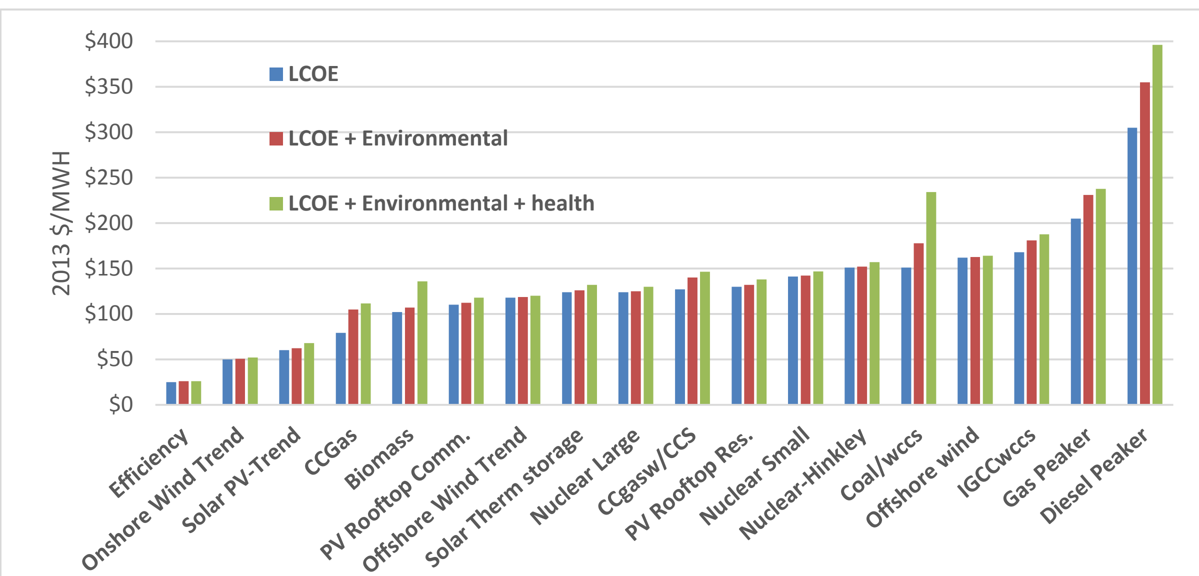
FIGURE VII-10: RESOURCE COST DOMINATE THE ECONOMIC ANALYSIS

LCOE + Environment + Carbon



Sources: LCOE from Lazard as in Figure V-1. Non-carbon externalities from Benjamin K. Socacool and Michael Dworkin, *Global Energy Justice* (Cambridge, 2014), p. 149, adapted from Thomas Sundqvist, "What Causes the Disparity of electricity Sources?," *Energy Policy,* 32 (2004); carbon cost of $40/ton applied to lifecycle greenhouse emission rates from W. P. Moomaw, et al., *Annex H, Methodology: IPCC; Special Report on Renewable Energy Source and Climate Change Mitigation,* 2011.

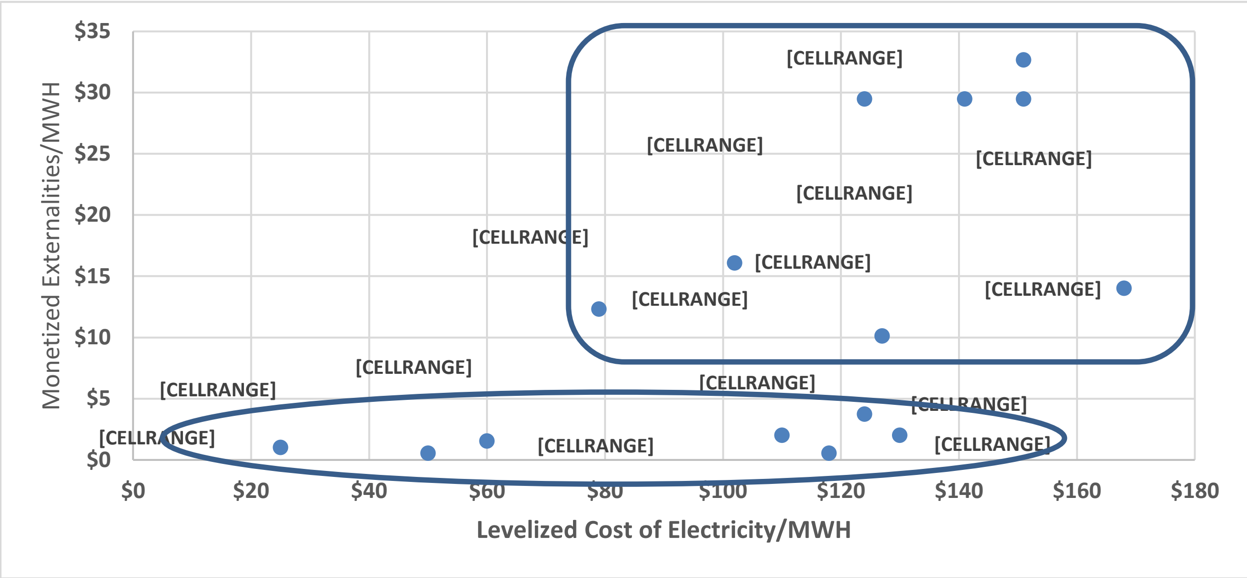
LCOE + Environmental + Health



Sources: LCOE from Lazard as in Figure V-1. Environmental and Health Cost from, Alexandru Maxim, 2014, "Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis," *Energy Policy*, 65, Table 8 and 9, with carbon capture and storage environmental externalities set at half of the externalities of the unababted resource.

Figure VII-11 makes the same point by showing the correlation between resources costs and external costs. As shown in Figure VII-10, including all of the non-carbon externalities associated with these resources strongly reinforces the case for building a low carbon sector on the basis of efficiency and renewables.

EXHIBIT VII-11: LEVELIZED COST AND MONETIZE EXTERNALITIES OF LOW CARBON RESOURCE, WITH MID-TERM COST TRENDS



Source: See Figures VI-1 and VII-9.

The analysis externalities has not only expanded in recent years to the broader issue of sustainability,[169] but it has also begun to look at important interactions between climate change and non-carbon externalities, like heat waves and water use,[170]

[169] Dombi, 2014; Maxim, 2014.
[170] Pechan and Eisenach, 2014.

IX. THE IMPLICATION OF THE IMPENDING TRANSFORMATION OF THE ELECTRICITY SYSTEM

A. ECONOMIC FORCES DRIVING CHANGE

The cost trends and technological developments examined above establish the potential for a dramatic change in the electricity sector. Over the past two decades technological developments have disrupted the structure of the utility sector that dominated the 20th century and opened the door to a major transformation of the sector.

1. Supply-side

A late 2012 analysis from Citi Research concluded that "[o]n the residential-scale, solar is already competitive with electricity off the grid…Utility-scale solar will be competitive with gas-fired power in the medium term… Utility-scale wind is already competitive with gas-fired power."[171] Citi research presents the global view, but Credit Suisse takes an even more aggressive view of the development of renewables in the U.S. Credit Suisse and picks up the theme of the supply-side transformation being driven by renewable energy that Lazard and Citi discussed. Credit Suisse argues that over the next decade, renewable deployment will be substantial, able to meet five-sixths of the need for generation with the major renewables, with the result of reducing the pressure on gas supply.

> We see an opportunity for renewable energy to take an increasing share of total US power generation, coming in response to state Renewable Portfolio Standards (RPS) and propelled by more competitive costs against conventional generation. We can see the growth in renewables being transformative against conventional expectations with renewables meeting the vast majority of future power demand growth, weighing on market clearing power prices in competitive power markets, appreciably slowing the rate of demand growth for natural gas. [172]

While Credit Suisse cites policies that are promoting renewables as the context for the transformational impact on supply, it also argues that the renewables have become cost competitive with conventional baseload generation.

> Renewables are cost competitive to even cheap against conventional generation. The clearing price for new wind and solar continues to fall with improvements in utilization and falling capital costs. For wind we are seeing utilization rates 15–20 percentage points higher than 2007 vintage turbines, regularly supporting PPA pricing at or below $30/MWH that effectively 'creates' long-term equivalent natural gas at <$3/MMBtu. Lower capital costs for solar have dropped PPA pricing to $65–80/MWH from well over $100/MWH, making solar competitive with newbuild gas peaking generation.[173]

McKinsey reaches the same conclusion as Citi and Credit Suisse in projecting cost parity for solar with conventional generation within the next decade, but they go on to argue that this

---

[171] Citi Research, 2012, pp. 54, 55, 56. The academic literature reflects this trend as well. See, for example, Sener, Can and Vasilis Fthenakis, 2014; Hernandez-Moro and Martınez-Duart, 2013; Reichelstein, Stefan and Michael Yorston, 2013: Bazilian, Morgan, et al., 2013; Branker, K., M.J.M. Patha and, J.M. Pearce, 2011.
[172] Eggers, Cole and Davis, 2013b, p. 1.
[173] Eggers, Cole and Davis, 2013b, p. 1.

can have a dramatic impact on the marginal demand for conventional resources. The report argued that the growth of solar has an "outsize" effect on the demand for base load generation.

> These cost reductions will put solar within striking distance, in economic terms, of new construction for traditional power-generation technologies, such as coal, natural gas, and nuclear energy. That's true not just for residential and commercial segments, where it is already cost competitive in many (though not all) geographies, but also, eventually, for industrial and wholesale markets…
>
> Solar could seriously threaten the latter because its growth undermines the utilities' ability to count on capturing all new demand, which historically has fueled a large share of annual revenue growth. (Price increases have accounted for the rest.)
>
> Depending on the market, new solar installations could now account for up to half of new consumption (in the first ten months of 2013, more than 20 percent of new US installed capacity was solar). By altering the demand side of the equation, solar directly affects the amount of new capital that utilities can deploy at their predetermined return on equity. In effect, though solar will continue to generate a small share of the overall US energy supply, it could well have an outsize effect on the economics of utilities—and therefore on the industry's structure and future.[174]

The importance of the impact of renewables at the margin was also emphasized by analysts at Sanford Bernstein, who noted that at "a conference… discussing the implications of distributed solar on U.S. utilities" the surprise

> was that – for the utility executives who spoke – the issue of whether solar is going to ramp up in the U.S. was not raised. Instead, the discussion from utilities themselves went directly to the issue of how to reach an accommodation with this rapidly expanding and disruptive technology…. Two things stand out. First, this is a live issue in one of the largest power markets in the world, with solar at .17% of global demand. Second, trends that start in California tend to travel well.[175]

These observations not only correct the mistaken belief that the overwhelming cause of the woes of the "nuclear renaissance" is cheap gas, they also counter the fear campaign that nuclear advocates rely on to discredit natural gas because of price volatility. Not only is the long term pattern for natural gas not volatile,[176] but reducing supply pressures with renewables would dampen any volatility.[177]

2. Demand-side

A second important trend driving change in the electricity sector is a reduction in demand growth. Credit Suisse notes the important role that declining demand growth plays in driving the transition of the electricity sector.

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[174] Frankel, Ostrowski, and Pinner, 2014.
[175] Bernstein, 2014, p. 3.
[176] Cooper, 2013c.
[177] Eggers, Cole and Davis, 2013b.

> The impact of energy efficiency has become more of a focal point after another year of lackluster power demand growth in 2013 and disappointing usage trends across customer classes.[178]
>
> Our take: Energy efficiency remains an under-appreciated but very important trend in power markets that will lead to structural drags on power demand growth impacting the outlook for competitive power market recovery and where utility capex will need to be allocated. We model efficiency lowering annual demand growth by ~70 bp (.7%) a year from a 'normal' baseline, putting core growth at +0.5-1.0% with downside risk barring better economic recovery…
>
> Our outlook for slower demand growth relative to a 'normal' +1.5% pushes out reserve margin equilibrium by 1–3 years, creating another unwanted headwind for competitive power.[179]

Credit Suisse notes that the slowing of demand growth places a great deal of pressure on the economics of utilities not only where it adds to the downward pressure on prices set in markets, but also in regulated states, where rate structures have relied on growing demand to ensure recovery of fixed costs.

> Regulated Utilities. Slower demand growth will hurt revenue growth between rate cases for most utilities, putting pressure on their ability to offset cost inflation and rate base growth leading to lower earned ROEs. We think utilities will need (a) to work with regulators to develop mechanisms that help to offset efficiency drag through decoupling, energy efficiency trackers, etc. and (b) focus on O&M cost management to reduce inflationary pressures[180]

One of the critical mistakes made in the effort to justify the construction of large reactors at the height of the "nuclear renaissance" was to assume substantial rates of demand growth. Long before the great recession, demand growth had been slowing. Even with the return of economic growth, demand for electricity has not returned to its historic levels. While the devices that make up the digital economy consume electricity, the fact that many are portable and mobile has placed a premium on efficiency. It is reasonable to assume that demand growth will be small or even negative in the decades head.

However, beyond the fact that efficiency lowers the cost of carbon reduction, efficiency has two impacts on the economics of resource acquisition. First, as demand growth slows, the addition of large, central station facilities add very large increments of supply that may result in excess capacity. Second, in the near term efficiency is a response that buys time for alternative technologies to develop. Given cost trends, this improves the prospects for renewables, whose costs have been falling.

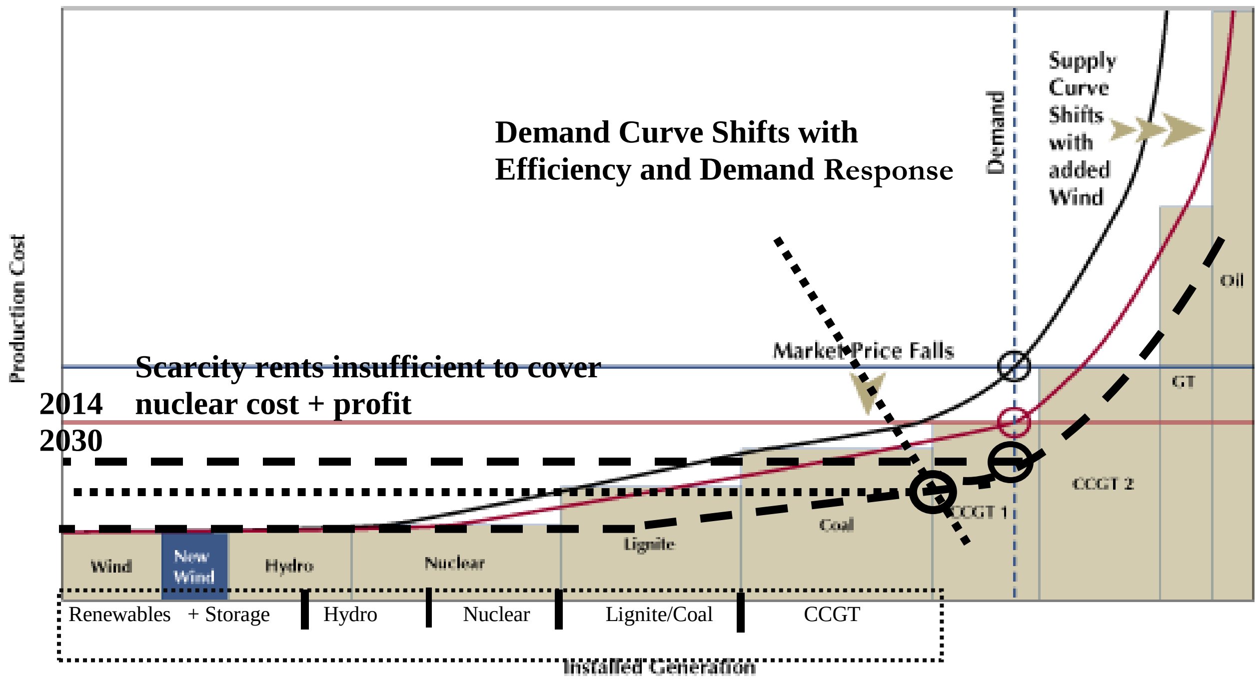
A utility sector that moves toward a more diversified, distributed resource base and directly addresses the storage issue will put further pressure on high capital cost resources. The process of innovation for some alternatives is midstream, while for others, like storage it is just beginning. The pressure will continue to mount. Supply shifts to renewables and gas. Efficiency lowers demand and demand response shaves the peak.

