CLIMATE POLICY FOR THE REAL WORLD

CALIFORNIA'S PROVEN APPROACH TO BUILDING AN EFFECTIVE, EFFICIENT, AND FAIR PACKAGE OF CLIMATE POLICIES

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By Chris Busch and Hal Harvey

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EXECUTIVE SUMMARY

California's climate policy is a success. Greenhouse gas emissions are falling, and the state has one of the strongest economies in the world. In April and May, California's economy was responsible for generating half of all the jobs created in the nation. California-born innovations, in technology and public policy, are spreading all over the globe. These conditions indicate Governor Brown's Executive Order, setting a 2030 target to reduce emissions 40 percent below 1990 emissions levels, is an ambitious but completely achievable goal for the state.

Last year's passage of SB 350—the Clean Energy and Pollution Reduction Act— set in law important initiatives, requiring utilities to deliver at 50 percent renewable electricity by 2030 and the California Energy Commission to double the pace gains in existing building energy efficiency. But work remains as policymakers finalize the policies that will put us on track to 2030.

A question under discussion is how to strike the right balance between the state's performance standards, which establish emissions and energy use requirements for a range of products and uses, and its cap-and-trade program.[1] While the cap-and-trade program has an important role, this paper argues California's performance standards are essential—and are mainly responsible for the state's low-carbon progress so far.

California has a long history with performance standards. Starting in the 1970s in response to energy crises, California embarked on a journey to reduce economic vulnerability and environmental destruction through the use of performance standards. The state launched an energy efficiency revolution with its outstanding energy performance standards programs for buildings and appliances, which many other states and countries have since replicated. California has also led the way in cutting conventional and greenhouse gas pollution from cars and trucks. Strong performance standards have spurred the technological revolution in hybrid and zero-emission car technologies that has resulted in growing numbers of these vehicles on the road today. The state was also an early mover on renewable energy, for example through its renewable portfolio standard, and continues to succeed in this realm too, again having global implications. California's long history of performance standards demonstrates the value these policies have had in lowering energy use and reducing greenhouse gas emissions.

Setting a price on carbon emissions, as California's cap-and-trade program does, provides a valuable economic incentive for investment and other behavior. It likewise internalizes the carbon emission "externality," which exists when market decisions fail to capture costs or benefits. Large externalities lead to inefficient markets outcomes. Correcting this externality through a price on carbon emissions has important efficiency benefits for both capital and operational decisions.

[1] For example, performance standards are exemplified in building codes, appliance efficiency standards, carbon dioxide (CO_2)/mile standards for cars, and the low-carbon fuel standard.

In California's most recent cap-and-trade permit auction, on May 18th, the majority of the permits made available went unsold—the first time this has happened since the program's inception in 2013. This reflects legal uncertainty around the future of the cap-and-trade program and the fact that emissions appear to be below the level of cap. Both performance standards and the cap-and-trade program—but especially performance standards—have driven emissions down. The overhyped headlines around the cap-and-trade program do not mean it is failing. The cap-and-trade program design is fundamentally sound, and is bolstered by its automatic tightening mechanism whereby allowances are held back if they are not in demand at a minimum price.

While cap-and-trade has an important place in the package of policies, carbon pricing is not a silver bullet for meeting California's emissions reduction goals. Several market failures limit its effectiveness. For instance, many energy users are limited in their ability to react to price fluctuations, and consequently, have limited scope to modify their energy use. As an example, consider the "split incentive" problem facing the building sector: For most renters, it's a fair bet the building owner not paying the utility bill. If the building owners aren't paying the bills, then carbon pricing that raises the price of energy has no impact on the building owners, and therefore creates no incentive for them to install more efficient equipment, such as high efficiency water heaters or low-emissivity windows. Even though it may be cost-effective to build an efficient building, the impacts of carbon pricing are not felt by those who incur the costs of constructing a more efficient building. Therefore, carbon pricing provides a weak incentive for investing in the efficiency of new buildings.

Performance standards help to capture these and other low-cost reductions by offering a more targeted and certain demand-side signal: The innovator does not have to anticipate what other technologies across the entire economy they will be competing against.

Performance standards and carbon pricing need to be supplemented with government investment in research and development (R&D). While the technologies necessary to achieve our 2030 emissions target already exist, we need further innovation to meet longer-term goals. California should continue to fund basic R&D and demonstration projects to solve the basic engineering problems needed to move innovations out of the lab and to the cusp of commercialization.

The sum of the evidence indicates California's current approach—which includes performance standards as the core of climate policy, with supplemental support from a broad carbon price signal and R&D investments—is the best one. This hybrid of complementary approaches is what has gotten us this far and is the right approach for the next phase of climate policy. California policymakers should double down on what is working by extending the cap-and-trade program beyond 2021, including tighter emissions limits, and strengthening the suite of performance standards in place today, including the low-carbon fuel standard.

1. INTRODUCTION

What is the most effective and efficient approach to climate policy? That question looms larger than ever since the United States, China, European Union, and 172 other countries signed the Paris agreement on climate change. This agreement represents a high water mark for political momentum: Now is the time to turn emissions reduction pledges into action, and smart policy design will determine whether or not these commitments lead to real-world progress.

Three-fourths of the climate problem comes from burning fossil fuels, and that can only be changed with smart energy policy. Broadly speaking, there are three types of policy to decarbonize the energy sector—performance standards, like building codes; economic signals, such as a carbon price; and support for research and development (R&D). Each type of policy has its advantages and disadvantages, impacts the effectiveness of other policy types, and works best when intelligently combined with the other types.

Some argue economic signals such as carbon pricing are sufficient on their own to solve climate change. Pricing signals are important, but when used in isolation, they are insufficient for the task. Carbon pricing as the sole climate policy results in higher short-term costs because some very attractive mitigation options with net economic benefits (savings exceeding costs) are not price-sensitive.

Fortunately, one of the world's most sophisticated and successful approaches to climate policy already exists in California. The state uses a hybrid approach based on a foundation of performance standards, with carbon pricing to motivate the more price-sensitive actors in the economy, and R&D to make the other strategies cheap and feasible.

This policy framework bucks certain neoclassical economic orthodoxies, but the evidence from California suggests it is working. California's experience so far can be summed up in Figure 1, which shows a remarkable reduction in CO_2 and conventional air pollution, even as the economy booms.

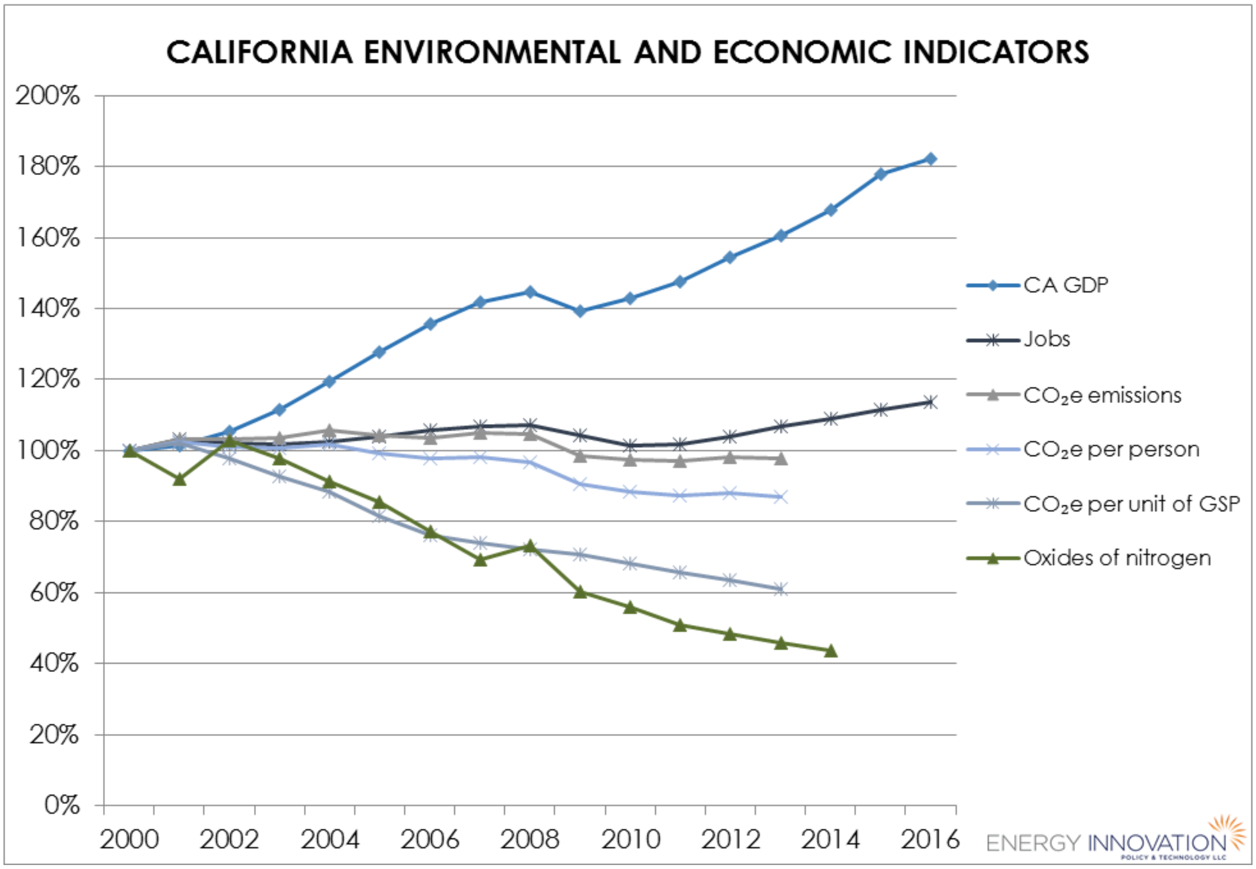

Figure 1. California environmental and economic indicators (Source: Energy Innovation)

Figure 1 shows CO_2 and criteria (local and regional) pollutant emissions are declining apace with statewide economic growth. As of 2014, CO_2 emissions have fallen nine percent below their peak of 2004, and stand only two percent above the 2020 target, which requires a return to 1990 levels. Emissions per dollar of Gross State Product (GSP) and emissions per person have fallen 46 percent and 17 percent, respectively, since 2000.