Efficiency can be added to the earlier analysis of the downward pressures on market

[178] Eggers, Cole and Davis, 2013a, p. 1.
[179] Eggers, Cole and Davis, 2013a, p. 1.
[180] Eggers, Cole and Davis, 2013a, p. 3.

clearing prices that backs out fossil fuels as depicted in Figure IX-1. Efficiency lowers demand at the peak and demand management makes it more price elastic.

FIGURE IX-1: CONTINUING DEPLOYMENT OF WIND, EFFICIENCY AND SUPPLY-DEMAND MANAGEMENT



Source: Doug Vine and Timothy Juliant, 2014, *Climate Solutions: The Role of Nuclear Power,* Center for Climate and Energy Solutions, April, p. 6, with authors additions.

B. THE CHALLENGE OF INSTITUTION BUILDING

In this paper and earlier analyses I have shown that some financial analysts have been at the forefront of raising important issues when it comes to the development of alternatives and nuclear power including

- identifying the implications of the dramatically declining cost and the increasing potential for deployment of alternatives – wind, solar and storage,[181]
- questioning the unrealistically optimistic cost projections offered by nuclear advocates in the early days of the "nuclear renaissance" and warning that new reactor construction would place severe burdens on utility finance, [182] and
- recognizing the economic problems of aging reactors in wholesale markets

[181] Lazard, 2011; Citi Research, 2012; Eggers, Cole and Davis, 2013.
[182] Cooper, 2009b, reviews several of these analyses including, Moody's, 2009; Moody's, 2008; Standard & Poor's, 2009; Standard & Poor's, 2008; Standard & Poor's, 2007; Maloney, Stephen, 2008; Maloney, Stephen, 2009; Edward Kee 2009.

where renewables and efficiency are putting downward pressure on prices.[183]

Therefore, we should not be surprised to find financial analysts who have signaled the dramatic impact that the emergence of the 21st century electricity market could have on the 20th century utility business model.

> Investors beware: Distributed generation (DG) could kill utilities as we know them today. It could take a decade or more in the United States, but some European utilities already are facing change-or-die challenges due to DG. Technologies such as rooftop solar reduce the value of utilities' century-old centralized networks, and erode their efficient-scale competitive advantage. As more customers adopt DG, utilities' costs to maintain and operate the grid must be spread across a smaller customer base, raising customer rates and increasing the economic incentive to cut the cord. The death spiral ends when investors—equity and credit—are left holding an empty purse of dormant power plants and copper wires.
>
> We think the sector's imminent demise is premature, but DG is already starting to shrink some utilities' economic moats. The electric utilities industry group Edison Electric Institute (EEI) recently identified DG as the largest disruptive threat to utilities'' business models and financial health. We agree. Utilities' efficient-scale competitive advantages rely on their centralized network monopolies, but that breaks down when customers become self-sufficient competitors. The cost-of-service regulatory model that allows utilities to earn at least their cost of capital in the long run also breaks down when fewer and fewer customers are bearing the costs of maintaining the centralized network. Ultimately, utilities' earnings will shrink, cash flows will suffer, ROIC will fall, and utilities' interest and dividend payments will become less certain.[184]
>
> Change is sweeping across the planes of our energy landscape. The combination of solar leasing, advances in renewable energy storage, and the brave new world of the "Internet of Things" spell doom for utilities as we know them. Utility shares could be worth a lot less, and sooner than investors would care to recognize.
>
> The electric utility business model has remained stubbornly unchanged for much of the last 50 years. While telecoms, health care, and other industry structures have hurtled ahead -- for better or worse -- in response to our modern technological and regulatory framework, the system that powers our homes and businesses seems almost anachronistic at this point. Utilities invest in building large-scale generation plants and a transmission and distribution architecture to move power from source to end user, and then recoup costs through the rates they charge customers.[185]

It is not only high capital cost generation that is feeling the profit pressures. Ironically, many in the utility industry – the non-nuclear part, which is the majority – recognize the forces operating on the industry. "Disruptive" is the watchword for this analysis. The Edison Electric Institute document referred to in the first quote above recognized the potential disruption.

> Recent technological and economic changes are expected to challenge and transform the electric utility industry. These changes (or "disruptive challenges") arise due to a convergence of factors, including: falling costs of distributed generation and other distributed energy resources (DER); an enhanced focus on development of new DER technologies; increasing customer,

183 Credit Suisse, 2013; UBS Investment Research, 2013a, 2013b, 2013c; Platts, 2013, Moody's, 2012
184 Bischof, 2014.
185 Murphy 2014. Parker, et al., 2014, p. 3.

> regulatory, and political interest in demand side management technologies (DSM); government programs to incentivize selected technologies; the declining price of natural gas; slowing economic growth trends; and rising electricity prices in certain areas of the country… the industry and its stakeholders must proactively assess the impacts and alternatives available to address disruptive challenges in a timely manner.[186]

A year later, The Edison Electric Institute formed an alliance with a leading environmental group (NRDC) to call for changes in tariff and rates structures that recognize the emerging reality. Their joint statement recognizes the inability/inappropriateness of recovering capital costs in variable charges and the need to transform the grid and its operation into a two-way network that supports decentralized behaviors at the edge of the network to improve the efficiency of the sector, but requires a physical and institutional transformation.

> The future of America's vital electricity sector will continue to be a promising one as long as regulatory policies are fair and forward looking. As we move into a new age of innovation, the use of the grid is evolving, facilitating power flows in two directions, so that customers can engage in both purchases and sales of energy, and provide other services such as balancing, voltage support, and voluntary load management. Innovation is providing new incentives for customers to use the grid more effectively and efficiently, optimizing the use of existing infrastructure.[187]

Thus, the electricity sector has moved well beyond the point where environmentalists and renewable advocates argue for the possibility of a transformation. We now have Wall Street analysts and important segments of the utility industry not only observing the ongoing transformation, but also noting the need for institutional and infrastructural change to smooth it. This economic transformation makes it clear that base load should not be characterized as a myth; rather it is an antiquated concept that has outlived its economic usefulness and is rapidly becoming obsolete.

The electricity system is well into the transition from a "fuel based" traditional load-following centralized electrical grid to an active and smart "renewables-based" electrical distribution system that integrates distributed supply with managed demand.[188]

I do not mean to suggest that the transformation of the electricity sector is a simple task. As suggested by Figure IX-2, while falling costs and rising renewable load factors are the engines that are driving the change, it requires substantial new physical and institutional infrastructure that is centered on system integration and management.

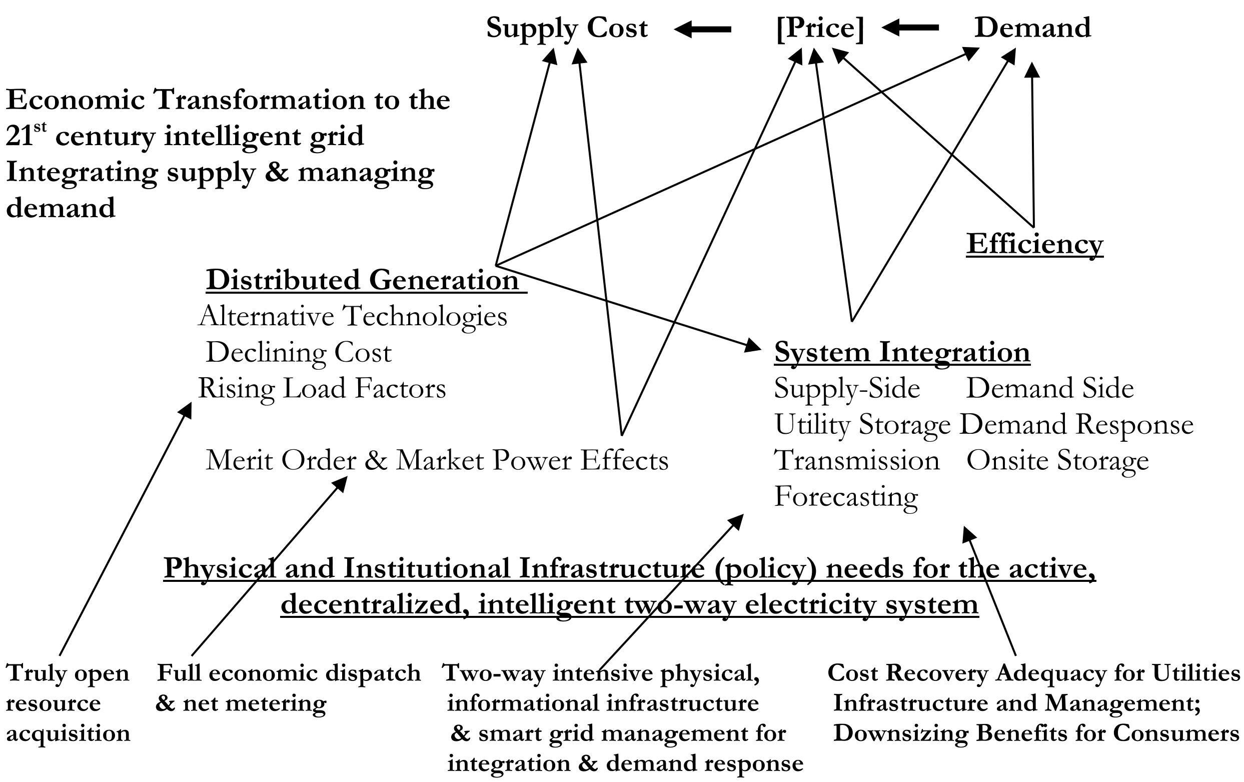
Cost recovery to ensure the deployment of adequate facilities, a problem that plagues electricity markets in general,[189] can be compounded by the expanding role of decentralized resources with low operating costs. Incentives to innovate and compensation for intensive system management is a new challenge.

---

[186] Kind, 2013, p. 1.
[187] EEI/NRDC, 2014.
[188] Steinke, Wolfrum, and Hoffmann, 2013, Ippolito, M.G., et al., 2014.
[189] Pringles, Olsina and Garcés, 2014; Edenhofer, et al., 2013; Bushnell, J. 2010,

FIGURE IX-2: THE ECONOMIC, PHYSICAL AND INSTITUTIONAL TRANSFORMATION OF THE 21ST CENTURY ELECTRICITY SYSTEM

20th century, passive, dumb, load-following central station-oriented grid

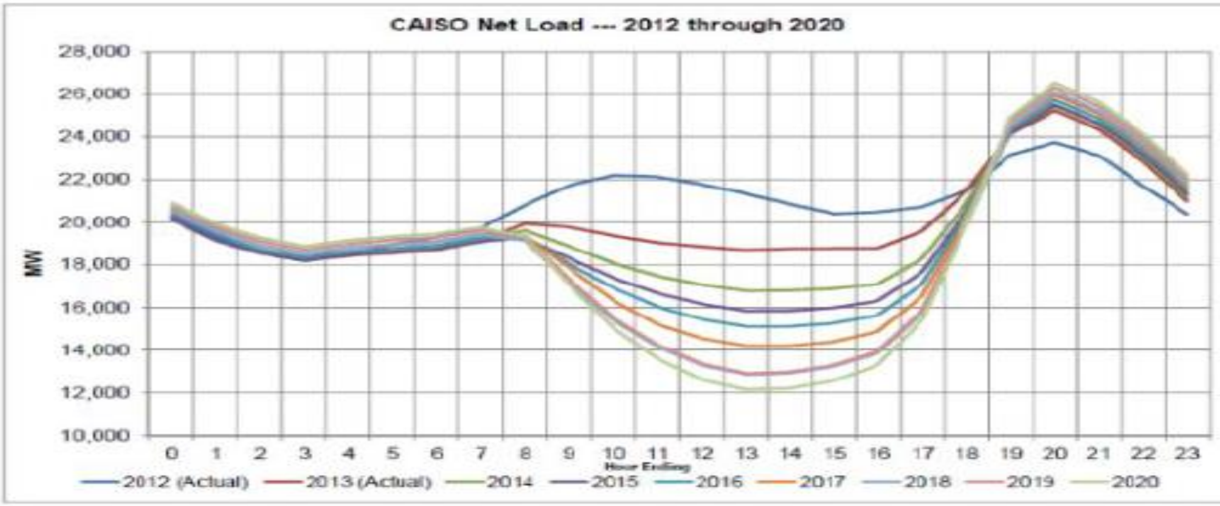


The challenges of implementing the new system of active management with an expanding role for renewables have come to be symbolized in a graph that depicts the load profile of the system, which resembles a "duck" (see Figure IX-3). When renewables enter a grid that has been built around central station facilities and load-following peaking power, the demand for baseload power falls (the belly of the duck), while the demand for peaking power rises slightly (the neck of the duck). The step climb from the belly to the neck of the duck is a two edged challenge for the system.

Bernstein research described one side of the challenge with respect to the upper graph in Figure IX-3.

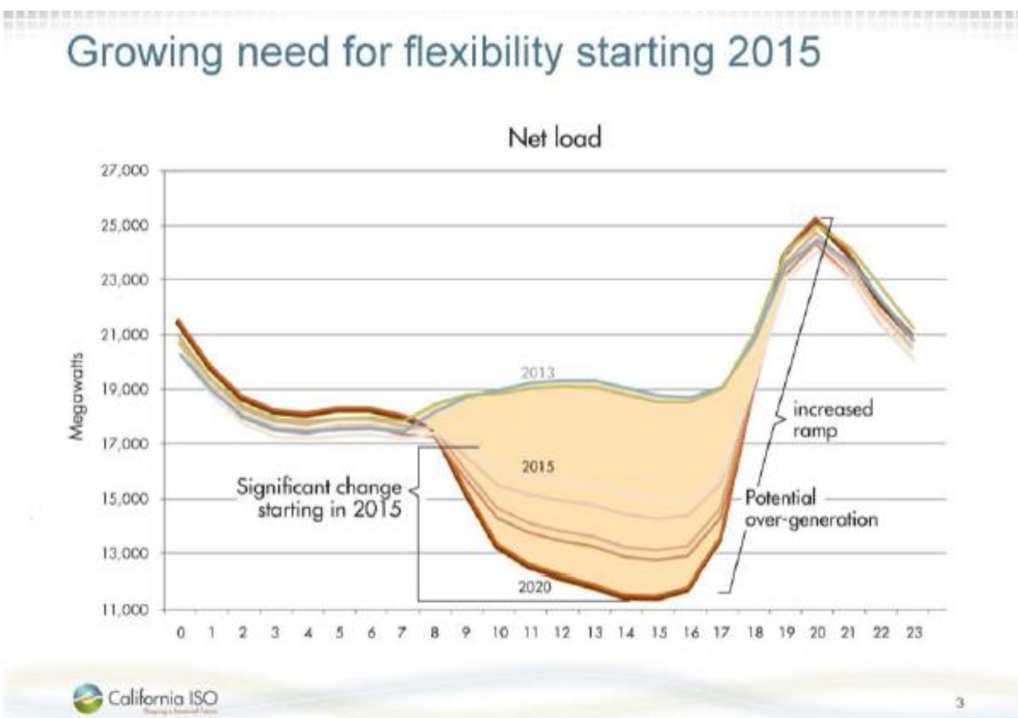
> CAISO [California Independent System Operator] Peaking Duck sounds like a delicious Asian-Latino inspired poultry dish. Instead it is the future of merchant power markets globally. The Top blue line (the buck's back) represents 24 hour demand for electricity in Caledonia in 2012. Daytime demand for power from sources other than wind and solar in 2012 peaked around midday. As more solar capacity is installed, that peak is lower in 2013 (the red line) and the forecast is that by 2020 that demand profile will resemble the green line (the duck's belly). Daytime power demand collapses.

FIGURE IX-3: SOLAR'S EFFECT ON ON-GRID POWER DEMAND: THE CAISO PEAKING DUCK OF NET LOAD



Net Load = Load - Wind - Solar

Source: Parker, et al., *Bernstein Energy & Power Blast: Equal and Opposite… If Solar Wind, Who Loses?* April 4, 2012, p.2.



Chet Lyons, Energy Strategies Group, Guide To Procurement Of Flexible Peaking Capacity: Energy Storage Or Combustion Turbines?

> For companies selling electricity into merchant or competitive markets like California, this is disaster. Demand during what was one of the most profitable times of day disappears. With it, the need for part of the merchant disappears too, for all but the dinner hour. And that is the issue competitive generators face globally in the 2020-scenario: how to live off demand on two hours per day.

Bernstein research focuses on the plight of generators who live off of high load and peak load prices. In the duck graph, the number of hours and the amount of load they are dispatched to meet declines much more than the slight increase in net load in the evening. The graph represents two other, equally, if not more important changes.

- The net load to be met by non-solar resources declines by about 17%. Assuming that most of that load is fossil fuel, this represents a major reduction in CO_2 emissions. This is a benefit, not a problem.
- The second change involves the challenge of meeting the higher peak, which is slightly higher, but more importantly, climbing the much steeper grade to reach the peak.

Ensuring the reliability of this system is a challenge that requires the transformation of the system to two-way management of supply and demand. The solution to the steep climb to the peak that has been offered by a number of analysts and implemented in a number of nations is to use intelligent, active grid management to raise the belly and lower the neck of the duck (see Table IX-1). Lovins identifies nine measures that can be implemented to manage the decentralized electricity system. The Regulatory Analysis Project identifies almost a dozen policies that can be implemented in a dynamic electricity system that actively manages supply and demand, which can lower the peak by 30%, dramatically increasing the system-wide load factor.[190] In fact, they count as a benefit to developing the integrated system of supply and demand management steps to "Retire inflexible generating plants with high off-peak must run requirements."

The reduction of use of generation in the short term is place in the range of 10% to 20%. This should be considered a transformation dividend with respect to carbon reduction. The downward pressure on peak and average prices, which has been observed in systems that are, at best partially designed to exploit this aspect of the emerging electricity system, are an economic dividend that would be reinforced by a successful transformation of the system.

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[190] Jim Lazar, 2014, *Teaching the "Duck" to Fly*, Regulatory Analysis Project, January 2014. Needless to say, there are many other general analyses of the possibility and benefits to aggressively integrating renewable supply and demand in the long term. The RAP analysis provides a clear, concrete basis for translating these benefits into cost analysis of presently deployed systems.

TABLE IX-1: MEASURES TO MANAGE AN INTELLIGENT, DECENTRALIZED ELECTRICITY SECTOR AND REDUCE PEAK LOAD

Lovins	Regulatory Analysis Project	Clean Coalition
Efficiency	Target efficiency to peak reduction	
Forecasting		
Demand response	Aggressive Demand Response	Demand Response
	Manage water heater loads to reduce peak	
	Target fixed cost recovery to ramping hours	
Diversify supply	Retire must run base load	Curtail Base load Import/Export
Technology	Integrated power transactions,	
Geography	Target solar to peak supply (west orientation)	Curtail renewables
Dispatchable renewables	Solar thermal with storage	
Distributed storage	Utility storage in strategic locations; Air conditioning with storage	Storage

Source: Amory Lovins, *An initial critique of Dr. Charles R. Frank, Jr.'s working paper "The Net Benefits of Low and No-Carbon Electricity Technologies," summarized in the Economist as "Free exchange: Sun, Wind and Drain,"* Rocky Mountain Institute, August 7, 2014. Jim Lazar, *Teaching the "Duck" to Fly*, Regulatory Analysis Project, January 2014.

The Regulatory Analysis Project describes the result as follows, with respect to the upper graph in Figure IX-4.

> Thus, our modified post-renewable load is easier to serve than the actual load projected to exist would have been without the addition of renewable resources. This is desirable for almost any electric utility system, including those without significant renewable energy deployment issues.
>
> It's evident that the net load (including solar and wind) after application of the ten strategies is a much more uniform load to serve from dispatchable resources even with the non-solar/wind resources than the load that was forecast for this period without solar and wind. The peaks have been lowered, the troughs raised, and the utility has control over a portion of the load to schedule when it can most economically charge water heaters, air conditioners, and batteries. In essence, the effect of the ten strategies is to reduce both peaking needs and ramping requirements.

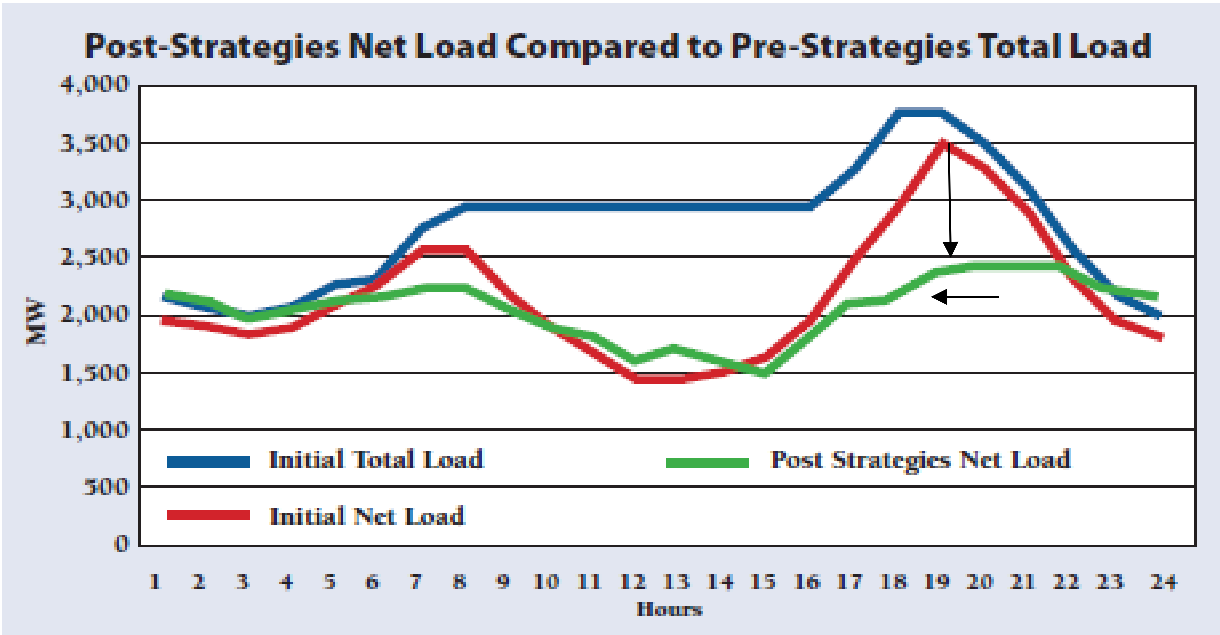
By implementing the management measures identified in Table IX-1, the shape of the duck becomes sleek and it is able to fly. For example, half a dozen advanced industrial countries (Denmark, Ireland, Germany, Sweden, Spain, Portugal) have achieved three times the penetration of wind per capita as the U.S., even though the U.S. has a much greater wind potential.[191] The emerging consensus is that systems with up to 30% or 40% renewables can be managed quite well. Under the EPA preferred option, the U.S. would be less than one-third that level. Proposals to increase renewables put the figure at about half that level. In short, at the

[191] Sahu, Hiloidhari and Baruah, 2013, pp. 349–353.

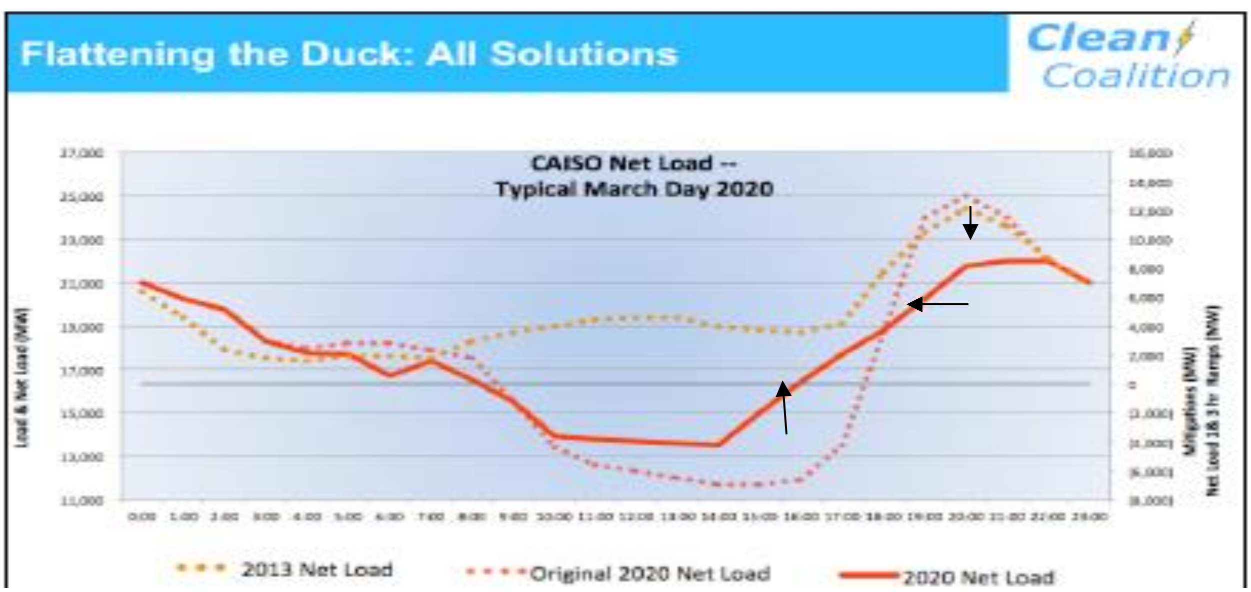
levels of penetration of renewable resources for the mid-term period affected by the EPA rule, the challenge of integrating renewable resources appears to be entirely manageable.

FIGURE IX-4: THE BENEFITS OF ACTIVELY MANAGING RENEWABLE SUPPLY AND DEMAND

Teaching the Duck to Fly



Source: Jim Lazar, *Teaching the "Duck" to Fly*, Regulatory Analysis Project, January 2014, pp. 21-22.



Source: Clean Coalition, *Flattening the Duck,* December 16, 2013.

The analysis of integrating much higher levels of wind and solar has progressed to utility sponsored detailed studies of the impact and necessary changes in the grid. [192] A study conducted for PJM members, which included only one of the many measures identified above to improve grid management – i.e. geographic diversity of renewables, which is a natural occurrence if high levels of renewables are pursued, since the resource is generally dispersed – found that 30% penetration of renewables is easily manageable.[193]

The analysis of the potential transformation has progressed to modeling how to build a sector that captures the synergies of utilization of geographically diverse and widespread renewables, combined with key infrastructure components of – transmission and the tradeoff[194] with storage[195] and demand response[196] to lower cost and meet demand. In fact, some have argued that the benefits of stimulating innovation are so large that they can even offset the apparent "cost" of phasing out nuclear power altogether,[197]

> Our results show that phasing out nuclear power would stimulate investment in R&D and deployment of infant technologies with large learning potentials. This could bring about economic benefits, given the under provision of innovation due to market failures related to both intertemporal and international externalities.[198]
>
> The evolution of the renewables costs in the coming years will not be independent of the future of nuclear power, as well as of energy and climate policies. In this context of uncertainty, policymakers need to understand the economic consequences of nuclear power scenarios when accounting for its interplay with innovation and cost reduction in renewables.[199]

It is of utmost importance at this moment that the legitimate challenges of building these institutions are not exacerbated by the opposition of powerful incumbents. The institutional changes are direct challenges to the structure on which nuclear power and other incumbents depend. Open resources acquisition, economic dispatch and net metering dramatically reduce the rents available to fund nuclear construction and sustain its high capital costs. The two-way, information intensive system that allows integration and management of supply-side and demand side resources involves an entirely different set of skills and assets that are irrelevant,even, antithetical, to nuclear resources. Indeed they replace central station generation.

---

[192] On system integration generally see, for example, Lu, Xi, 2013; Veena, P., et al., 2014; Phuangpornpitak, N. and S. Tia, 2013; Jamel, M.S. A. AbdRahman and A.H. Shamsuddin, 2013; Chaves-Avila, Hakvoort, and Ramos, 2014. On resource diversity, see for example, Tascikaraoglu, A., and M. Uzunoglu, 2014., Grossmann, Wolf D., Iris Grossmann and Karl W. Steininger, 2014.

[193] General Electric International, Inc., 2014; Oggioni, Murhpy and Smeers, 2014.

[194] Rasmussen, et al., N.D.; Schaber, Steinke Hamacher, 2013; Rodriguez, 2013; Rasmussen, Andresen, and Greiner, 2012 ; Greiner, et al., 2013.