Local air pollutant emissions reductions have been even more pronounced. Oxides of nitrogen (NO_X) emissions, a major contributor to ground-level ozone and the most troublesome type of pollution in the South Coast Air Basin, are 56 percent below the 2000 level; other criteria pollutants like fine particulate matter have seen similar declines.

The graph shows GSP and jobs have both grown steadily in the aftermath of the recession. In 2016, GSP and jobs are up about 82 percent and 14 percent, respectively, since 2000. The state captured half of all jobs created in the United States in April and May,[2] and the unemployment rate of 5.3 percent is the lowest since June 2007.

2 Stephen Levy, April 2016 Jobs Report, Center for the Continuing Study of the California Economy

While the economy is performing well in a broad sense, California's innovation economy is also sprinting ahead. A recent survey counted more than 500,000 clean energy jobs in California in 2015, and the state has ranked first overall in statewide clean tech leadership since 2010. Venture capital investment has poured into the state's clean tech companies in industries like solar power (SolarCity), advanced zero-emissions vehicle manufacturers (Tesla), and energy efficiency firms (EnerNOC).

In 2014, the state garnered a record $5.7 billion in clean tech venture capital investment—69 percent of total national clean tech investment—and California has captured $27 billion over the past decade. Venture capital is a good indicator of innovation activity, but it is only one segment of investment in clean tech, which totaled $31 billion statewide in 2014. Clearly, clean energy need not be a "job-killing" policy.

2. WHY IT IS IMPORTANT TO GET POLICY RIGHT

DEEP EMISSION REDUCTIONS

Effective climate policy will quickly and significantly drive down greenhouse gas emissions. Climate impacts are happening more rapidly than scientists had expected even just a few years ago. The two degrees Fahrenheit of warming seen since the pre-industrial benchmark has already produced a crescendo of devastating storms, droughts, flooding, rising seas, and more severe wildfires. The catastrophic impacts of runaway climate change on California, in particular, are well-documented.

To effectively mitigate the worst impacts of climate change, climate policy must deliver large-scale, rapid CO_2 emissions abatement. To be maximally effective, policies must be substantiated and improved with data collection, monitoring, analysis, and improvement—and sound enforcement is crucial.

EFFICIENCY

Effective climate policy is efficient: It delivers benefits with very low costs, or even economic gains. This conserves resources for other societal goals, and also engenders greater political support for further, stronger efforts.

Efficient policy sends the right investment signals while invigorating the private sector. Government investment must play a role, especially in transportation and electricity grid infrastructure, but most investment will come from the private sector, which controls and directs the lion's share of capital. "Investment-grade policy," then, will set clear, long-term signals so companies can set R&D and capital investment plans accordingly. It will be technology-finding (rather than specifying technology) and, symmetrically, price-finding. Investment-grade policy should require continuous improvement to stimulate and take advantage of innovation.

TECHNOLOGY INNOVATION

Policy can accelerate innovation by adding more **supply**, via well-designed research programs, or **demand signals**, such as a renewable portfolio standard or a price on carbon, which conditions the market to reward cleaner technologies. Both supply-side and demand-side policy are necessary, with the former helping develop more fundamental insights, and the latter driving technologies toward commercial competitiveness.

CO-BENEFITS, SUCH AS CLEAN AIR AND BETTER QUALITY OF LIFE

Most climate solutions also offer other valuable benefits in addition to carbon emission reductions. Though many economic models focus exclusively on the costs and benefits for those covered by regulation, policymakers should consider the broader suite of societal impacts. Policy design should aim to maximize the co-benefits of climate policies, while keeping in mind benefits for privately regulated parties arising from flexibility and coordination with other jurisdictions.

Multiple co-benefits arise from climate change mitigation: Renewable energy technologies lead to better air quality and improved health. More energy-efficient technologies lower energy bills and reduce exposure to energy price volatility. Smart urban design reduces vehicle miles traveled and transport emissions, while increasing land value and improving the quality of life. Reduced fuel consumption in cars and trucks will cut our dependence on foreign oil, along with the associated national security and economic risks.

Better urban design gives people access to the walkable, transit-oriented, and mixed-use neighborhoods that are in strong demand but currently undersupplied by markets. In such neighborhoods, people are not forced to drive everywhere, enabling them to live more active and healthy lifestyles. Similarly, improved bike pathways can encourage more bike travel, reducing transportation fuel demand and improving health. Better urban design also reduces infrastructure costs for local governments and alleviates pressure on already congested roadways.[3] All of this adds up to greatly improved quality of life.

Better local and regional air quality is a particularly valuable benefit, and an important factor in spurring countries to take on commitments to fight climate change. Los Angeles has the cleanest air in decades, yet remains the most polluted city in America by the measure of ground-level ozone. This is one indicator of the significant health benefits to be had from improving California's local and regional air quality. The American Lung Association's *State of the Air 2016* report study found six of the nation's most polluted cities are in California. Annually, more than 20,000 Californians and their families suffer premature deaths due to air pollution. Research conducted at Lawrence Berkeley National Laboratory (LBNL) shows the state's 2030 and 2050

[3] New roads will fail to reduce traffic congestion, as acknowledged by California's Department of Transportation.

carbon emission targets will be very helpful in reaching new and stronger federal air quality standards. Clean air benefits are also crucial in China, India, and other developing countries, which are suffering from increasingly dangerous air.

California has also set out to ensure climate policy contributes to a fairer society, in both environmental justice and socioeconomic terms. Lower-income households are disproportionately affected by unhealthy air. State law requires at least 25 percent of revenue from the cap-and-trade program to fund projects improving air quality in disadvantaged communities, and policymakers are far exceeding that level.

Through a range of investments and other programs—better public transit, access to solar for low-income renters, and electric car-sharing in low-income communities—California is proving the clean economy can work for everyone.

3. THREE TYPES OF POLICY

As previously mentioned, there are three main approaches to energy policy—economic signals, performance standards, and support for R&D of new technologies. When used together, these approaches can reinforce each other and drive innovation, while decreasing costs and stimulating economic growth. There are other enabling, energy-related policies that do not fall neatly into these three categories. Examples of enabling policies include easier permitting for renewable energy facilities, financing support, public investment in infrastructure (such as public transit), and the use of government procurement to speed deployment of clean technologies.

ECONOMIC SIGNALS

Economic signals leverage market forces by pricing energy and infrastructure to better reflect their true costs, including externalities such as threats to human health, ecosystems, and national security. They are particularly useful for influencing behavior where consumers are sensitive to prices, or where industrial decisions can be influenced by a carbon price. Economic signals can influence equipment purchasing decisions as well as energy consumption, especially in industrial processes. The impact of a price signal will likely grow over time, and a long-term price signal will affect long-term investment decisions. In economic terms, long-term elasticities can be quite different than short-term elasticities. Economic signals complement performance standards by creating a market incentive for better, more efficient products. This paper focuses on carbon pricing in discussing economic signals, however, there is also a role for targeted fees and incentives.

PERFORMANCE STANDARDS

Performance standards set criteria that must be met by energy-using products or by energy-generating technologies. For example, a performance standard on building equipment might require water heaters to achieve a minimum level of energy efficiency. Renewable portfolio standards require utilities to procure a minimum percentage of their delivered electricity from renewable sources, providing an example of how performance standards can target large industries.

Standards are particularly useful when prices are unlikely to affect behavior (for reasons we describe below), and therefore nicely complement economic signals. Performance standards focus on desired outcomes, and do not prescribe technological approaches. They are clear on the ends, but remain neutral on the means.

Setting performance standards for energy technologies and systems can spur technological innovation by enabling flexibility in how required outcomes are achieved, while also ensuring cost incentives are retained. For example, every refrigerator manufacturer is motivated to achieve the performance requirement in the least expensive way possible.

SUPPORT FOR RESEARCH, DEVELOPMENT, AND DEMONSTRATION (R&D)

Support for R&D includes funding for early-stage science in the laboratories. It is widely recognized that the private sector underinvests in research for inventions with social benefits. In addition to basic research, new technologies must be helped through early stages of engineering learning-by-doing with support for demonstration products.

POSITIVE FEEDBACKS AMONG THE THREE TYPES OF POLICIES

Economic signals, such as carbon pricing, incentivize emission reductions where price is an effective driver. Carbon pricing unleashes the power of markets to find creative and unexpected emission reductions regulators might not be able to specify through more targeted means.

Performance standards requiring more energy-efficient consumer products help capture low-cost emission reductions that are not readily motivated by pricing strategies. By ensuring these price-resistant reductions are effectively accomplished, the effort required for carbon pricing is lessened, enhancing efficiency. The emission reductions motivated by performance standards are not always low-cost ones (the net benefit energy efficiency options at the far left of the cost curve). In some cases, performance standards are useful for driving some emission reductions that have costs higher than the marginal carbon price. This is necessary to drive transformation in particular sectors where pricing strategies are known to be less effective, such as the transportation sector.

Structured support for R&D also develops a pipeline for fundamental technological progress, reducing future costs of complying with performance standards and responding to economic signals. In turn, demand-side performance standards and economic incentives send a signal to potential innovators their work will be rewarded in the marketplace. Figure 2 illustrates these dynamics.

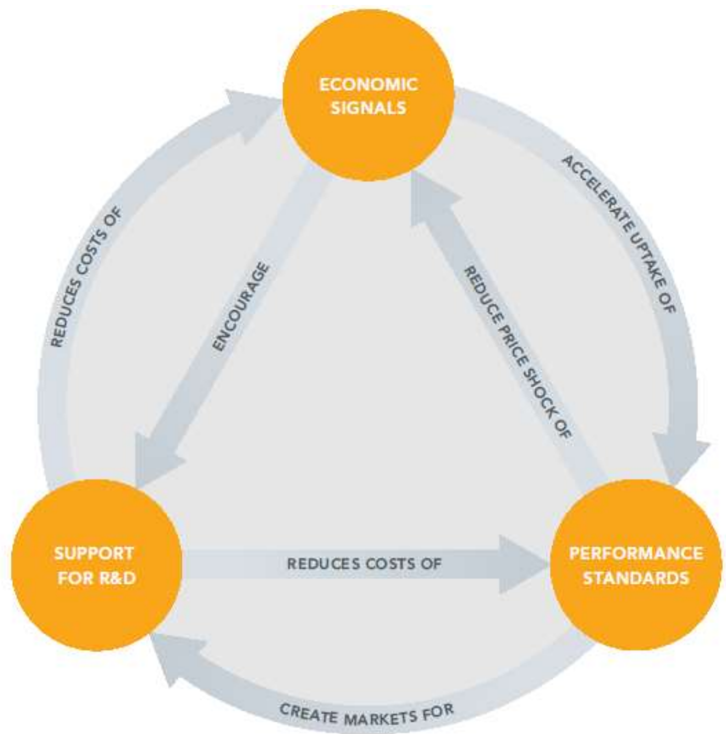

Figure 2. Positive feedbacks from synchronous deployment of three types of policies (Source: Energy Innovation)

4. CARBON PRICING: ADVANTAGES AND LIMITATIONS

This section uses carbon pricing to mean either a carbon fee or a carbon cap-and-trade program. These are mirror image mechanisms: A fee has financial certainty and environmental uncertainty, and a well-designed cap-and-trade program reverses these characteristics. But within reasonable boundaries, the two policies act the same way by adding a price to carbon, which is either defined (with a fee) or revealed (with a cap). California has pioneered a hybrid of these two approaches through the adoption of a price floor and a soft price cap. The soft price cap is achieved through the use of an allowance price containment reserve, whereby allowances are released if prices climb to predefined levels, which increase over time.