[195] On storage and its integration with renewables to achieve reliability see Katarzyna Sobotka, 2009; Bose, Tapan K., et al., N.D.; National Renewable Energy Laboratory, N.D**.** Boie, Inga, et al., 2014; Pleßmann, Guido, et al., 2014**;** Komiyamaa, Ryoichi and Yasumasa Fujiib, 2014; Elkind, 2010; Hasan, Nor Shahida, et al., 2013; Koohi-Kamali, et al., 2013; Díaz-González, et al., 2012; Ippolito, 2014; Lu, 2013; Steinke, 2013. Gao, Dan, et al., 2013, Kucseraa, Dénes and Margarethe Rammerstorfer, 201; Cau, 2014.

[196] On demand management, see for example, Falsafi, Zakariazadeh and Jadid, 2014; Arif, Ahmer, Fahad Javed and Naveed Arshad, 2014; Biegela, Benjamin , et al., 2014; Bergaentzlé, Claire, Cédric Clastres, and Haikel Khalfallah, 2014, Occonnell, et al., 2014.

[197] Zelenika-Zovk, Pearce, 2011

[198] De Cian, 2012, p. 14.

[199] De Cian, 2014, p. 1-2.

The baseload dominated electricity system was created by policy support and subsidies for physical and institutional infrastructure that favored a specific type of technology. The dominant incumbents will seek to slow or stop the spread of alternatives to defend what amounts to trillions of dollars of investment and assets sunk into fossil fuels.[200]

> Their diffusion can be slowed by effects of path dependence and lock-in of earlier technology systems…. high carbon technologies and supporting institutional rule systems have co-evolved, leading to the current state of 'carbon lock-in'. For example, reductions in cost and the spread of infra- structure supporting coal- and gas-fired electricity generation enabled the diffusion of electricity-using devices and the creation of institutions, such as cost-plus regulation, which encouraged further investment in high carbon generation and networks. This created systemic barriers to investment in low carbon energy technologies…. the proposition that industries or technologies whose ascendancy is threatened by new competition tend to respond, carries some weight. It also suggests that actors, such as large energy companies, with substantial investments in the current system and its technologies, and relatively strong political influence, are likely to act to frustrate the implementation of institutional changes that would support the implementation of low carbon technologies.[201]

The conflict between nuclear technologies and the alternatives is inevitable and crucially important to determining the future path of the electricity sector. There are fundamental economic, technological, and institutional incompatibilities between the two approaches, which have given rise to a frontal assault by nuclear advocates on the alternative resources and institutions that will support them.[202]

Nuclear power is the least attractive asset, followed by the fossil fuels. To defend itself from the growth of superior alternatives, nuclear utilities and advocates have launch an all-out attack on policies that create opportunities for the alternatives (see Table IX-2).

UBS put it succinctly, "Large-scale power generation, however, will be the dinosaur of the future energy system: Too big, too inflexible, not even relevant for backup power in the long run."[203]

Lovins elaborates

> "All of the above" scenarios are… undesirable for several reasons….
>
> First, central thermal plants are too inflexible to play well with variable renewables, and their market prices and profits drop as renewables gain market share. Second, if resources can compete fairly at all scales, some and perhaps much, of the transmission built for a centralized vision of the future grid could quickly become superfluous. Third, big, slow, lumpy costly investments can erode utilities' and other provider's financial stability, while small, fast

[200] Bianconi and Yoshino, 2014, refer to this as the escalation of commitment. See also Bloomberg, 2014; Arbuthnott and Dolter, 2014; Farrar-Rivas and Ferguson, 2014; CERES, 2013,

[201] Pearson and Foxon, 2012, pp. 123–124.

[202] Hildmann, Ulbig and Andersson, 2014, show that if baseload facilities could stop acting llke aseload facilities, they would fit into to emerging electricity system. "Given base load power plants that have sufficient operational flexibility in terms of fast ramping, start/stop times and minimum operation point requirements, energy-only markets seem to work even for high RES penetration scenarios. (p. 13).

[203] UBS, 2014b, p. 1.

granular investments can enhance it. Competition between those two kinds of investments can turn people trying to recover the former investments into foes of the latter – and threaten big-plant owners' financial stability. Fourth, renewable, and especially distributed renewable, futures require very different regulatory structures and business models. Finally, supply costs aren't independent of the scale of deployment, so PV systems installed in Germany in 2010 cost about 56–67% less than comparable U.S. systems, despite access to the same modules and other technologies at the same global prices.[204]

TABLE IX-2: THE NUCLEAR INDUSTRY'S BROAD ATTACK ON RENEWABLES

	Federal	States
Direct (Attack Programs that Support Renewables)		
Renewable Energy Production Credit[1]	X	X
Renewable Energy Portfolio Standard[2]	X	X
Efficiency Portfolio Standard[3]	X	X
Net Metering		X
Taxes and Fees[4]	X	X
Indirect (Implement Programs to Support Nuclear)		
EPA Rule Bias[5]	X	X
Wholesale market manipulation		
Above Market/Guaranteed Rates	X	X
Alter dispatch order to favor base load [6]	X	X
Demand Response[7]	X	X

Notes:
1 General opposition to and specific cutbacks in renewable commitments.
2 Includes shifting from "renewable" to "clean" standard.
3 General opposition to and specific cutbacks in utility efficiency programs.
4 Taxes on renewables, Minimum Offer Price Rules.
5 Allowing subsidies and incentives for nuclear. Giving system benefits for reliability, onsite fuel storage.
6 Must run rules/Take or pay clauses.
7 Opposition to bidding demand response in wholesale markets.

Nuclear Information and Resource Service, *Killing the Competition: The Nuclear Industry Agenda to Block Climate Action, Stop Renewable Energy, and Subsidize Old Reactors,* September, 2014

C. THE PRUDENT POLICY CHOICE

The most recent report of the Intergovernmental Panel on Climate Change suggests that the prudent economic choices are also the prudent climate change actions.

- Speed is essential.[205]
- Flexibility and innovation combine with speed to hold costs to modest levels.[206]
- Efficiency is the first pillar for a successful response.[207]
- The electricity sector is the second pillar.[208]
- Renewable technologies are the best hope for near term reductions.[209]
- Natural gas is an attractive option.[210]
- Nuclear power continues to be plagued by long-standing problems.[211]

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[204] Lovins, 2011, p. 216.
[205] IPCC WGIII AR5, 2014.
[206] IPCC WGIII AR5, p. 17
[207] IPCC WGIII AR5, p. 21.
[208] IPCC WGIII AR5, 23.
[209] IPCC WGIII AR5, 23
[210] IPCC WGIII AR5, 23.
[211] IPCC WGIII AR5, 23.

- Carbon capture technologies are uncertain.[212]

Thus, there is a fundamental choice to be made about the structure of the electricity sector in the 21st century. Given the economic plight of nuclear power, the push to adopt policies that will force it into the low carbon resource portfolio is essentially an effort to resist the underlying economics and jerry-rig the outcome in favor of nuclear by negating or slowing the evolution toward more decentralized resources. It is no longer a question of just subsidizing nuclear, although huge subsidies would be necessary to preserve it. Nuclear advocates have launched a frontal attack on the alternatives to slow or prevent the installation of a new utility model.

The potential contribution of the non-nuclear low carbon alternatives, which are less costly and more environmentally benign, has only begun to be exploited and the prospects are quite good.[213] The prudent approach to resource acquisition is to build the institutional and physical infrastructure that achieves the maximum contribution from the more attractive resources available in the near and mid-term.

Dealing with a potentially fundamental change requires a broader perspective on potential benefits, as well as challenges. The replacement of the incumbent fossil-fuel based regime with the distributed approach constitutes a major change that challenges the incrementalist, marginal analysis of traditional cost-benefit analysis, as noted in Chapter VI. A wide range of opportunities is opened that can change the game primarily by eliminating the wall between supply and demand behind which the 20th century baseload model was built including – the interrelationship of battery powered vehicles and the electricity grid,[214] the smart grid,[215] the Internet of things,[216] and multiple roles for solar power.[217]

X. IMPROVING THE EPA ANALYSIS AND PROPOSAL

Although the EPA's analysis of its preferred Option 1 is intended to demonstrate that the chosen standard complies with the CAA and APA legal requirements and is not a prescription of

[212] IPCC WGIII AR5, 24.

[213] See for example, Hoffert, M.I.,2010; Bettencourt, L.M.A., Trancik, J.E., Kaur, J., 2013; Petkovi, Dalibor, 2014; Sueyoshi , Toshiyuki and Mika Goto, 2014; Chmutina, Ksenia and Chris I. Goodier, 2014; Maia, Trieu, et al., 2014; Santiago, de Souza and Bezerra, 2014; Sueyoshia, Toshiyuki, Mika Gotob, 2014; Johnson, Erik Paul, 2014; Zheng, Chengn and Daniel M. Kammen, 2014.

[214] Heymans, et al. 2014, Reber, et al., 2014, Loisel, Pasaoglu and Thiel, 2014, Parsons, et al., 2014,

[215] The Smart Grid is at the classic turning point in early diffusion and in need of social support to overcome concerns and attitudinal barriers grounded in the real world experience of consumers. Naus, 2012, p. 436, Smart grids generate three key new information flows that affect social relations. Practice theory can reveal the ways in which households handle/govern information. Householders show ambivalence about the workings of the different information flows. Policies should account for the 'bright' as well as the 'dark' sides of information.Park, 2014, p. 211, We examine what factors influence electricity consumers' smart grid acceptance. We test the smart grid technology acceptance model including the perceived risk as a main factor. The importance of consumer education and public relations of the smart grid has been confirmed. Another short cut to ensure the acceptance of the smart grid is to mitigate the anxiety about the risk in the use of the Smart grid. Pepermans, 2014, Guizhou Ma and Cong, 2015.

[216] Both in its interaction with smart grid and directly in transforming production and distribution processes Ravindranath, 2014, Poindexter, 2014, Stephenson, 2014.

[217] Solar as a both baseload resources, (e.g. Pfenninger, et al., 2014) and a distributed resource (rooftop PV).

how the states should meet the standard, the EPA analysis is an important benchmark. It has certainly provided a launchpad for a great deal of debate about the proposed rule. This Chapter shows that Option 1 is quite moderate, even weak, compared to the level of reduction in carbon emissions that is technically feasible, economically practicable and cost beneficial, as suggested by the independent analysts discussed above. Since Option 1 is clearly justified, I do not devote any attention to Option 2, which would certainly fail to constitute a "Best System of Emission Reductions."

The Brattle Group describes the methodology used by EPA to set the targets as follows:

> The 2030 emissions standard formula… differs from typical measures of emissions rates; it represents neither the fossil fuel fleet emissions rate (emissions divided by generation from the fossil fleet) nor the emissions rate of the entire generation fleet… Instead the EGU CO_2 emissions standard is calculated as the ratio of expected future emission after implementing the assumed building blocks.
>
> The resulting measure is relatively unintuitive, but it was constructed as a way to incorporate the benefits of activities "outside the fence" of fossil generating units rather than just physical changes at individual fossil plants.[218]

As I have shown in these comments, EPA has chosen the right direction. It is absolutely critical to design a standard that incents activities "outside the fence" of fossil generating units for two reasons,

- the least cost approaches to reducing carbon emissions, while meeting the need for electricity, involve resources that are outside the fence,
- the future of the electricity system lies "outside the fence" of central station generation.

However, heading in the right direction does not mean they have chosen the best route. This section shows that EPA has made some serious wrong turns that will make the journey to a low carbon future too slow and more costly than it need be. It can be argued that the EPA has failed to propose a rule that is a "Best System of Emission Reduction," not because it is too demanding, but because it is too easy.

The Chapter begins by showing that the independent analyses discussed in Chapters II and VII indicate the carbon reduction from efficiency and renewable could be much larger. I then explain why the suggestion that states should go out of their way to support nuclear power is misguided, to say the least.

A. Efficiency and (Non-Hydro) Renewables

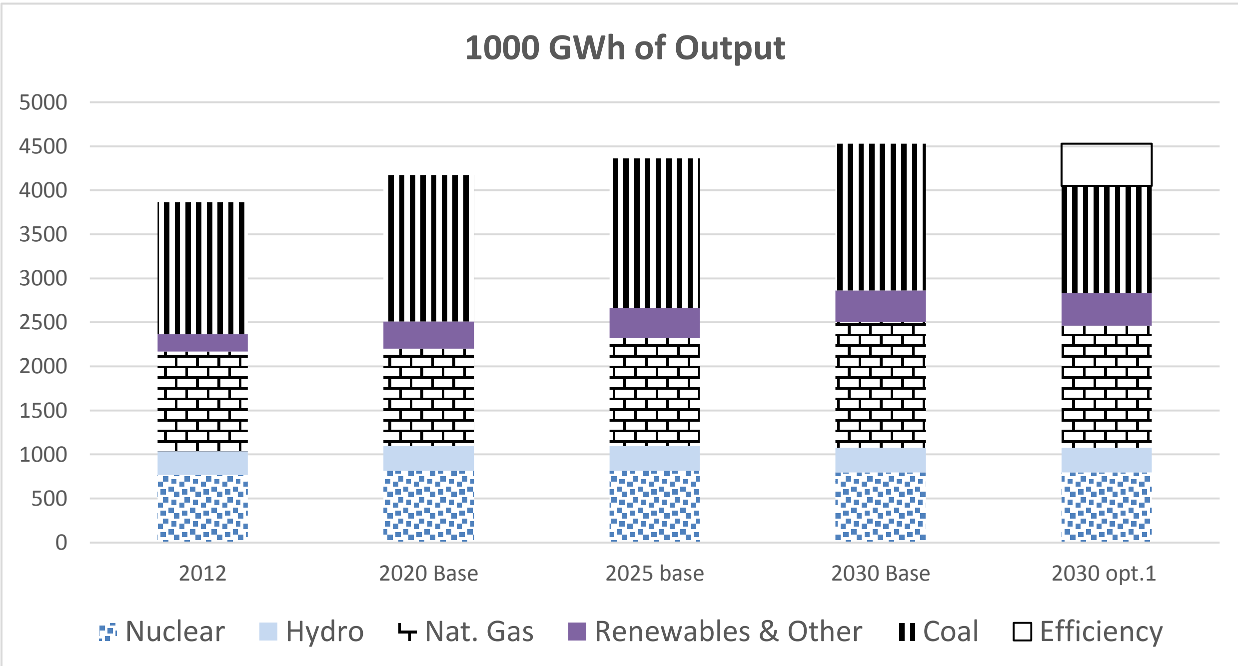
1. Potential

[218] Brattle Group, 2014.

Figure X-1 shows the resource mix for the base case and the policy case (Option 1). There are several key points about the scenario.

FIGURE X-1: IN THE POLICY CASE, NUCLEAR, HYDRO AND RENEWABLES ARE FLAT, GAS IS DOWN SLIGHTLY AND COAL IS DOWN A LOT

80% of the Reduction in Coal and Gas is attributable to Reduced Demand (i.e. efficiency)



Source: EPA, Regulatory Impact Assessment, Tables 2-2 and 3-11.