ADVANTAGES

Properly-designed carbon pricing policy 1) induces people to make better choices when they buy energy-consuming equipment, 2) helps to level the playing field for renewable energy with fossil fuel incumbents, and 3) corrects the prices facing energy consumers so they take into account the cost to society for the pollution, national security threats, and climate change caused by our fossil dependence. Carbon pricing is most effective when set by a policy with a long time horizon.

Unlike many other policies, a carbon price directly affects both investments and behavior, sending a consistent signal across the life of any product or practice. Because pricing carbon allows the free market to seek many ways of abating carbon, it should find low-cost options and stimulate new technologies for future reductions. This reduces the information burden on regulators, by taking advantage of information known to market actors but difficult to observe or collect as a government agency. This is particularly attractive in the context of a program to control emissions of greenhouse gases, which are nearly ubiquitous and are emitted by a diverse range of sources touching every major sector of the economy.

In the context of an economy-wide emissions cap, i.e. one that includes a specific target for reductions such as in California, a cap-and-trade program offers quantitative certainty. The cap provides a backstop mechanism for the suite of performance standards.

A cap-and-trade program also provides a platform to link with other jurisdictions, as California and Ontario have shown. This serves to expand the scope for investment to flow to the lowest cost mitigation options.

Pricing carbon has another bonus: By putting a cost on socially undesirable behavior (pollution), carbon pricing provides an efficient source of revenue. Additionally, unlike taxes on labor, capital, or sales, revenue collected from introducing a carbon fee increases economic efficiency.

Finally, and significantly, if even modest carbon fee proceeds are spent on R&D and smart and equitable strategies to accelerate clean energy, it engenders a virtuous cycle, speeding the whole process.

For all these reasons, pricing carbon has attracted adherents across (most of) the political spectrum, from four-time Republican cabinet member George Shultz and Bush-era Treasury Secretary Hank Paulson, to the New York Times editorial page, and Senator Bernie Sanders. Carbon pricing is championed by both the conservative American Enterprise Institute and the progressive Center for American Progress. A half-dozen oil majors (none of them American) have joined the call, making their case in a recent letter to the United Nations Secretary General.

LIMITATIONS

These features aside, carbon pricing at levels currently seen in most jurisdictions fails to affect many consumer decisions, and affects few industry ones. For all its virtues, in too many cases carbon pricing alone is simply not the most efficient approach. Below, we survey the market failures and market limitations creating the need for a silver buckshot approach—i.e., many and varied policies—instead of a silver bullet approach.

Split incentive

Consider buildings, which represent about 40 percent of energy use in America. The people who make choices about a building's energy efficiency almost never pay for the energy those buildings consume: A subdivision developer or an office building architect don't typically cover tenants' utility bills.

Structural choices about building energy efficiency are made by individuals and firms who are not affected by energy waste. Similarly, renters, and sometimes even owners, are not positioned to ensure walls are well-insulated, ducts wrapped, or glazing specified with proper emissivity. Tenants therefore have very limited options to improve efficiency; a carbon price simply adds to the dweller's cost of energy. It has limited effect on the decision-making of the company constructing the building.[4]

This market failure in the building sector is called a "split incentive," since those who make capital decisions do not pay utility bills. Extrapolating from one apartment or house to the 100 million buildings in America—all heated, cooled, or lit—begins to outline the scope of the problem.

"Homo economicus" vs. real world consumer decision-making

Another limitation of carbon pricing is that most people do not act like the perfectly rational, utility-maximizing agents ("homo economicus") populating traditional economic theory. Many consumers avoid math unless absolutely necessary or lack the ability and willingness to calculate rates of return, which are preconditions for efficient investment in more energy-efficient products.

People also tend to exhibit great impatience, and even if inclined to do the math and estimate long-term returns, are not willing to wait for them. Many studies have found a high consumer barrier to being willing to make investments in energy efficiency.

For example, one study[5] sold identical refrigerators, some labeled with very low energy consumption and higher purchase price, and others with lower price and higher energy consumption. By manipulating these two numbers, the study's authors were able to evince consumers' implied discount rate. The result: Consumers would only make incremental capital investments if they could earn back that money in two years or less. In other words, they implicitly demanded a 50 percent or greater annual return on their money.

A survey of studies finds consumers demand rates of return in the range of 20-100 (indicating the need for the efficiency investment to pay for itself in as little as one year) and even higher.[6] A whopping carbon fee would be required to bust through that much consumer indifference.

In contrast, the utilities supplying electricity for the refrigerators routinely invest in technologies requiring eight or more years to pay back. The difference between utility payback requirements for supply (12 percent or so) and consumers' preferred payback for efficiency (say 50 percent)

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[4] It is worth noting California has developed an approach that retains the price signal, but neutralizes the overall consumer effect. The carbon price is reflected in electricity prices, but since consumers receive lump sum payments in an equal amount, on average, the consumer faces no effect on their disposable income. Hence, it is appropriate to distinguish between the cost of energy on a unit basis and the energy bill.

[5] http://www.sciencedirect.com/science/article/pii/0360544283900944

[6] See Table 2 of "Energy efficiency and conservation: Is solid state lighting a bright idea?"

unnecessarily costs the country tens of billions of dollars and hundreds of millions of tons of carbon pollution every year. While a carbon price helps to tilt the scales in the direction of more investment, it does not fully solve such instances of multiple overlapping market failure.

Economic theory tends to defer to the consumer as the best utility maximizers for themselves, even if they demonstrate socially-detrimental behavior. Economists refer to this as "revealed preference," and take a position that government intervention on such activities would be misguided, as it typically carries some dead weight loss to society. Yet, revealed preferences did not prevent the Chicago Fire, though consumers could have demanded sprinkler systems or masonry instead of wood construction: Instead of "caveat emptor," putting the entire burden on consumers to detect substandard products, we learned to rely on building codes to keep buildings from burning. The same logic holds for energy efficiency.

Clean technologies also face issues of risk aversion and limits on disposable income. Compared to commercial or industrial decision makers, residential households tend to be more risk-averse with greater sensitivity to initial capital costs because they lack liquidity and have a higher cost of capital or limited access to capital. This effect is even more pronounced in lower-income and capital-constrained households. For wealthier households, the problem known as "salience" is a barrier to efficient investment. For some of these wealthier households, the electricity bill is simply not large enough to worry about.

Carbon price signal lost in the noise

Even big, supposedly profit-maximizing industries are susceptible to leaving the proverbial $20 bill lying on the sidewalk.[7] Consider the natural gas industry's strong incentive to avoid natural gas leaks. More leakage means less product available for sale, but significant evidence exists of missed opportunities to reduce pollution in ways that would have generated profits. Figure 3 presents the results of an emissions reduction cost curve developed by ICF International.[8]

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[7] This is the way many economists describe opportunities in which net economic benefits are obtained through government intervention, as $20 bills lying around to be claimed. They do this to encapsulate their view that not very many of these net benefit interventions exist because of their expectation that people or firms act in ways that conform with the rational utility and profit maximizing decision making in the neoclassical model.

[8] ICF International. 2014. Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries

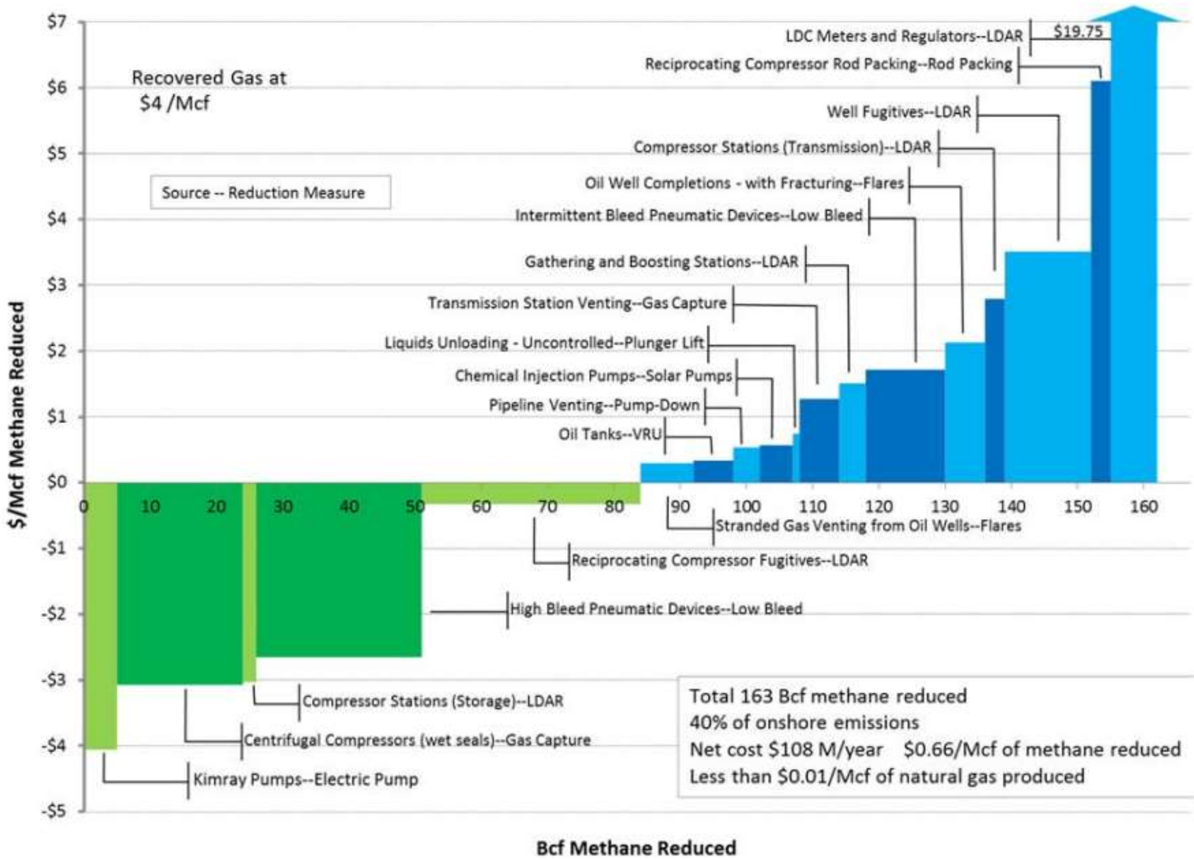

Figure 3. Significant net negative costs for natural gas leak abatement (Source: [ICF International, 2014](#))

The figure shows, in green, negative cost (i.e. profit-generating) options for the natural gas industry. Why is the natural gas industry wasting large opportunities to save money on energy under very good economic terms? Even though the economics of reducing waste are good, their size (small compared to the whole business) does not merit CEO attention, or even the dispatch of a lowly maintenance team to mop up these opportunities. In addition to inattention, low salience may be an issue. Taking a purely private perspective, capital may be more profitably deployed elsewhere, such as drilling new wells.

And for companies outside the energy space, the indifference threshold is even higher. The CEOs of major corporations have not historically spent much time worrying about how to save energy in their facilities, though this is beginning to change. They have to focus on product, innovation, bringing in new talent, regulation, and the media.

Energy is way down on the list of concerns: A carbon price nudges that attention, but not by much. Industries already routinely overlooking energy savings opportunities paying for themselves will do so even with a carbon price.

There's more: Most companies have separate budgets and decision-making processes for capital and operating expenses, so savings in one that come at the cost of expenditures in the other rarely find favor. A carbon price helps, but does not overcome these barriers.

Even large industries, which should be the economic actor most resembling profit-maximizing behavior of economic theory, are beset with foregone opportunities to save money. Generic uses such as motors, compressors, and boilers present a good target for performance standards.

Oil's monopoly on vehicle transportation fuels[9]

Oil's monopoly on transportation fuels is another problem for policymakers pressing to decarbonize the transportation sector. This is an example of technology lock-in, also known as path dependency, due to network externalities. Network externalities arise when the consumption choice of one actor affects other consumers, for example when our current transportation fuel distribution network produces technology lock-in. In practical terms, the electric vehicle charging network and hydrogen fuel cell fueling network are not yet mature enough to compete with the near-ubiquity of gas stations, and price signals on their own are not strong enough to overcome this.

Price resistance in the transportation sector

The transportation sector vividly illustrates the issue of how resistant some energy use and emissions are likely to be to carbon pricing alone, especially at politically realistic levels. Consider the problem of passenger vehicle emissions, the single largest source of CO_2 emission in California. The main determinants of transportation energy demand are land use patterns, travel mode choice, and type of motor vehicle driven, for people who drive.

Land use patterns effectively limit the choice most people have to respond to carbon pricing. Population density and land use (i.e. how sprawled a place is) determine how far people must travel to go to work, drop their kids at school, and get to the grocery store. In California, and the United States generally, suburban sprawl has tended to force people to rely on cars for almost all travel. In these places, population density is too low to provide cost-effective transit coverage, and there are few places nearby enough to walk or bike comfortably. While there may be some scope to reduce low value travel, most of this travel demand is effectively locked in over the short-to-medium run, as relatively few alternatives exist.

In theory, over the long run, a carbon price would induce some people to move closer to work, and could induce more focused development patterns. The problem is that the homes in walkable, transit-oriented urban neighborhoods that are closer to jobs are already in short supply. NIMBYism and concerns about gentrification create barriers to a supply response. A carbon price will have almost zero effect when it comes to increasing the supply of homes in urban core areas. On the demand side, transportation costs are a major expense, but for many families, other housing characteristics will be more important, such as the quality of the school

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[9] This is a monopoly in the common usage definition-- the exclusive possession or control of the supply or trade in a commodity or service – though not in the technical economic sense, which would require a single seller of fuels.

district. This limits the effectiveness of carbon pricing, and creates a basis for a law such as SB 375, which encourages communities that are less sprawling and more walkable and easier to serve with public transit.

The freedom that people have to respond to carbon pricing is also constrained by the vehicle they drive. While a carbon price will help tip the scale in favor of a more energy-efficient vehicle choice at the time of purchase, not many drivers will change their schedule for buying a new vehicle in response to carbon price alone. People hold on to their vehicles for years, increasingly so. Recently, the amount of time U.S. car buyers keep their new vehicles before selling them increased to an average of 6 ½ years.

If all the gasoline taxes in the United Kingdom were called, say, "carbon taxes," they would amount to about $420 per ton of CO_2.[10] That is far beyond any proposal anywhere for a pure carbon price, but the U.K. still imposes (via the E.U.) a fuel efficiency standard to make vehicles more efficient.

Limits of carbon pricing for technology innovation

The research literature recognizes technological progress as the combination of two factors; "technology-push" (research and development) and "demand-pull" (deployment support, which can be achieved with pricing or performance standard policies.).

The need to support R&D—the technology push establishing a pipeline for new technologies—is one of the areas where many economists agree on the need for government policy. For example, in a recent paper Covert, Greenstone, and Knittel (2016) state, "at a high level, there are two market failures—greenhouse gas emissions are not priced adequately, and basic or appropriable research and development is too often underfunded—and the corresponding solutions of pricing emissions and subsidizing basic research and development are easy to identify." Thus, there is broad agreement on the need for increased funding of R&D to provide "technology push." The front end of the technology pipeline has to be primed.

Economists (Burtraw et al. 2005) have pointed out the value of flexibility for encouraging innovation compared to some of the earliest "command and control" policies, which established best-available control standards that were highly prescriptive and not innovation-friendly. However, it is important to point out that performance standards, which are flexible and technologically-neutral, are indeed innovation-friendly. Their comparison to best-available control standards is not appropriate.

Taylor (2012) finds cap-and-trade programs can actually have the effect of weakening innovation if they weaken the demand signal. Taylor documents how innovation, measured by patent

[10] The U.K. gas tax is about 76 p/liter. This implies a price increment of 2.86p/gallon or $3.78/gallon at the June 27, 2016 exchange rate.

activity, slowed down after the introduction of cap-and-trade programs for sulfur dioxide and oxides of nitrogen: "[C]ommercially oriented inventive activity declined during trading for SO_2 and NO_x indicator technologies of varying cost, performance, and market trends, dropping from peaks observed before the establishment of cap-and-trade programs to depths a few years into trading. The implication is that cap-and-trade programs do not inherently provide sustained incentives for private sector R&D investments in clean technologies, but may add to the uncertainty inherent in inventive activity," (Proceedings of the National Academy of Sciences, pages 6-7). Recent research by Vollebergh and Van der Werf (2014) and Dechezlepretre (2016) highlights the value of performance standards as part of a suite of policies designed to achieve low carbon innovation.

Carbon pricing is certainly helpful, but broad economy-wide pricing as the only demand-pull instrument is insufficient; the economy-wide demand signal is too diffuse. The potential innovator must scan a very broad set of potential low carbon competitors and estimate the likelihood that any of these diverse technologies might achieve cost superiority first. This introduces some risk and additional analytical complication compared to a more targeted demand-side policy, such as a performance standard.

Optimal policy design for technological innovation will therefore also include performance standards. A more targeted demand-side signal through the use of performance standards is more readily perceived and relied upon by potential innovators. The innovator does not have to anticipate what other technologies across the entire economy they will be competing against. For example, an appliance manufacturer might be on the fence about whether or not to invest in improved efficiency. A carbon price will affect a broad range of products, so it may be unclear to the manufacturer how they should invest in R&D. In contrast, a minimum energy performance standard for new refrigerators will create a mandatory demand-pull signal, better encouraging manufacturers to invest in R&D.

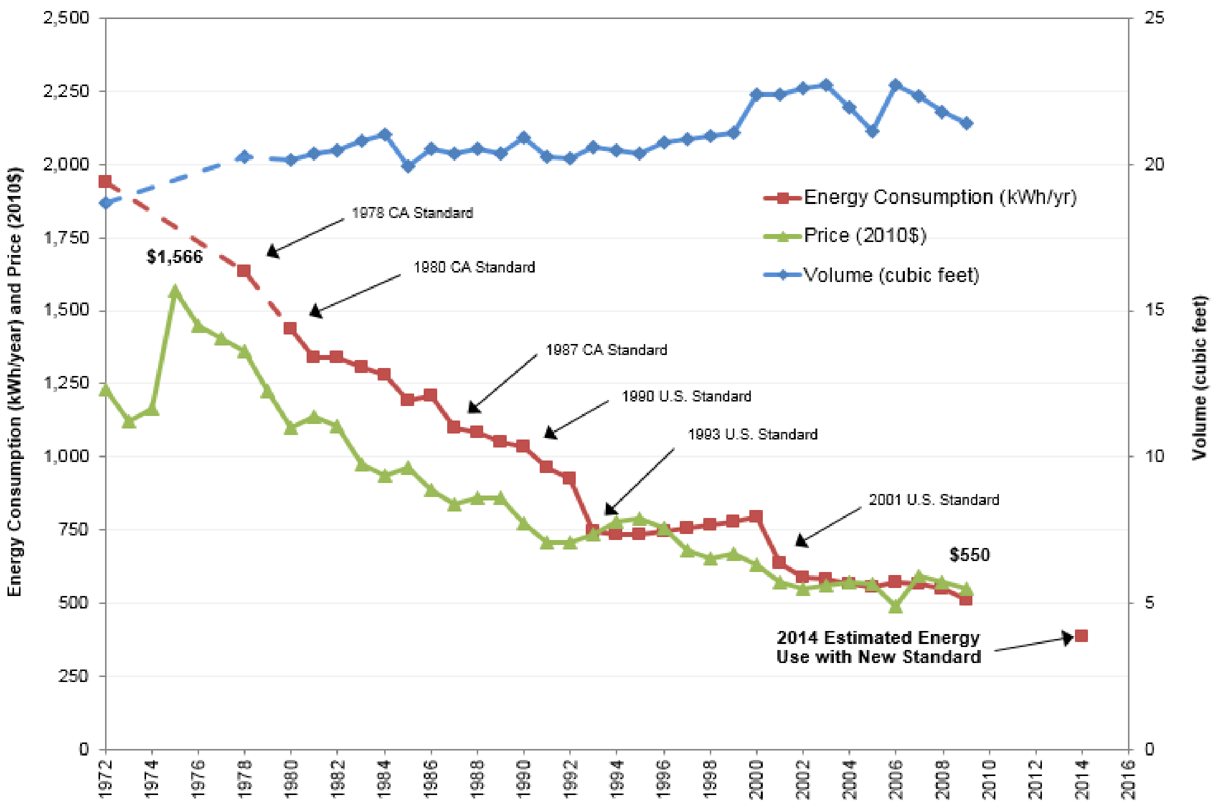

Figure 4. Refrigerator efficiency gains as price falls (Source: [Appliance standards awareness project](#))