First, contrary to the claims of some, all low carbon resources play a part in reducing emissions.

- Nuclear power and hydro are essentially flat in the base case and the policy case.
    - All nuclear power, currently operating and under construction, is assumed to continue to produce electricity, with the exception of a small number of normal retirements (2.5% of total output) in the policy period (2020 – 2025).
    - All currently operating hydro power is assumed to continue to do so.
- Natural gas increases significantly and steadily in the base case through 2030 (26%). In the policy case it drops slightly (3%). Even in the policy case, the output of natural gas-fired generation is more than one fifth higher than the base year (2012).
- Renewables grow by over 80% in the base case. However, the additional increase in renewables under the policy case is minuscule, less than .5%.

- Efficiency is the key to the carbon reduction.
  - Output from coal-fired generators is projected to grow slightly in the base case (11%). In the policy case, it declines by 27%.
  - The total output in the policy is projected to be 11% lower than the base case. This is the effect of efficiency improvements.
  - The efficiency improvement decreases the rate of growth of output from just under 1% in the base case to .25% in the policy case. The base case demand embodies some efficiency improvement as a result of the kinds of utility programs the EPA rule models.

Looking at the policy scenario from the point of view of physical quantities, 80% of the reduction in carbon emissions is due to the reduction in output, even assuming that the coal output is 6% more efficient with respect to carbon emissions. Thus, in the policy case the electricity sector carbon footprint will be defined by

- strong growth in renewables as a result of the economic fundamentals in the base cases and
- a much larger reduction in emissions as a result of efficiency stimulated by policy. Leaving aside efficiency improvements in the base case, efficiency accounts for almost three times as much reduction as renewables.

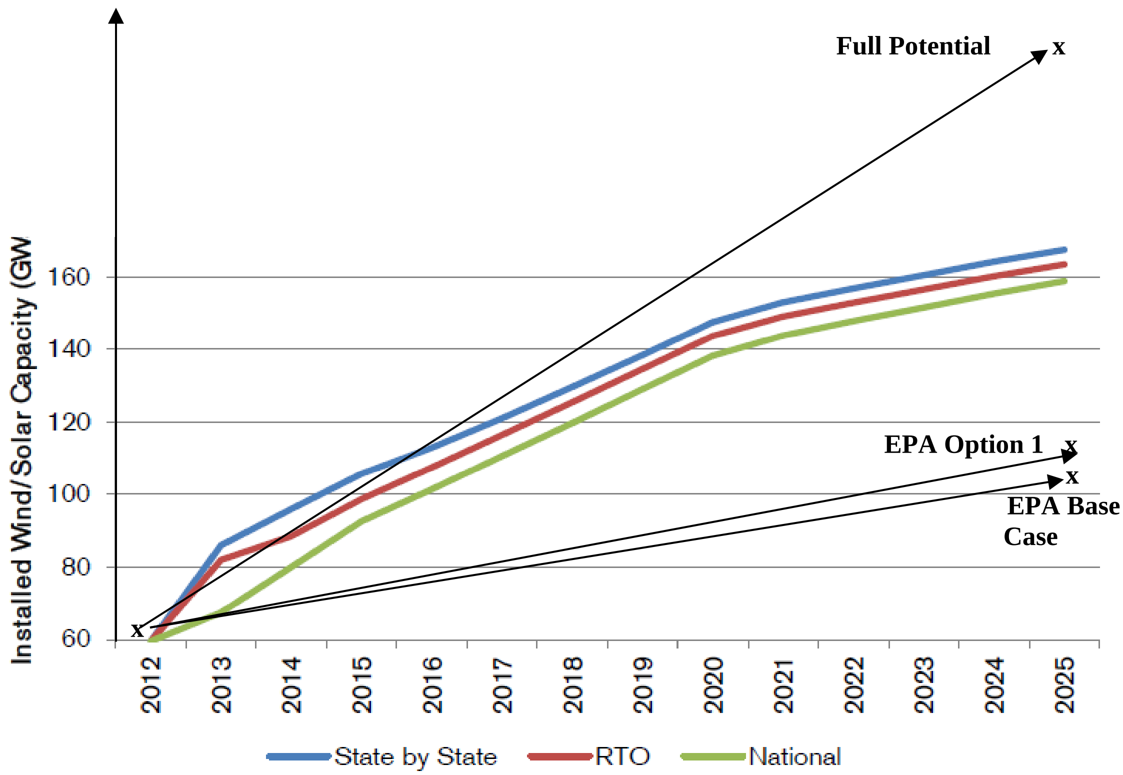
Even looking at the total change in emissions (base case plus policy) the reduction of consumption, which must be considered efficiency driven (since the economy is assumed to grow), accounts for over 50% of the total reduction in emissions.

It is important to emphasize in the strongest terms possible that EPA has set out in the right direction. Efficiency is the least cost option. The base case pattern of changes in the generation mix and level of output are consistent with the economic fundamentals discussed earlier. Wind is the next lowest in cost, followed by solar as the cost trends continue to develop. The potential contribution of these three resources is quite large and other advanced industrial nations have achieved much higher levels of carbon reduction utilizing these three resources, while transforming their electricity systems to deliver reliable power.

While the contribution of efficiency and renewable to the reduction of carbon emissions that results from the combination of the base case trends and the policy case in the EPA analysis is impressive, it is well below what the literature reviewed above deems economic and achievable. According to the Citi projection of base case growth, which includes only existing state RPS programs, at least 60% more could be achieved with renewables, as shown in Figure X-2. Since two-fifths of the states have not adopted RPS programs, it is reasonable to assume that a policy case in which the remaining states sought to increase renewable energy to roughly the same level, the amount of renewables would double.

FIGURE X-2: CREDIT SUISSE PROJECTION OF RENEWABLE GROWTH COMPARED TO EPA OPTION 1 ACHIEVED: EPA LEFT A LOT ON THE TABLE

Projection of Renewable Growth Compared to EPA Option 1



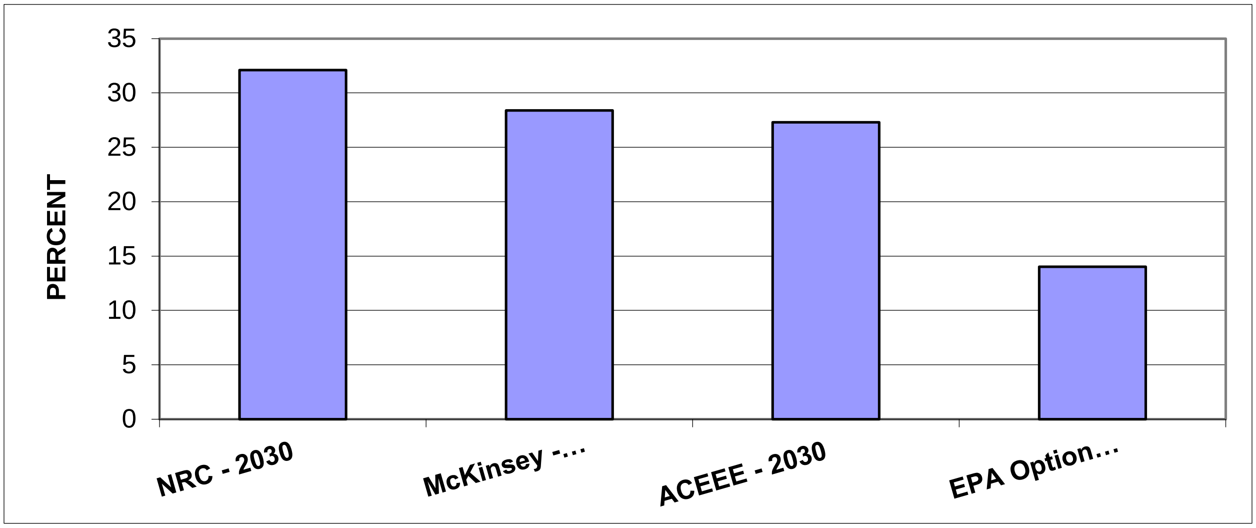
Source: Dan Eggers, Kevin Cole, Matthew Davis, *The Transformational Impact of Renewables*, Credit Suisse, December 20,2013, p. 18., EPA, *Regulatory Impact Analysis*, 2004, Table 3-11.

As shown in Figure X-3, the contribution of efficiency could also double, based on the estimates of the national experts discussed earlier. In both cases the projected costs are competitive with the current cost of natural gas, so these carbon reductions impose very little increase in the cost of electricity. This outcome results from the fact that policy helps to overcome the efficiency and innovation gaps.

One of the primary sources of untapped carbon reduction from efficiency involves appliance efficiency standards, building energy codes and combined heat and power. While appliance efficiency standards are frequently adopted at the federal level, states do have the ability to adopt their own standards. Building energy codes are a state and local matter. Combined heat and power is a local and state regulatory arena. EPA should adopt an methodology to account and provide incentives for the states to adopt higher appliance efficiency standards and building energy codes.

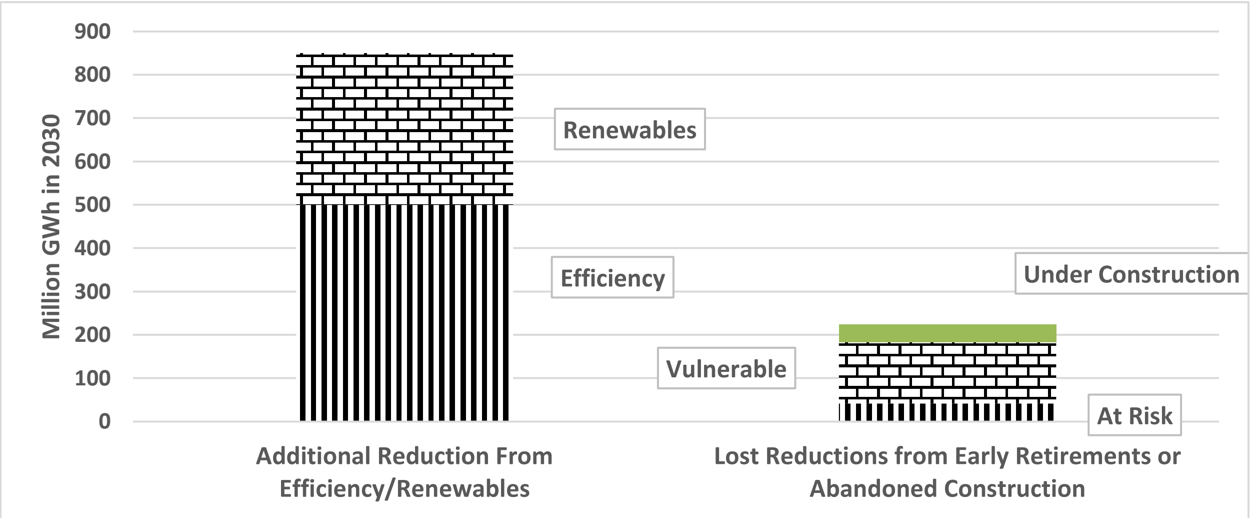
The large potential for additional carbon emissions reductions from low cost efficiency and renewables has a major implication for the EPA analysis, as shown in Figure X-4. As discussed in the next section, capturing just one quarter of the potential additional reduction in carbon emissions would offset the loss of generation from all of the reactors I have identified as vulnerable to early retirement plus the abandonment of the reactors under construction, which I have shown are uneconomic. Thus, fixing these two aspects of the EPA analysis results in more carbon reduction at a lower cost. This would move the EPA standard in the direction of a "better" system of emissions reduction.

FIGURE X-3: EFFICIENCY POTENTIAL FROM MAJOR NATIONAL STUDIES COMPARED TO EPA OPTION 1 ACHIEVED EFFICIENCY: EPA LEFT A LOT ON THE TABLE



Sources and Notes: See Figure II-1 and EPA, *Regulatory Impact Analysis,* 2004, Table 3-11.

FIGURE X-4: THE UNTAPPED CARBON REDUCTION POTENTIAL FROM EFFICIENCY & RENEWABLES VASTLY EXCEEDS THE POTENTIAL LOSS FROM REACTORS THREATENED WITH EARLY RETIREMENT AND THE ABANDONMENT OF REACTORS UNDER CONSTRUCTION



Sources and notes: Figure IX-3, and EPA, *Regulatory Impact Analysis,* 2004, Table 3-11. At risk reactors and vulnerable reactors are identified in Mark Cooper, *Renaissance in Reverse,* 2013. Quantities are taken from EIA, *Annual Energy Outlook: 2014,* Nuclear Alternative Cases, with 5.7 GW at risk, one-half of the accelerated retirements between 2020-2040 assumed by 2030 (19 GW) and 5.5 GW of current construction. An 85% load factor is assumed, since old and new plants tend to have below average load factors.

2. Erroneous Cost Estimation

Because efficiency plays such a large part in carbon reduction in the policy case, the cost of efficiency makes up the bulk of the cost of the policy. EPA includes not only the resource cost of efficiency, but also the program costs of implementing policies to achieve the higher levels of efficiency. It assumes that program costs are equal to resource costs. The estimate of the current cost of efficiency with program costs is $55/MWH. Chapter V showed that the resource costs are in the range of $25/MWH.

EPA then assumes a substantial increase in the cost of efficiency, which ends at almost $89/MWH. There is no evidence to support the assumption that the cost of saved energy will rise in real terms. Over the course of 30 years the engineering and empirical analysis of the cost of saved energy has shown there is a slight tendency for those costs to fall as economies of scale and learning affect the deployment of efficiency measures. The projections in the literature assume this pattern will persist.

The likelihood that the cost of saved energy will not rise is reinforced by the fact that much of the increase in saved energy will come from states that have not had vigorous programs to tap this resources. At least for the period that the EPA rule covers, efficiency gains still involve a lot of low hanging fruit. The experience in the electricity sector should also lower the startup costs, of utility programs as effective models have been worked out over decades in the leading states. States that worry about the cost of implementation can copy the successful programs.

Assuming flat costs for efficiency will have a dramatic impact on the estimation of the cost of the Clean Power rule. Given the large role of efficiency, the cost would be reduced by about one-quarter. The benefit cost ratio would increase substantially to 7 or 8 to one.

Ironically, since EPA assumes almost no increase in the deployment of renewables in its policy case, the declining cost of renewables plays almost no role in defining the benefit cost ration of the Clean Power Rule.

B. The Repeated, Persistent and Dramatic Failure of Nuclear Technology

1. Construction of New Reactors

a. The Reality of Dim Prospects

Over the past 5 years my analysis has shown that even with massive new subsidies in the first decade of the 21st century "nuclear renaissance" technology was an abysmal failure, unable to compete with the available alternatives. It is too big to properly meet demand, too expensive to compete on cost, takes so long to build it creates significant marketplace risk, and requires so much sunk capital that it causes severe financial risk. Recognizing that the "renaissance" technology is uneconomic, over 90% of the projects that were contemplated using the "nuclear renaissance" technology in the U.S. were cancelled or mothballed. The projects that have moved forward are behind schedule and over budget.