Figure 4 shows a classic example of innovation in refrigerator efficiency that occurred in response to performance standards, first set by California and later adopted by federal statute. The figure illustrates how energy efficiency and costs improved dramatically, even as refrigerators grew in size. The fact that size remained undiminished is important because economic theory critiques often imply hidden quality sacrifices in such energy efficiency policies, and criticize engineering studies for ignoring these.

Another example of technological innovation through demand-pull performance standards is the California renewable portfolio standard (RPS). In 2002, California became an early adopter of a RPS policy, requiring utilities to steadily increase the use of renewables in their electricity generation (today, the state's electricity is sourced from a roughly 25 percent renewable mix). Last year, California extended this requirement with a new law that sets a floor of at least 50 percent renewable electricity by 2030. Policies like the California RPS establish the certain, targeted, long-range future commitments that drive fundamental innovation. In the case of the RPS, the economic signal is quite clear: Renewable energy generators regularly sign Power Purchase Agreements guaranteeing they can sell their output for 15 to 25 years—precisely the kind of future revenue stream certainty that unleashes investment and innovation.

Renewable energy policy in California, Germany, China, and other leading countries has dramatically driven down the cost of wind and solar. Figure 5 illustrates how costs have fallen with increased deployment.

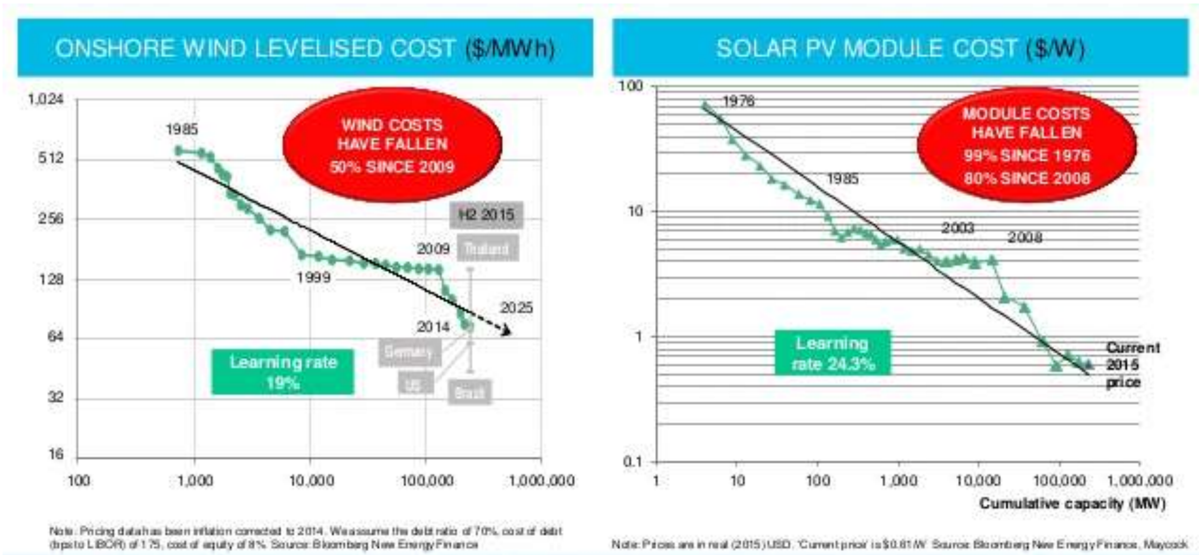

Figure 5. Declining costs with increasing deployment for wind and solar energy technologies (Source: [Bloomberg New Energy Finance)](#)

While progress on wind and solar has been incredible, Figure 5 shows batteries (a key factor in overall electric vehicle costs) and LED lighting have witnessed enormous cost declines as well.

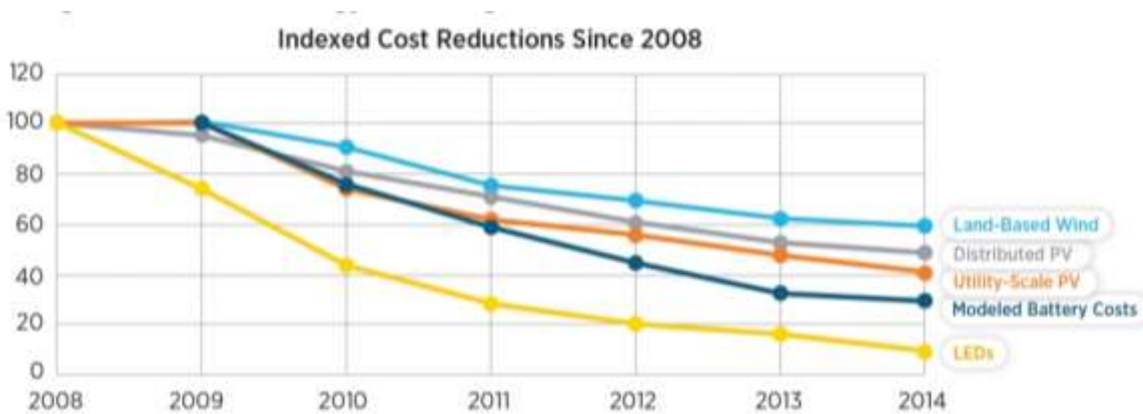

Figure 6. Dramatic cost improvements for five clean energy technologies (Source: [U.S. Department of Energy)](#)

The Appendix presents cost curves for each of the five technologies shown in Figure 6 in tandem with deployment statistics, illustrating the role of learning-by-doing in each case.

Energy policy is one important element of low carbon innovation. Innovation is a complex process. Other reasons for California's success include the state's research investments, such as the Public Interest Energy Research program, and its research and educational institutions.

PRICING SUMMARY

The list of market failures described above indicates a carbon price is no silver bullet. While carbon pricing would help in some sectors—providing a good signal for infrastructure decisions and generating revenue efficiently—in terms of CO_2 emission abatement, the most important policies in the U.S. and across the world have been well-designed performance standards.

This is not altogether surprising: Performance standards are simple, and they work. We insist on minimum levels of performance through health and safety standards in many realms: Untainted meat, clean water from our taps, hotels and offices not prone to burning down, and cars able to survive most crashes.

Those social benefits are profound—and they all come from smart performance standards. We do not impose a tax on unsafe cars, or on flammable hotel rooms, or meat with ptomaine. We simply expect—and demand, via performance standards—these products to be consumer-ready.

5. HOW TO CHOOSE

When you unpack energy decision-making, a carbon price is clearly excellent for driving decisions where:

- The economics of going clean are close to the cost of pollution (i.e., there are ready alternatives on the margin),
- Energy costs are a significant part of a budget or a business, or
- The infrastructure or investment decision-maker is affected by the cost of energy.

A carbon price works in energy-intensive industries that are not easily relocated to cheap energy areas, and which have technology options to reduce energy waste. It is great for market-based electricity dispatch decisions, and where competing options are closely priced on the margin (note, renewable energy already has a zero marginal cost, so it gets dispatched regardless, and a carbon price does not help it).

Performance standards capture low-cost emission reductions that are not responsive to prices, comprising the negative cost portion of the emission reduction cost curve. Performance standards are also useful for providing a demand signal for technology innovation that is recognized as critical to meet long-run decarbonization targets.

Figure 7 (below) presents a stylized illustration of how the three types of policies target different emission reductions. The curve approximates the abatement cost curve developed by McKinsey & Company in their influential work on the supply of carbon mitigation options, first unveiled almost a decade ago. The x-axis depicts the amount of carbon reduced. Each box represents a different technological option. The y-axis shows the price of each. The boxes at the left of the curve and below the horizontal axis indicate reductions where energy savings exceed the additional upfront costs of more energy efficient capital (i.e., net benefit measures). Examples of such options are building energy efficiency improvements, which are price-resistant and best targeted by performance standards. In the middle of the curve are the options most likely to be successfully targeted by a carbon price absent problems such as split incentives. At the right-hand side of the curve are the higher priced options, given current technology. These may be targeted through R&D policies, including demonstration projects to help move technologies beyond early engineering stages to near commercial readiness.

Figure 7 also shows, in yellow, learning-by-doing gains that may be available. These are the cost reductions that may follow from new knowledge gained with greater deployment, including production or installation efficiencies.