Face with utter failure, the nuclear industry shifted its hope and hype to small modular reactor (SMR) technologies, but I have shown that this technology does not solve the fundamental economic problems of nuclear power. They remain much more costly than the alternatives and, while they are more attractive than large nuclear reactors on some of the other important economic characteristics, they do not come close to being more attractive than the other alternatives available.

The rapid and stunning reversal of fortune suffered by SMR technology before it even got off of the drawing board is emblematic of the 50 year history of commercial nuclear power in the U.S. and underscores the folly of relying on nuclear power as one of the pillar on which the decarbonization of the electricity sector stands. [219] Historical experience and contemporary economics strongly support the conclusion that nuclear power will fail to deliver on its promises leaving a costly hole in the decarbonization undertaking.

Babcock & Wilcox, one of the firms that had received a federal subsidy for SMR development, stepped back from the development of SMR technology[220] because of the failure "to secure significant additional investors or customer engineering, procurement, and construction contracts to provide the financial support necessary to develop and deploy mPower reactors."[221] The company declared it "still expects to license mPower reactor by the mid-2020s."[222]

> The issue, he insists, is that the market for small reactors is likely to be about three to five years further out than B&W anticipated when it started the program in 2009.
>
> That is because... the growth in demand for electricity remains weak, and may even flatten out over the next few years….Combine that fact with the low cost of natural gas plants in the current market, and he estimates the market for mPower has been pushed back three to five years. That makes it hard to justify significant investment now…
>
> Now the company is looking at slowing investment and waiting until the market catches up with the technology.[223]

Westinghouse, another of the leading U.S. developers of small modular technology and the vendor supplying the design for the large nuclear projects under construction in the U.S., also announced it was stepping back from development of small modular nuclear technology. [224] The

---

[219] Lewis, 2013, notes that in February, 2013, "tow of the biggest innovators of SMRs right, now Babcock & Wilcox, an engineering behemoth… and Westinghouse, the electricity giants… Both are wildly optimistic about SMRs future," a year later they had both slashed their investment.

[220] Downey, 2014. The extent of the pullback by B&W caught the nuclear advocates by surprise. From spending around $80 million per year, initial figures of less than $60 million were floated, but the actual figure was put at $15 million, with the departure of the head of the program.

[221] Roanoke.com, 2014.

[222] Henderson, 2014.

[223] Downey, 2014.

[224] Litvak, 2014; Adams, 2014. The failure to secure a government subsidy had foreshadowed the decision (Barker, 2013). Although Westinghouse said it would focus on its AP-1000 projects, it also noted that "Westinghouse will focus its attentions on its decommissioning business, which is a $1 billion dollar per year business for the firm – which is equivalent to Westinghouse's new reactor construction business, and rededicate its staff to the AP1000 reactor design."

reason for the decision: Westinghouse could find no customers. Instead of pushing ahead to build SMRs, Westinghouse said it would focus on decommissioning of existing reactors. The retreat came even though its utility partner, Ameren had convinced the state of Missouri to spend $40 million supporting the technology.

Westinghouse used language that is similar to the Babcock and Wilcox explanation, not only in blaming cheap gas, but also in declaring that it did not want "to get ahead of the market."[225] In the case of Westinghouse, their caution was tied to the failure to find orders for its AP600, a medium sized reactor that had been licensed fifteen years earlier[226] and its claim that it needed a large book of orders, 30-50 reactors (7 to 10 GW given its design). Westinghouse had spent close to a decade propounding a theory of economic competitiveness that had become gospel among nuclear advocates, yet, in stepping back it was clear that they "had no way to calculate the cost"[227] and much larger subsidies would be necessary to move the technology forward.

The declarations of confidence in the technology could not hide the fact that in less than a decade its development was ―grinding to a halt.[228] The collapse of the SMR hype is extremely important in the policy context.[229] The failure of SMR technology makes it impossible to ignore the huge scale that nuclear power demands to succeed. Shifting that need up in the supply chain to a manufacturing facility does not eliminate its importance. The problem that utilities have in swinging the financing and development of large reactors is replaced by the even bigger problem that vendors have, but it is essentially the same problem. Westinghouse and B&W are big names in the nuclear space, had thrown a great deal of weight and money into advancing SMRs as the next big thing and the savior of the nuclear industry, but they failed.

The market recognizes what the nuclear advocates and the EPA continue to ignore. Blaming cheap gas and a temporary slump in demand ignores the fundamental changes in the electricity sector. A comprehensive view that includes **all** of the emerging alternatives **and** the history of nuclear technology and cost escalation explains why nuclear technology, large or small, cannot find either customers or investors today and suggests that the market will not "catch up" any time soon. The failure to find customers and investors is the ultimate rejection in a capitalist economy. The only way to save the failed technology is to blame the market.[230]

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[225] Litvak, 2014.
[226] Litvak, 2014.
[227] Adams, 2014a, a leading advocate of nuclear power used this phrase.
[228] Martin, 2014, "who had authored positive study of SMR at Navigant, admitted that even the low estimate of 4.6 GW by 2030 ―seems optimistic now."
[229] Lewis, 2013.
[230] Turmelle, 2014, There was nothing wrong with these plants," Fertel said. "There is something wrong with the design and operation of the markets in which they are operating. They do not value the base load capacity that can be dispatched when needed, do not provide value for fuel end technology diversity;" Daniels, 2014, Exelon officials have met with Senate President John Cullerton. And CEO Chris Crane met in recent weeks with Illinois House Speaker Michael Madigan to brief him on the problems. "It's about market conditions and the impact on the nuclear fleet"… Exelon's plants are buffeted by low wholesale power prices tied to surging natural gas production and slack demand. In addition, the company has complained of **acute pricing pressures** at nukes near wind farms, which can profit from tax subsidies while depressing spot prices and forcing nukes to sell their output at a loss. Exelon lobbyists have floated the idea of creating a state "clean energy" standard or credit that would recognize the nukes for their clean-air and their dependability as a 24/7 power sources. That designation would entitle the plant to extra payments in some form – presumably from ratepayers.

b. "To Go" Costs Are Substantial

Ignoring the cost of constructing new reactors (because the decision to build has been made), as suggested by EPA is incorrect because **the costs have not yet been sunk.** The incremental or "to go" cost are substantial. The "to go" costs of those nuclear reactors can be avoided. Moreover, all of the reactors under construction are well behind schedule and over budget. Further slippage and cost over runs are a distinct possibility.

Sound economic analysis and prudent resource acquisition require the responsible authorities to continuously evaluate ongoing projects. In a competitive market economy, decisions to invest must be constantly revisited. If the cost of the project rises or costs for alternative projects fall sufficiently to make continuing on the chosen path uneconomic, the project should be abandoned.

In South Carolina, my analysis showed that continuing to build the Summer reactors would cost ratepayers $10 billion more than terminating the project.[231] In that analysis, the comparison was with natural gas because that was the referent that the utility had, incorrectly, selected. If the full range alternatives were considered in making the decision to continue construction, the waste of resources would be even greater.

In fact, the initial decision to commence construction of the reactors was fundamentally flawed because it did not consider the full range of alternatives. The EPA should not be rewarding such economically flawed analysis and decision making. Under the principle of allowing the states flexibility, it is their prerogative to impose uneconomic costs on their ratepayers, but the EPA should not be encouraging such behavior. If anything, the EPA should state a strong preference for least cost solutions under the proposition that the lower the cost of carbon abatement, the greater the reduction is likely to be.

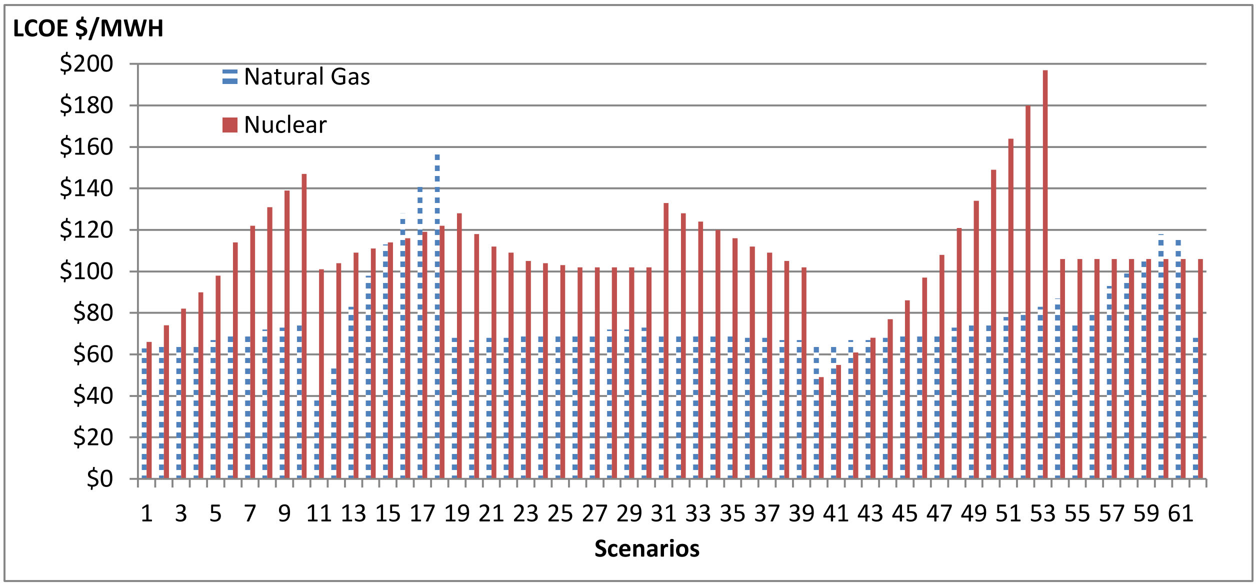
Given the high and uncertain cost of nuclear reactor construction, nuclear advocates who could not project what it would actually cost to build 'renaissance" reactors, put forward "break even analyses. That is, they calculated how much nuclear reactors would have to cost to beat natural gas. I have shown that those initial analyses were riddled with analytic flaws and erroneous assumptions. The utility calculations continue to be plagues by flaws, as I showed in demonstrating that the "to go" costs in South Carolina are far higher than cancelling the reactor would be. Two recent studies of nuclear construction reaffirm that finding.

Figure X-5 shows the results of a generic study of U.S. nuclear costs compared to natural gas prepared in 2013. Hogue presents seven cases where he selects high and low values for the key variables from an underlying analysis of a wide range of possibilities. These involve the author's judgment about which scenarios are plausible from within a much wider array of possible outcomes. These involved a range of assumptions on construction costs, fuel costs and CO2 costs. Exhibit IX-5 also shows outcomes for three other variables that Hogue analyzed – load factor, plant life and the cost of capital, but did not specify high and low cases.

[231] Cooper, 2012c.

Gas is lower in cost in just under 90% of the scenarios. Its costs advantage in those scenarios is just over $38/MWH. In contrast, nuclear is less costly in just over 10% of the scenarios and its cost advantage is less than half that – just over $16/MWH. Clearly, natural gas is a much more attractive option. Since efficiency, wind and solar with the cost trend have an advantage over gas that is larger than $16/MWH, it is safe to conclude that nuclear is never less costly.

FIGURE X-5: ESTIMATED BREAK EVEN COST COMPARED TO NATURAL GAS FOR SCENARIOS AND HIGH LOW VALUES FOR MAJOR VARIABLES



Source: Michael T. Hogue, 2012, *A Review of the Costs of Nuclear Power Generation,* Bureau of Economic and Business Research David Eccles School of Business, University of Utah, February, Tables Base Case 20, Hi Const. 26, Low Const. 24, Lo Fuel 40. Hi Fuel 38, Lo CO2 44, Hi CO2 42, Lo Load Factor 32, Hi Load Factor 32, Short Life 30, Long Life 30 Hi Hurdle 34, Lo Hurdle 34.

The results of an even more recent "break even" analysis support this conclusion. As shown in Figure X-6 the study used eight cost factors and two scenarios, one that was more favorable to nuclear (optimistic) and one that was less favorable (pessimistic) to create cost comparisons. As shown in the top graph in Figure X-6, compared to Lazard's estimate, nuclear is never preferred. The lower graph uses Lazard costs to identify the break even against a portfolio made up of efficiency, wind and solar. Against that low carbon, non-fossil fuel portfolio nuclear is two to three times as costly. With such a severe cost disadvantage, one can argue that new nuclear reactors do not belong in a Best System of Emission Reducitons.