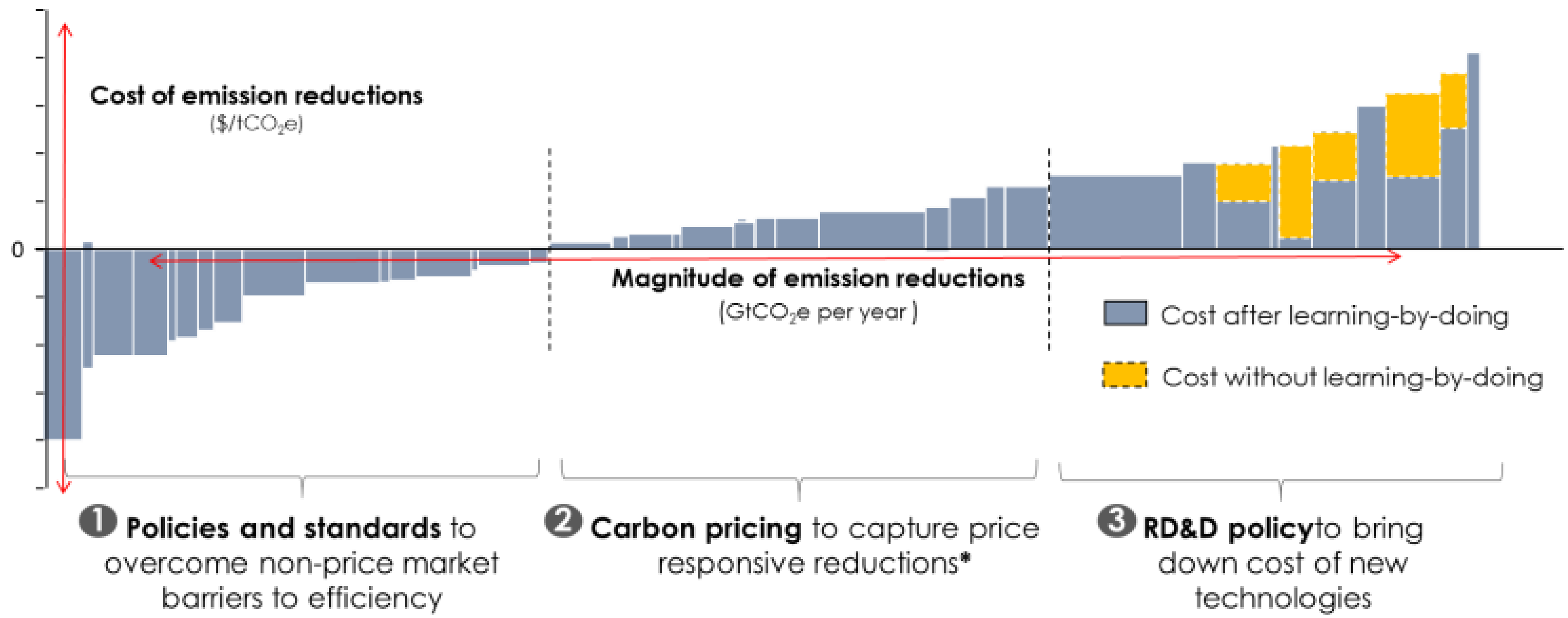

Figure 7. A stylized emission reduction cost curve showing the roles for different types of policies (Source: Energy Innovation).

Figure 7 is highly stylized. The real world is messy—the degree of price responsiveness is likely to be much more heterogeneous in reality. Figure 8 illustrates the real heterogeneity found across the supply curve, based on work by a team led by Stanford Professor Jim Sweeney. Even though the data are no longer current and it is a difficult graph to read (readers can go to the source link to view the original), the graph provides a rich and empirically-grounded view of how price responsiveness and price resistance are distributed across a real world emission reduction curve.

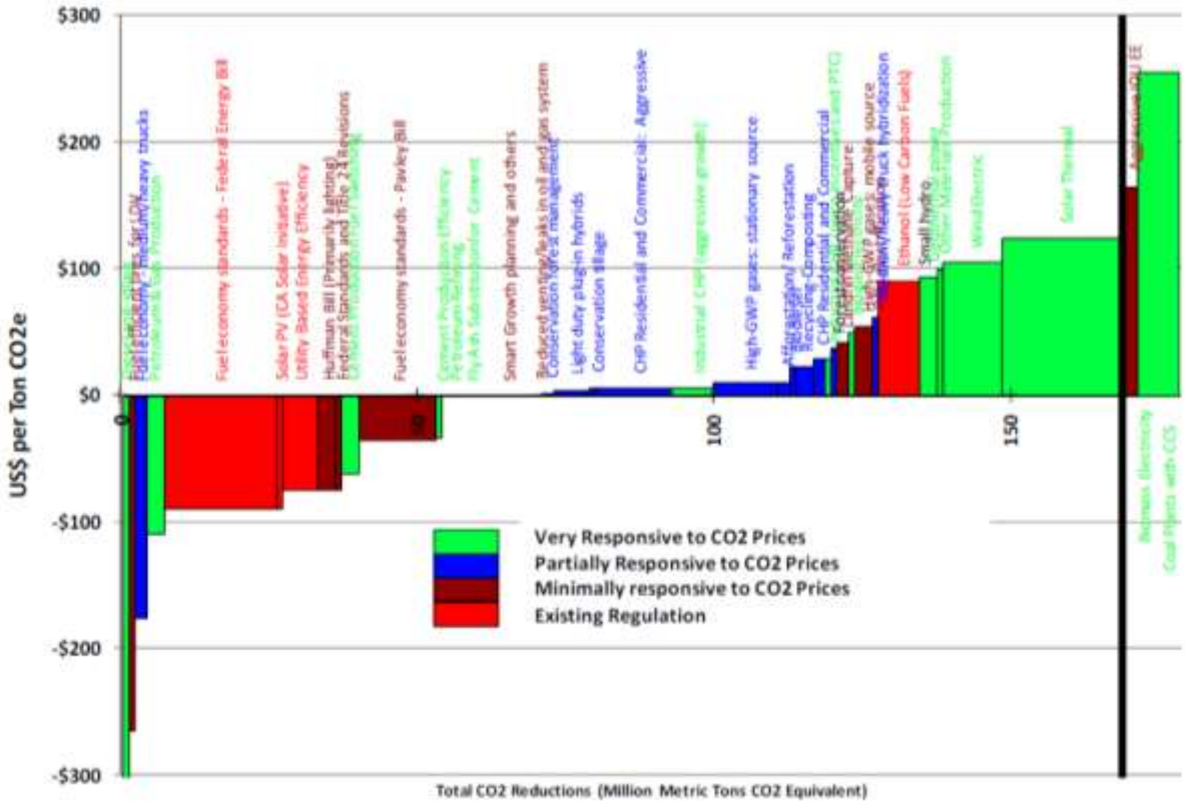

Figure 8. Price responsiveness varies across different options for emission reductions (Source: [Jim Sweeney at al., 2008](#))

The preceding discussion focuses on the selection of policies, but takes for granted key steps to actually constructing a sound package of policies. The first task is setting an emission reduction target, guided by science and taking into account the relevant jurisdictions' stage of development (i.e. advanced economy, middle income, or developing country).

Second, an analysis of the technological, economic, and co-benefits of mitigation options is necessary though integrating all these aspects and endogenously representing interactions of policy impacts has been a challenge for climate policy modelers. Energy Innovation's [Energy Policy Simulator](#) provides an innovative, free, open-source quantitative tool for doing this. It has not yet been customized for use in California, though it is readily available for this use.

6. THE EVIDENCE FROM CALIFORNIA'S EXPERIENCE

THE TIMELINE OF CALIFORNIA POLICIES

During the energy crises of the 1970s, California embarked on an energy policy journey to reduce economic vulnerability and environmental destruction. It has been a bumpy road at times, with some missteps, but the state launched an energy efficiency revolution that has resounded across the world—as the refrigerator example above hints.

California led the world in cutting conventional and greenhouse gas pollution from cars, and spurred the hybrid and electric car technologies on the road today. The state dramatically accelerated energy-efficient home technologies, and started the move to drive down the price of renewable energy.

But California has made mistakes too. In its eagerness to promote independent (non-utility) power, it vastly overpaid for new generators under the "Standard Offer Four" contracts in the 1990s. A later move to deregulate utilities resulted in gaming by such independent power producers, most notably Enron, and blackouts ensued.

And in some realms, the jury is still out. Auto manufacturers rail against the Zero Emission Vehicle (ZEV) program, but the standards have spurred a huge amount of innovation. The trend in ZEV purchases shows promising exponential growth, but this will need to accelerate further to meet the state's targets.

The most interesting case study, perhaps, is the statewide carbon cap, authorized by AB 32 in 2006. California's AB 32 is the umbrella law setting the state's overall trajectory and limits on statewide emissions. It requires the California Air Resources Board (CARB) to put in place policies reduce statewide emissions to no greater than their 1990 level—431 MMT of CO_2e (carbon dioxide equivalent)—by 2020, and to continue reductions thereafter.

In 2008, CARB finalized its first Scoping Plan, which provides the coordinating framework for the suite of polices needed to achieve the 2020 target. The Scoping Plan also included an innovative cap-and-trade program with the broadest economic coverage of any such emission trading program.[11]

So far, California's policy has performed as well as, or better than, expected. Sector-specific performance standards are driving down carbon and inspiring innovation, and the cap-and-trade

[11] The statewide limit of 431 MMT of CO_2e must be distinguished from the cap established by the cap-and-trade program, which only covers CO_2 emissions from energy combustion. The statewide limit covers a larger set of pollutants, including methane emissions, and extends to non-energy processes, such as land use change and forestry.

program is in place to sweep up low-cost reductions left behind—a great symbiosis between the two approaches.

Within Governor Brown's fourth term, 2030 emissions goals have come into focus as a policy target, recognizing the rapid approach of 2020 and the need to set an interim target between then and 2050. In April 2015, the Governor signed an executive order to put in place a 2030 target to reduce economy-wide emissions 40 percent below their 1990 levels, part of a suite of "pillar initiatives" announced in his January 2015 inaugural address, which set high-level performance targets that will be crucial to achieving the overall 2030 emissions target.

Vehicles and Fuels

From that recent history, we step back to the origins of the state's efforts to reduce air pollutant emissions. California's leadership in pollution mitigation is decades old and was born of necessity. By the 1950s, Southern California's air pollution was reaching crisis proportions. The state put in place the nation's first motor vehicle emission standards in 1966, producing bolt-on pollution control technologies, such as air pumps improving combustion efficiency. In 1970, CARB required auto manufacturers to meet the first standards controlling smog-forming hydrocarbon and NO_X emissions, thus beginning California's drive toward perfecting modern performance standards.

Los Angeles in 1955 (Source: Los Angeles Times)

The federal Clean Air Act of 1970 gave California special authority to enact stricter air pollution standards for motor vehicles than the federal government. This authority was used to set performance standards, which incremented steadily over the years, which ultimately cut conventional pollution from cars by 99 percent and trucks by 96 percent, and it has been an unmitigated success.

In 2002, AB 1493, a bill setting tailpipe CO_2 emission standards for light-duty vehicles, was California's first attempt to use this special Clean Air Act authority for greenhouse gases. In cooperation with CARB, the Obama administration later coordinated federal rulemaking around vehicle fuel economy standards to effectively align these with the trajectory California set under AB 1493.

CARB was an early leader in policies supporting the emergence of ZEVs. In 1990, CARB approved the first ZEV rules, requiring ZEVs comprise at least 10 percent of 2003 model year cars offered for sale in California. The program has gone through modifications over time to allow for crediting of advanced cars that may not quite rise to the zero-emission threshold, such as plug-in hybrids.

Today, California is the second largest market for electric vehicles in the world, after China, with 200,000 plug-in electric vehicles on its roads. By 2025, CARB expects zero-emission or plug-in hybrid vehicles will account for one in seven new cars sold in California (15.4 percent) and more than 1.4 million zero-emission and plug-in hybrid vehicles on the road, due to the program. Nine other states have followed California's leadership to put in place ZEV requirements today.

CARB broke new ground in 2007 with the Low Carbon Fuel Standard (LCFS) executive order signed by Governor Schwarzenegger, later adopted under AB 32 authority as an early action item. This performance standard requires average carbon intensity of fuels sold in California fall to 10 percent below the 2010 level by 2020, providing a direct mechanism to reward companies supplying low-carbon fuels in California. Companies producing fuel with carbon content below the standard generate credits they can sell to other fuel providers. Any traditional fuel provider who reduces the lifecycle emissions of their product to at least the level of the standard would not be required to acquire LCFS credits.

So, as long as a fuel supplier makes steady progress in decarbonizing the fuels they sell, they need not incur any financial obligation. But companies not achieving the required progress on decarbonizing fuels can comply by acquiring LCFS credits from other companies selling low-carbon fuels. California has put in place a price cap on the policy, meaning if LCFS credits rise to a pre-determined price, they will be injected into the marketplace in order to ensure the price rises no further.

The LCFS is the state's most direct policy aimed at building low-carbon transportation fuels: It is working well so far, putting pressure on a hundred-year-old practice of single-source fuels. The dominance of biofuel blends in the transportation market lets the financial incentive be felt strongly by fuel producers, but not as much by consumers since, in most blends, the petroleum fraction effectively subsidizes the lower-carbon biofuel fraction. Since the LCFS program began in 2011, and through the end of 2015, it has helped drive down emissions from fuels by about 16.6 million metric tons of CO_2. The increased supply of clean fuels has displaced about 6.6 billion gallons of gasoline and diesel fuels.

EVALUATION

California's experience so far has implications for policy design and how to best accomplish three goals for climate policy: effectiveness, efficiency, and equity.

Effectiveness

A well-designed cap-and-trade program has the potential to effectively drive down emissions. It has certainly done so, for example, in the case of sulfur dioxide emissions nationally, helping to solve the problem of acid rain.

In this section, we focus on the question of which policies should receive credit for the emission reductions California has achieved to date—and their related economic impacts.

Evidence suggests performance standards are primarily responsible for California's reduction in GHG emissions, namely for the following reasons:

1. The cap-and-trade program has only attempted limited stringency to date.
2. Performance standards have surely been binding, and steadily ratcheting up over years and, in some cases, decades.
3. Analysis by CARB and LBNL has concluded this.

The state's cap-and-trade program is just getting off the ground, having launched in 2013. It has drawn global attention and has generally been performing well, with high compliance rates and no indications of excess burdens. For most of the program's history, carbon prices have been at or near the price floor (the minimum level at which bids will be accepted) that was established for auctioning the tradable allowances serving as permits to pollute under the program.

In California's most recent auction (May 2016), for the first time, most of the permits made available went unsold. Demand fell short of the supply of permits at the floor price (the minimum price at which CARB would allow them to be sold, currently $12.73 per ton of CO_2). More results over time will better reveal the true balance of supply vis-à-vis demand, but our preliminary results suggest there are two principle causes:

1. On the demand side, there is uncertainty about what the program will demand of regulated entities in the future. In part, this was due to a procedural decision in a pending case relevant for the program through 2020, but also recognition of the need to put in place program design certainty through 2030. Together, these effects combined to put downward pressure on demand.

2. On the supply side, emissions are below the cap. Both performance standards and the cap-and-trade program, but especially performance standards, have driven emissions down, leaving them below the level of the cap in the cap-and-trade program.

It is worth pointing out that CARB has an automatic cap tightening mechanism. When demand is below the level of supply at the floor price, some allowances are held back from the market and they are not released until the settlement price at auction rises above the floor price for two auctions in a row. This effectively creates an automatic mechanism for lowering the cap if reductions are occurring faster and more easily than had been expected.

The cap, floor price, and credit reserve mechanism were designed with the understanding that predicting market behavior was impossible, so the cap-and-trade system had to be flexible enough to adapt to a wide range of possible future conditions. The market is responding as it was designed to under current conditions, and is robust enough to self-correct if there is a countervailing swing in permit prices in the future.

It would be a mistake to judge the efficacy of the program by the amount of revenue raised at one or even a few auctions. After all, the program is designed to limit emissions, not raise revenue. The cap-and-trade program provides a helpful multi-sector price incentive. It casts a wide net to sweep up the last increment of reductions after performance standards have done their work. And it serves as a quantitative backstop to ensure overall emissions in California continue to decrease.

The recent slackening in demand and the appearance that companies covered under cap-and-trade have been able to bank allowances speaks to the effectiveness of the state's longstanding performance standards. Performance standards for renewable electricity, energy efficiency, and advanced vehicles—not the cap-and-trade program—have been the dominant force in changing the trajectory of California's emissions from increasing to decreasing. The clearest evidence of this is in the electricity sector, where the state's RPS has driven strong progress. The state's utilities deliver a mix of about 25 percent renewable electricity, and are expected to easily accomplish the statutory requirement for 33 percent renewables by 2020, and 50 percent by 2030. The growth of rooftop solar in the state has been mainly driven by net energy metering, which provides favorable terms for solar system owners to sell their excess power back to the grid. The success of net energy metering shows that narrowly tailored price signals of sufficient magnitude can be effective drivers of consumer choices in some instances.[12]

CARB's analysis as part of the 2008 Scoping Plan estimated about 80 percent of overall emissions reductions would be due to performance standards. More recent work by Jeffrey Greenblatt at

[12] The German experience with feed-in tariffs for rooftop solar provides another example of effective, tailored price signals.

Lawrence Berkeley National Laboratory has found that performance standards in the 2008 Scoping Plan and in more recent steps, such as SB 350, are by themselves sufficient to put the state on the path to achieving its 2020 goal. Greenblatt's work also concludes performance standards would enable the state to get most of the way toward the Governor's ambitious 2030 goal.

Unfortunately, backward-looking policy impact analysis is difficult, especially with multiple overlapping policy instruments. The challenge for ex-post impact studies involves figuring out what would have happened if the policy had not been implemented, while an ideal research approach involves randomized control trials. But in practice, there are no control groups for economy-wide low-carbon transformation efforts, making it nearly impossible to draw direct lines between climate policies and impacts in such cases.

More work should be done to exploit empirical data to understand what is working, but for now the best analytical approach includes a combination of common sense, observable correlations, and studies attempting to identify the impacts of single policies. In terms of environmental performance, there is a strong case performance standards are principally responsible for emission reductions that have been achieved.

Economic impacts and implications for efficient policy

It is also difficult to parse the macroeconomic impacts of the state's low-carbon policies and the implications for efficient policy design. No one has attempted a rigorous backward-looking econometric analysis of AB 32 thus far.

Broader economic factors—the national recession, housing crisis, and government cutbacks—have probably been the largest drivers of California's macroeconomic performance, making it difficult if not impossible to separate the signal from the noise.

But this much is clear: The particularly strong performance of the economy in recent years certainly fails to provide any evidence California's climate policies are dragging down growth. Global investment in clean technologies continues to surge, and state policies have helped spur the emergence of companies well-positioned to compete, as was evident in the economic survey in the introduction of this paper. The evidence suggests California's climate policy is affordable. If there are net economic costs, they are small compared to the overall size of the economy, and there may well be net economic benefits.

We can also look to the prospective modeling work (i.e. ex-ante analysis) that has been done to glean some insights into economic impacts, although these studies have typically suffered from their own limitations. Computable General Equilibrium (CGE) models, which regulatory agencies, including CARB, have used as the conventional analytical tool, are not structured to represent market failures. However, the economic analysis unit at CARB and UC Berkeley Professor David Roland-Holst found a creative way around this limitation. Where strong engineering studies of the expected technology outcomes and related benefits and costs exist, they are used directly as inputs to the economic analysis. Such an approach overcomes the inherent bias against government action that exists in Computable General Equilibrium models. Symmetrically, absent such an approach, there is no way for a CGE model to show a benefit from a policy. The idea that government action will never produce any positive effect is not credible.

We review two sets of prospective modeling results, both of which find the most efficient policy approach includes both carbon pricing and performance standards.

1. In 2010, CARB carried out a collaborative modeling exercise to explore how to strike the optimal balance between performance standards and carbon pricing in the AB 32 Scoping Plan laying out the path to 2020. In addition to David Roland-Holst, CARB worked with Charles River Associates (CRA), a consulting group commissioned by California industry groups.
2. In 2015, with updated data and policy inputs, Roland-Holst (2015) finds the same result in a study looking at the optimal policy for accomplishing the 2030 target.

In CARB's 2010 collaborative modeling exercise, the idea was to seek maximum alignment regarding inputs and assumptions in the modeling work. All three sets of models had been previously used to analyze California's 2020 climate policy choices. By harmonizing inputs, the work would provide new insights into the drivers of different results. The exercise tested the Scoping Plan package of policies as well as other scenarios representing either alternative program design (more or less reliance on performance standards) or sensitivity analysis around program design (including or excluding compliance offsets under cap-and-trade) or policy performance (testing what would happen if complementary policies turned out to be more expensive than expected).