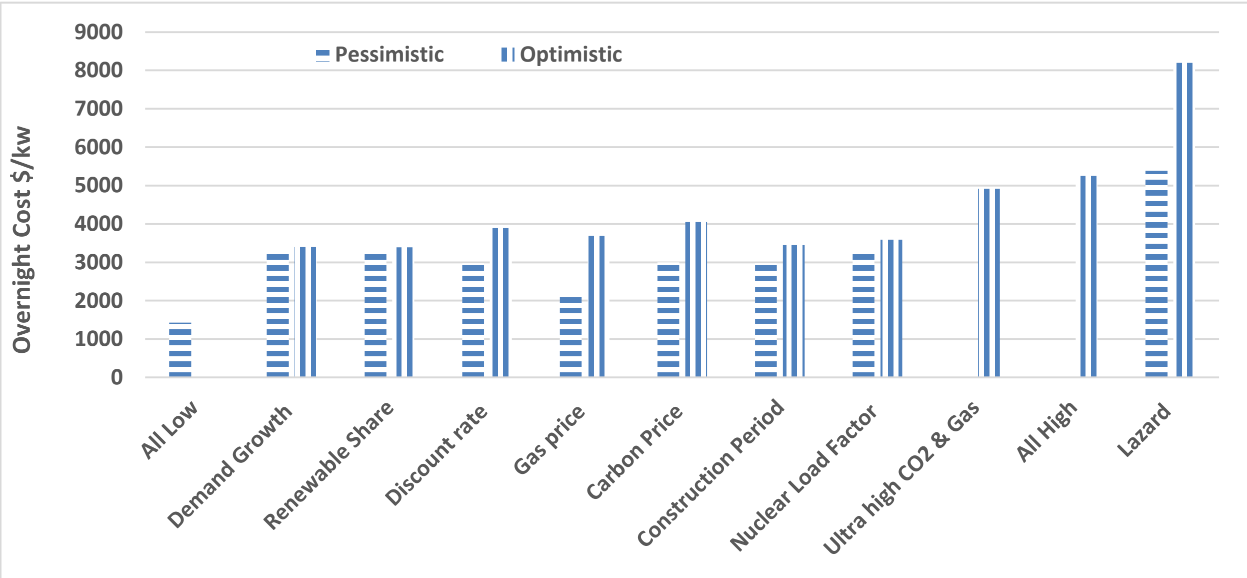
2. Operating Old Reactors

a. The Increasingly Dim Prospects

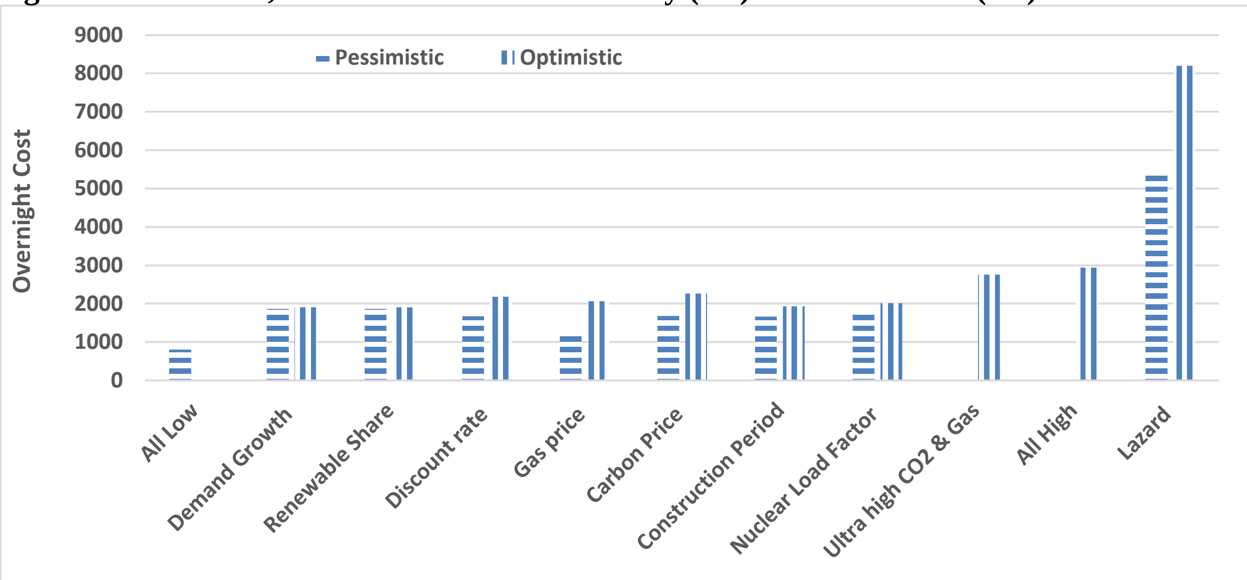
Over the course of the past decade, as the "nuclear renaissance" was collapsing, aging nuclear reactors also began to encounter serious economic problems. Operating costs were increasing with age, while the construction and operating costs of the alternatives were declining rapidly. The abandonment of five aging nuclear reactors signaled another turning point in the industry. Wherever market forces are allowed to set the price of electricity, small, aging reactors cannot compete. They are losing money and their owners are contemplating shutting them down before their licenses expire.

FIGURE X-6: RECENT NUCLEAR BREAKEVEN ANALYSIS WITH A NON-FOSSIL ALTERNATIVE

Against Gas



Against Alternative, Non-Fossil Bundle Efficiency (1/3) and Renewable (2/3)



Source: Linares, Pedro and Adela Conchado, 2013, "The economics of new nuclear power plants in liberalized electricity markets," *Energy Economics,* 40.

b. Unjustified and Misguided Subsidies

Nuclear power is the only technology that the EPA explicitly identifies as being in need of a subsidy and puts forward a concrete proposal. It argues that a $6/MWH subsidy would keep aging nuclear reactors that are not covering their costs online as low carbon resources. The analysis is incorrect at a number of levels.

First, the operating costs of aging reactors are substantial and growing rapidly. The shortfall is dependent on market conditions, which are moving in a direction that suggests the shortfall will continue to increase. If one compares the full cost of keeping aging reactors online to the full cost of the alternatives, it is not at all clear that subsidizing nuclear is cost effective.

Second, even if subsidizing ageing reactors was a sound economic recommendation, which it is not, the EPA's analysis makes no sense. Its proposal is based on the assumption that the risk of closure is randomly distributed throughout the nuclear fleet. It is not; the risk is concentrated in specific types of reactors (small, single units) in specific markets (pure wholesale markets). As a result the vast majority of the subsidy (94%) suggested by EPA is targeted at reactors that are not at risk.

Third the fact that EPA has singled out aging nuclear reactors as a potential target of additional subsidies not only violates the principle of technological neutrality, it also violates the principle of least cost in in several respects.

The resource cost estimates for efficiency, wind and in the mid-term solar, suggest that these alternatives are lower in cost than operating reactors. Moreover, as shown in Figure IX-4 there is no doubt that the potential contribution of these resources could easily offset the loss of low carbon output that might be lost as a result of the retirement of vulnerable aging reactors. Taking all costs into account, on a megawatt hour basis, the cost of keeping the at-risk reactors online is much higher than $6/MWH. The burden of the subsidy would fall on the individual states where the reactors are located and would be much heavier than suggested by EPA.

The social rate of return to subsidies has been much higher for renewables than for nuclear power both in terms of price, as shown above, and in terms of innovation. If subsidies are necessary to improve prospects for carbon reduction, the last place they should go is to nuclear power.

EPA relied on the statement in the EIA annual outlook that reactors with 5.7 GW of capacity are at risk of closing, which happens to equal 6% of current capacity. EIA was clearly referring to specific reactors, but EIA assumed 6% of capacity is at risk in every state, which makes no sense. A part of a reactor cannot be at risk. The risk factors attach to specific reactors in specific market conditions, as I described in my analysis of aging reactors summarized in Table X-1. The reactors that utilities have identified as at risk are listed in the table as are about two dozen more.

TABLE X-1: RETIREMENT RISK FACTORS OF THE NUCLEAR FLEET

Reactor/ Capacity (MW)	Economic Factors							Operational Factors			Safety Issues	
	Cost	Small	Old	Stand Alone	Merchant	20yr<w/o Ext.	25yrw< w/ Ext.	Broken	Reliability	Long term Outage	Multiple Safety Issues	Fukushima Retrofit
RETIRED, 2013												
Kewaunee	X	X	X	X	X						X	
Crystal River	X		O					X		O	X	
San Onofre					X	X		X		O	X	
AT RISK												
Ft. Calhoun	X	X	X	X			O	X		O	X	
Oyster Creek	X	X	X	X	X		O			X		X
Ginna	X	X	X		X		O				X	
Point Beach	X	X	X		X		O					
Perry	X	X		X	X	X					X	
Susquehanna	X			X	X				X			X
Davis-Besse	X		O	X	X		O		X	X	X	
Nine Mile Point	X		X		X		O			X	X	X
Quad Cities	X			X	X		O					X
Dresden	X		X		X		O					X
Millstone	X		O	X	X		O				X	
Pilgrim	X	X	X		X	X	O			X	X	X
Clinton	X			X	X	X						
South Texas	X			X	X	X				X		
Commanche Peak	X			X	X	X						
Three Mile Island	X		X	X	X		O			X		
Palisades	X		X		X		O			X	X	
Fitzpatrick	X		O	X	X		O			X		X
Sequoyah	X				X	X				X		
Hope Creek	X			X	X							X

Seabrook	**X**				**X**	**X**			**X**			
Indian Point	**X**		**X**		**X**		**O**			**X**		
Duane Arnold	**X**		**O**		**X**		**O**				**X**	**X**
Calvert Cliff	**X**		**O**		**X**		**O**			**X**	**X**	
Vt. Yankee	**X**	**X**	**X**		**X**		**O**					**X**
Browns Ferry			**X**				**O**		**X**	**X**	**X**	
Monticello	**X**	**X**	**X**			**X**	**O**				**X**	
Prairie Island	**X**	**X**	**X**				**O**				**X**	
Turkey Point	**X**	**X**	**X**			**X**	**O**			**X**	**X**	
Robinson	**X**		**X**			**X**						
Wolf Creek	**X**			**X**					**X**		**X**	
Fermi	**X**		**X**	**X**		**X**				**X**		
Diablo Canyon	**X**			**X**		**X**					**X**	
Cooper	**X**		**X**	**X**			**O**				**X**	
Callaway	**X**			**X**		**X**					**X**	
Cook	**X**		**O**				**O**		**X**		**X**	
LaSalle	**X**				**X**	**X**						**X**
Limerick	**X**				**X**	**X**						**X**

Sources and Notes: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013; UBS Investment Research, *In Search of Washington's Latest Realities (DC Field Trip Takeaways*), February 20, 2013; Platts, January 9, 2013, "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS," reporting on a UBS report for shareholders; Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012.; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages,* September 2006, "*The NRC and Nuclear Power Plant Safety in 2011,* 2012, and UCS Tracker); NRC Reactor pages.

Operational Factors: Broken/reliability (Moody's for broken and reliability); Long Term Outages (Lochbaum, supplemented by Moody's, o-current, x=past); Near Miss (Lochbaum 2012); Fukushima Retrofit (UBS, Field Trip, 2013)

Economic Factors: Cost, Wholesale markets (Credit Suisse) Age (Moody's and NRC reactor pages with oldest unit X=as old or older than Kewaunee, i.e. 1974 or earlier commissioning, O= Commissioned 1975-1979, i.e. other pre-TMI); Small (Moody's and NRC Reactor pages, less than 700 MW at commissioning); Stand Alone (Moody's and NRC Reactor pages); Short License (Credit Suisse and NRC Reactor pages).

In fact, EIA has an accelerated retirement scenario in which it not only assumes the 5.7 GW of at risk capacity is retired, but another 38GW of nuclear capacity is retired by 2040. My list of reactors covers just over 50GW of nuclear capacity that is vulnerable to early retirement based primarily on economic grounds, compared to the EIA total of 44GW by 2040. Three factors clearly establish the vulnerability to closure – merchant state (38GW), old (25GW) and standalone (24GW). The reactors on the list with two or more of these characteristics have 34GW of capacity.

If the electricity sector "lost" 34 GW of existing nuclear capacity and the reactors under construction were abandoned, as they should be on economic grounds, the reduction in low carbon resources would be easily replaced by efficiency and renewables at a much lower cost.

In the analysis of the potential impact of reduced nuclear output on carbon emissions modeled in Figure IX-4 above, I assumed that all of the at risk reactor were retired and half of the additional capacity that was retired in the accelerated nuclear strategy, which ran until 2040, was retired by 2030. There is four times as much potential carbon reduction from efficiency and renewables left on the table by the EPA standard than would be lost if this generation capacity were lost.

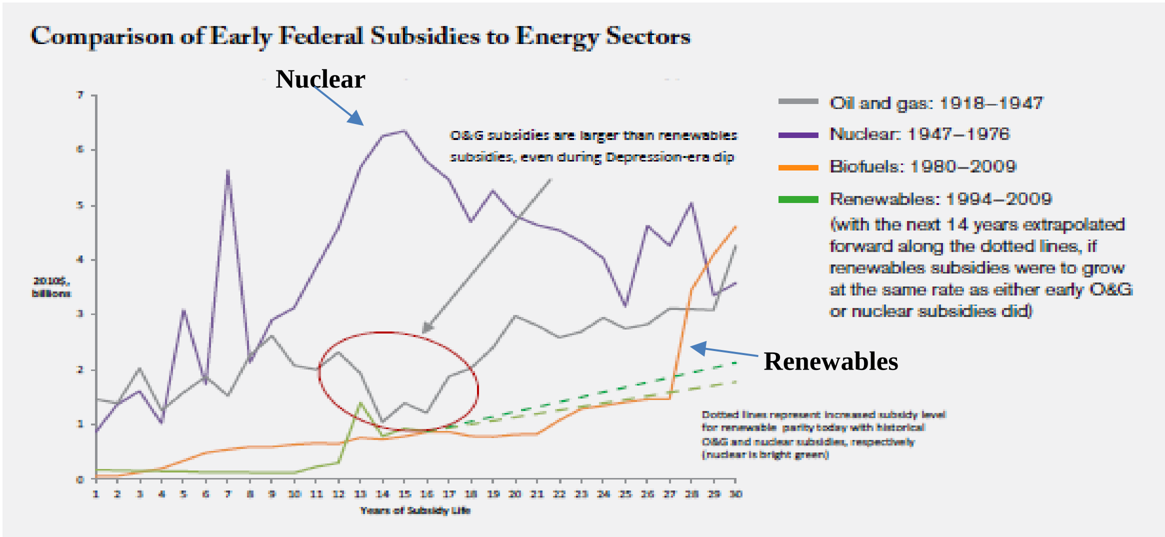
C. SUBSIDIES FOR RENEWABLES HAVE A MUCH HIGHER RATE OF RETURN

Subsidies play a crucial and unavoidable role in energy policy decisions. Renewables are in the early stage of development and receiving subsidies (see Figure X-7). The irony in the effort of the nuclear industry to secure additional subsidies to keep existing reactors online and advance the next generation of reactors, at the expense of alternatives, is that the incumbent baseload facilities, nuclear among them, were the winners in the past, in large part, because they were picked in the past and have been favored with policy advantages over a long period of time.[232] The fact that the incumbent technologies have been and continue to be the beneficiaries of subsidies reflects the fact that energy markets need these interventions to achieve important social goals, particularly when inertia must be overcome.[233]

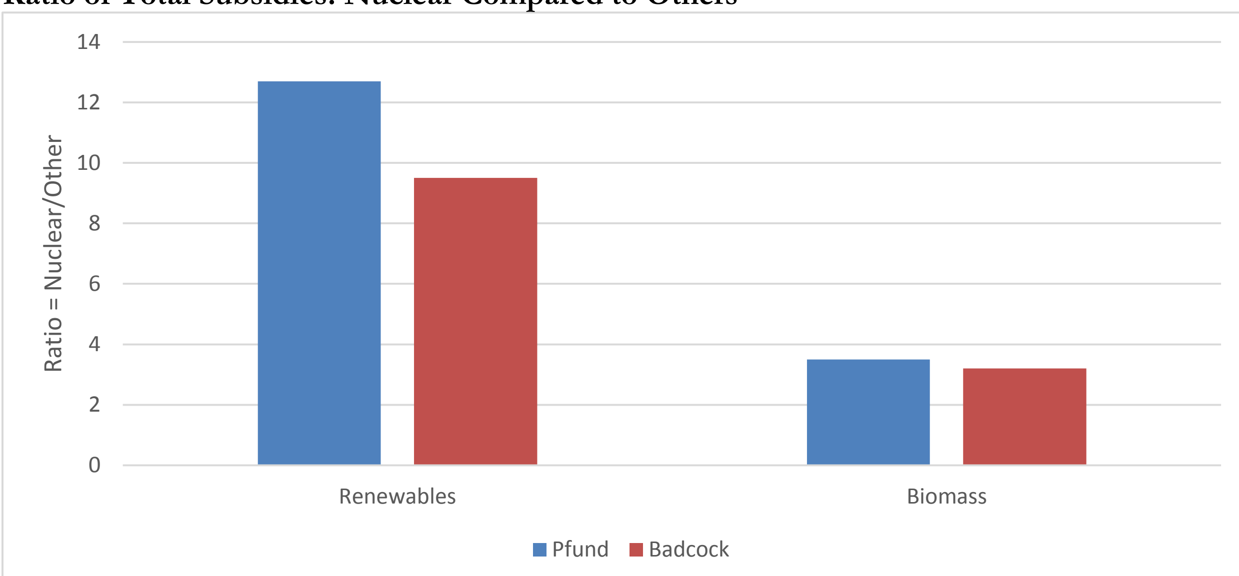
While the nuclear industry complains about the subsidies that are bringing renewables into the market today and resist programs to promote energy efficiency, analysis of the historical pattern demonstrates that the cumulative value of federal subsidies for nuclear power dwarfs the value of subsidies for renewables, as shown in the upper graphs of Figure X-7[234] Analyses of subsidies in globally reach similar conclusions.[235] These estimates of subsidies generally do not include estimates of the value of socialization of insurance and waste management.[236] The most critical point of the historical analysis is to recognize the timing of subsidies in the life cycle of technologies. Nuclear power required much larger subsidies earlier in the life cycle to get into the resource mix.

[232] Gross, et al., 2012, p.18.
[233] Gross, et al., p.18,
[234] Goldberg, 2000; Slavin, 2009; Branker, K., Pearce, J.M., 2010; Badcock, Lenzen, 2010; Pfund and Healey, 2011.
[235] Badcock, Jeremy and Manfred Lenzen, 2010;
[236] Zelenika-Zovk and Pearce, 2011, p. 2626,

FIGURE X-7: FEDERAL SUBSIDIES FOR INFANT ENERGY INDUSTRIES AND BEYOND



Ratio of Total Subsidies: Nuclear Compared to Others

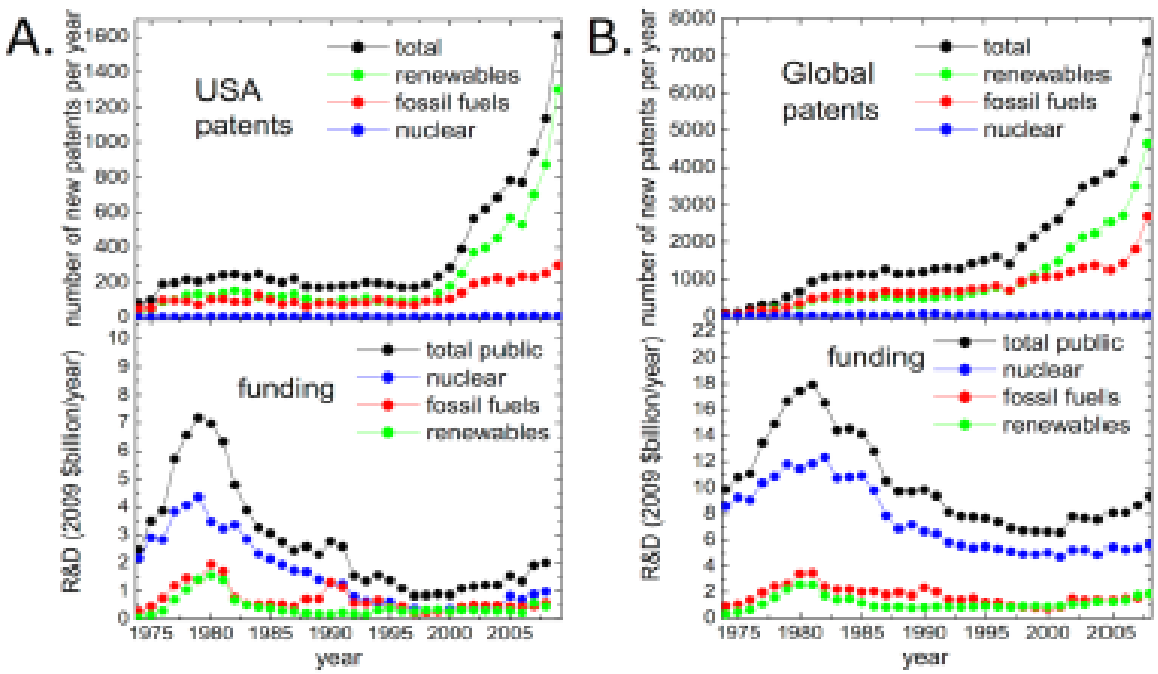


Sources: Nancy Pfund and Ben Healey, *What Would Jefferson Do? The Historical Role of Federal Subsidies in Shaping America's Energy Future*, Double Bottom Line Investors, September 2011, pp. 29–30; Badcock, Jeremy and Manfred Lenzen, 2010, "Subsidies for electricity-generating technologies: A review" *Energy Policy,* 38, Table 4.

There can be debate about the current level of subsidies, particularly given the difficulty of valuing the nuclear insurance and waste subsidies which are existential rather than material (i.e., without the socialization of liability and waste disposal the industry would not exist), but there is no doubt that the long-term subsidization of nuclear power vastly exceeds the subsidization of renewables and efficiency by an order of magnitude of 10 to 1 (as shown in the lower graph of Figure X-8).[237]

The ultimate irony is that with a much smaller level of subsidy to drive innovation and economies of scale, the renewables have achieved dramatically declining costs in a little over a decade, which is exactly the economic process that has eluded the nuclear industry for half a century. Figure IX-8 captures the essence of the subsidy issue by juxtaposing the magnitude and timing of subsidies and the extent of innovation, as measured by patents issued. The large and early support for nuclear is clear in the U.S. and the global data, as is the meager output of patents. In contrast, public funding for R&D for renewables was much smaller, but patent activity is much higher. The dramatic increase in innovative activity with relatively low levels of R&D subsidy and much lower cumulative levels of total subsidies, reflects the decentralized nature of innovation in the renewable space and leads to the dramatic pay-off in terms of declining price. As we have seen, while wind had the earlier success, solar is now catching up.[238]

FIGURE X-8: INNOVATION AND PUBLIC SUPPORT FOR R&D



Source: Bettencourt, Luı´s M.A., Jessika E. Trancik, and Jasleen Kaur, 2013, "Determinants of the pace of global innovation in energy technologies," ***PLoS ONE*****, October 8, p. 10.**

E. RECOMMENDATIONS

The states can and should implement least cost carbon reduction programs based on a more rigorous analysis of the evolving economics of low carbon resources and the emerging 21st century electricity system. The EPA can and should advance the Clean Power Rule toward this goal by making four changes in its analysis of the proposed standard.

[237] BWE, German Wind energy Association, 2012; Kitson, Wooders, and Moerenhout, 2011; Berwick. 2012; Energy Information Administration, 2011; Pfund and Healey, 2011; GAO, 2007; Goldberg, 2000.

[238] Badcock and Lenzen, 2010. Branker and Pearce, 2010.

- EPA should correct its analysis to render it internally consistent and reflective of current costs and cost trends, expunging all reference to subsidization of nuclear power.
- EPA should prepare a third option for consideration on the high side of the two presented.
- EPA should encourage the states to implement least cost approaches by indicating that the selection of resources that deviate significantly from this principle will be subject to close scrutiny.
- EPA should indicate that it will consider, evaluate and give full weight to state implementation approaches that incorporate the beneficial transformation of the electricity infrastructure

The decision to begin the process of decarbonizing the electricity sector does not change the abysmal economics of aging nuclear power one iota. Nuclear power cannot compete with a bevy of low carbon alternatives, especially in the time frame in which the Clean Power Rule will be in effect. The internalization of the social cost of carbon improves the prospect of all low cost alternatives as much as it helps nuclear power. EPA's mishandling of the nuclear analysis goes even farther. Even if EPA could show that a subsidy for aging nuclear power is necessary to achieve the carbon reduction goal, it has bungled the analysis of how big the subsidy should be and how it should be distributed.

Therefore, EPA's suggestion that nuclear power be singled out for a subsidy is fundamentally incorrect. Policies to accelerate the deployment of lower cost alternatives would be economically superior. Only if EPA concluded that the abandonment of nuclear power would be so pervasive that the alternatives could not meet the goals set by EPA might there be a justification for a nuclear subsidy. In fact, EPA has made no such showing and as I have shown in the analysis of efficiency and renewables, there is not one shred of evidence presented to suggest that it could.

Rather than try to repair the subsidy approach, the EPA should get out of the business of favoring specific technologies and be technology neutral. If EPA wants to get into the business of recommending subsidies for specific technologies, it should look at real world experience.

With a clear path of more attractive resources, we do not have to engage in the hundred year debate today, although there is growing evidence that prospects for high penetration renewable scenarios for the long terms are quite good.[239] The available and emerging alternatives can certainly carry the effort to meet the demand for electricity with low carbon resources a long way down the road,[240] well beyond the time frame of the EPA Clean Power Rule and certainly

[239] There are a growing number of scenario analyses at the global national and local levels (Jacobson and Delucchi, 2011; Jacobson, et al., 2013; Delucchi and Jacobson, 2011, Budischak, et al., 2013; Delucchi and Jacobson, 2013; Cochran, Mai and Bazilian, 2014), (Jacobson, Howartha and Delucchi, 2013) that suggest a high renewable penetration approach (80% or more) is quite feasible, particularly when coupled with energy efficiency (Howland, et al., New York State Energy Research & Development Authority, 2011).

[240] Jacobson and Delucchi, 2011; Jacobson, et al., 2013; Delucchi and Jacobson, 2011, Budischak, et al., 2013; Delucchi and Jacobson, 2013; Cochran, Mai and Bazilian, 2014.

long enough that the terrain of technologies available may be much broader before we have to settle for inferior options like nuclear power.

Based on the history of the performance of the nuclear and the alternative industries, there are good reasons to expect the alternatives will overcome their challenges more quickly and efficiently than nuclear technology.

First, in addition to the ongoing conceptual and design work, the nature of the renewable technologies involved affords the opportunity for a great deal of real world development and demonstration work before it is deployed on a wide scale. This is the antithesis of past nuclear development and the program that SMR advocates have proposed.

Second, the alternatives are moving rapidly along their learning curves. The ability to move down the learning curves exhibited by renewables and alternative technologies can be explained by the fact that these technologies actually possess the characteristics that allow for the capture of economies of mass production and stimulate innovation. They involve the production of large numbers of units under conditions of competition. Nuclear power, even SMR technology, involves an extremely small number of units from a very small number of firms, with the monopoly model offered as the best approach.

In short, the underlying conditions and recent decades of experience suggest that the dramatic reversal of fortune nuclear advocates technology are hoping for is not likely, to say the least, while the continued, dramatic decline in the cost of renewables, is quite likely and the prospects for the development of the building blocks of the 21st century electricity system are much better.

As large as the benefit cost ratio is in the EPA analysis of Option 1, I believe that when these modifications are made to the economic analysis, the potential benefits of a well-designed, least cost performance standard will exceed the costs by a much greater margin than EPA's Option 1 analysis suggests. When the economic analysis is corrected and a third, "high" reduction rule analyzed, the higher standard will be very attractive. Given that so much potential for low cost carbon reduction has been left on the table, it appears that a doubling of the contribution of efficiency and renewables, as some have suggested,[241] would be readily achievable and yield a substantially positive benefit cost ratio. Whether or not EPA adopts the higher standard, having the more rigorous analysis of a higher standard available would serve to expand the range of options considered by the states, laying the basis for higher levels of reduction of carbon emissions in the future.

In the past month, the U.S. and China made important commitments on carbon reduction and the European Union put forward a much more aggressive proposal. These announcements help to place the EPA proposal in perspective.[242] As shown in Figure X-9, EPA Option 1 is consistent with the U.S. China announcement. At the same time, a doubling of the carbon

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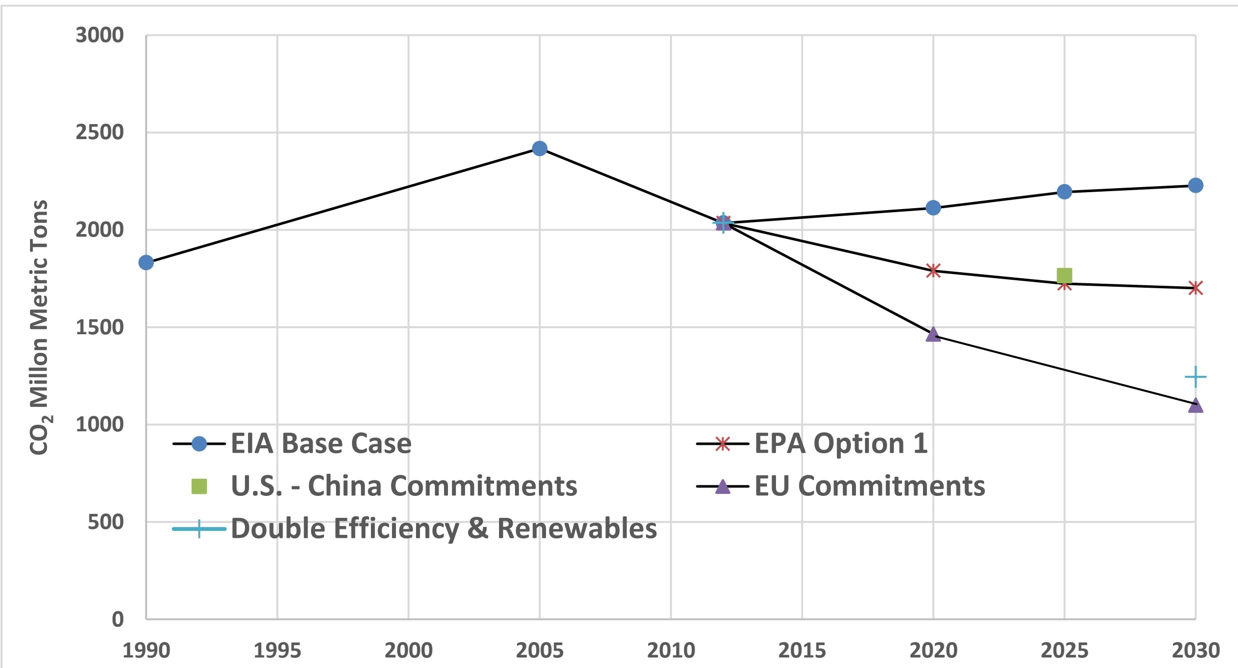
[241] Union of Concerned Scientist, 2014.

[242] Bosetti and de Cian, 2013, 56, Our results suggest that a moderate unilateral climate policy could induce a virtuous behaviour in non-signatory countries and that policies promoting the international transfer of technologies and knowledge could represent an effective complement to mitigation targets. Valentine, 2014.

reduction would still be considerably less than the target set by the European Union, in spite of the fact that the U.S. emissions are more than twice those of the EU per capita and three times those of China.

It is critically important at this turning point in global climate change policy for EPA and the U.S. to lay a strong foundation for a century of policy. A well-crafted performance standard that looks to the future by highlighting the role of efficiency, renewables and transformation of the system is an ideal place to start.

FIGURE X-9: EPA OPTION 1 COMPARED TO RECENT CARBON REDUCTION COMMITMENTS



Sources: EPA, RIA, Table 3-11; Energy Information Admnistration, *Annual Energy Outlook: 2014,* Appendix A. The EU goals for ty U.S. are modelled as 20% below 1990 by 2020 and 40% below 1990 by 2030. The U.S.-China Goal is modelled as 27% below 2005.

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