Both CARB and Roland-Holst's analysis find that the best economic results follow from the Scoping Plan's proposed package of policies that is heavy on performance standards with carbon pricing as an overlay. CRA was unwilling to include policies that provide present value energy savings that exceed upfront costs (i.e. negative cost measures, indicative of market failures). As a result, their best performing package is the one that uses carbon pricing alone. The upshot is these models are parroting back the underlying assumptions, which reflect world views about whether market failures other than the carbon pricing externality are negligible or not (Busch 2010). CRA's modeling approach and results reflect a view that government intervention cannot possibly produce economic benefits.

More recent work by Roland-Holst (2015) recognizes the increasingly widespread understanding of the opportunities presented by electrification of the transportation sector. The best economic performing package in his work requires robust performance standards. These economic benefits include greater certainty and higher job growth compared to the next best scenario.[13] "If Californians actually do transition to a pure electric light-vehicle fleet, the aggregate efficiency gains are virtually certain to outweigh AB32 compliance costs… Another immediate implication of the uncertainty in the cap-and-trade scenarios is that we need complementary policies, especially to move behavior (like Battery Electric Vehicle adoption) in directions that make net growth more likely. (Roland-Holst, 2015, p. 18)."

Indeed, one of Roland-Holst's central findings is performance standards (he calls them complementary policies, as they are often called in the AB 32 context) are crucial to getting the best economic result: "Recognizing sector needs for flexibility, adjustment costs for this economic transition can be substantially reduced by implementing policies that are complementary to Cap and Trade. With complementary policies, average long-term industry compliance costs appear to be quite low."

Roland-Holst provides a realistic view on market failures from within the economic profession:

> "In reality, of course, market imperfections in the climate change context are so numerous that nearly every AB32 supporter can point out a different favorite. Of course the most important one is the global carbon externality, an inconvenient disconnect between the private benefit of energy use and the public cost of the greatest environmental risk in human history. If this isn't enough to justify intervention in today's energy systems, we can also acknowledge universal subsidies to conventional modes transport, as well as oligopolies and/or monopolies in vehicle, conventional fuel, and electric power sectors. Fortunately, California hasn't been listening to the efficient markets argument for a long time. Indeed, so called command and control policies have been a hallmark of the state's environmental leadership, and the economic benefits have been many." (Roland-Holst 2015, pp. 41-42)

Technologically-detailed studies of vehicle electrification show the promise of net benefits as part of the larger shift toward greater electrification. Roland-Holst knows a Computable General Equilibrium, the standard economic model used for climate policy analysis, cannot accurately represent the complex engineering optimization dynamics that must be recognized in charting our low-carbon future.

Equity

Environmental pollution in California disproportionately burdens low-income households and communities of color. This inequitable distribution of the economy's environmental impacts,

[13] In 2030, +60,000 jobs and in 2050, +148,000 jobs. Jobs are defined as full time, permanent jobs.

and the effectiveness of local groups in drawing attention to this, have led state leaders to take an active approach to ensuring positive equity effects.

Under SB 535, the state is required to prioritize investments from the Greenhouse Gas Reduction Fund (GGRF) for projects that provide benefits for disadvantaged communities, defined as those suffering dual challenges of high pollution levels and socio-economic burdens. The law requires a minimum of 25 percent of revenue deposited in the GGRF to be allocated to projects that provide benefits to disadvantaged communities, and a minimum of 10 percent to be allocated to projects located within and providing benefits to disadvantaged communities. The state is far exceeding these minimum goals, as is shown in Figure 9.

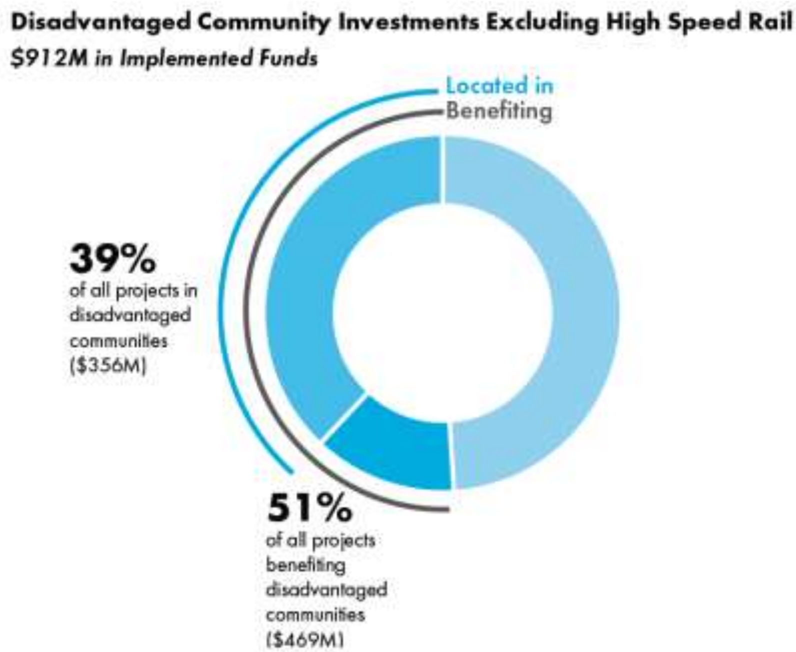

Figure 9. Investments from Greenhouse Gas Reduction Fund are Exceeding SB 535 Requirements (Source: CARB)[14]

Thirty-nine percent of revenue collected in the Greenhouse Gas Reduction Fund has been spent on projects located in disadvantaged communities, and 51 percent of revenue has gone to projects providing benefits to disadvantaged communities. In some cases, disadvantaged communities may benefit from nearby projects that are not technically within the bounds of the community. That is why the total benefits to disadvantaged communities are larger than those directly from projects within them.

[14] This figure highlights funds ($917 million) that have been implemented (i.e. released) as of the end of 2015. By the end of 2015, $1.7 billion had been awarded to specific projects and $2.6 billion had been appropriated. The Governor's proposed 2016-2017 budget appropriates an additional $3.1 billion.

Three types of Greenhouse Gas Reduction Fund projects are creating these benefits:

1. **Low-carbon transportation.** Transportation costs are the second largest part of the average family's budget expenditures, due to the relatively high costs associated with purchasing, operating, and maintaining a car. Transportation is also the largest source of air pollution in the state. This creates valuable opportunities for investments that combine carbon mitigation and equity enhancement. Below are three examples of such transportation investments:
   - Improving public transit service—as is happening under Caltrans' Low Carbon Transit Operations Program, which is supporting new and expanded services and facilities—improves mobility among disadvantaged communities and low-income residents. Compared to car ownership, public transit is a more affordable option and can lower air emissions.
   - In the same vein, projects that increase the supply of affordable housing near transit lead to greater transit use, providing economic benefits for low-income households as well as air quality benefits. An example is the Anchor Place project in Long Beach.
   - An emerging type project will establish electric vehicle car-sharing programs in disadvantaged communities and will ensure they are priced to be accessible. This provides both local air quality benefits and enhanced mobility benefits for lower income communities, where people may not be able to afford the current higher upfront cost of electric vehicles.
2. **Energy.** Support for energy efficiency upgrades help reduce utility bills, which can be particularly valuable for low-income households. The state is also engaged in path-breaking efforts enabling low-income households in disadvantaged communities to host solar panels on their roofs, which also have the effect of lowering utility bills. Examples of these efforts are as follows:
   - The state's Low-Income Weatherization Program helps reduce energy use and energy costs.
   - A new program, run by Grid Alternatives, provides rooftop solar power to households in disadvantaged communities at no cost. Though the solar upgrade is free, participating households must contribute at least something to the project, such as sweat equity or offering meals to the solar installation team.
   - The Single Family Affordable Homes program also offers incentives for low-income households to help cover the costs of going solar. These efforts are funded by electricity ratepayers and administered by the Public Utilities Commission—the only example here that is not funded under the Greenhouse Gas Reduction Fund.

3. **Natural resources.** The state's urban forestry program is planting trees in disadvantaged communities throughout the state, providing community shading and reducing energy demand while improving active transportation and recreational opportunities for these residents.

Solutions to inequality and poverty will be mainly driven by economic, labor, and education policy. Nonetheless, California policymakers are working to ensure climate policy contributes to the emergence of a more equitable economy. California's "climate dividend," which every household[15] receives biannually through their utility bills, is one step that will clearly offer progressive income effects. Additionally, though not accounted for in the benefits to disadvantaged communities, CARB expects investments in the state's high speed rail system to produce jobs and economic benefits in areas that have struggled economically. Initial development of the system is focusing on the Central Valley, where unemployment is more than double the state average.

Looking forward, there is every reason to believe the positive impacts on economic fairness will only continue to grow as the state's climate policies mature. A Consumers' Union analysis finds the net effect of California's transportation policies will save the average household over $1,200 per year in 2030. A study by the UCLA Luskin Center for Innovation, which specifically analyzes the impact of the state's cap-and-trade program on low-income households finds they will be better off, saving hundreds of dollars on energy costs by 2020.

A concluding observation is that the places where pollution is disproportionately concentrated are also the places that will see disproportionate benefits from its clean-up. So, there is an aspect of improved environmental justice inherent in California's transition to clean energy. Global warming itself will have disproportionate impacts on the most vulnerable people. Reducing the damages that would follow from runaway climate change offers the largest benefits from disadvantaged people.

7. WRAPPING IT UP

Governor Brown made the right decision in proposing the 2030 statewide emissions target of 40 percent below 1990 levels. This goal is ambitious and will provide a foundation for truly sustainable economic growth. Now California must get the policy design details right to continue to provide a working model of successful decarbonization. Many of the state's key initiatives have been operating for years or decades, providing policymakers feedback on what works.

Performance standards have proven to be effective at spreading the deployment of more energy-efficient technologies and at increasing the availability of renewable electricity. While

[15] In an Investor Owned Utility electricity distribution company's service territory.

performance standards deserve principal credit for the state's success thus far, downplaying the cap-and-trade program's importance in the 2030 package of policies would be a mistake. It has a valuable role to play as part of the overall portfolio of policies, especially as the required pace of emission reductions ramps up. The sum of the evidence indicates California's current approach—which includes performance standards as the core of climate policy, with supplemental support from a broad carbon price signal—is the best one. California policymakers should double down on what is working.

APPENDIX. EVIDENCE ON LEARNING-BY-DOING FROM DEPLOYMENT

Figure 6 synthesizes the data from five more detailed graphs developed by the U.S. Department of Energy. These graphs, which show deployment in addition to price gains, better illustrate the learning dynamic of how deployment helps drive down costs.

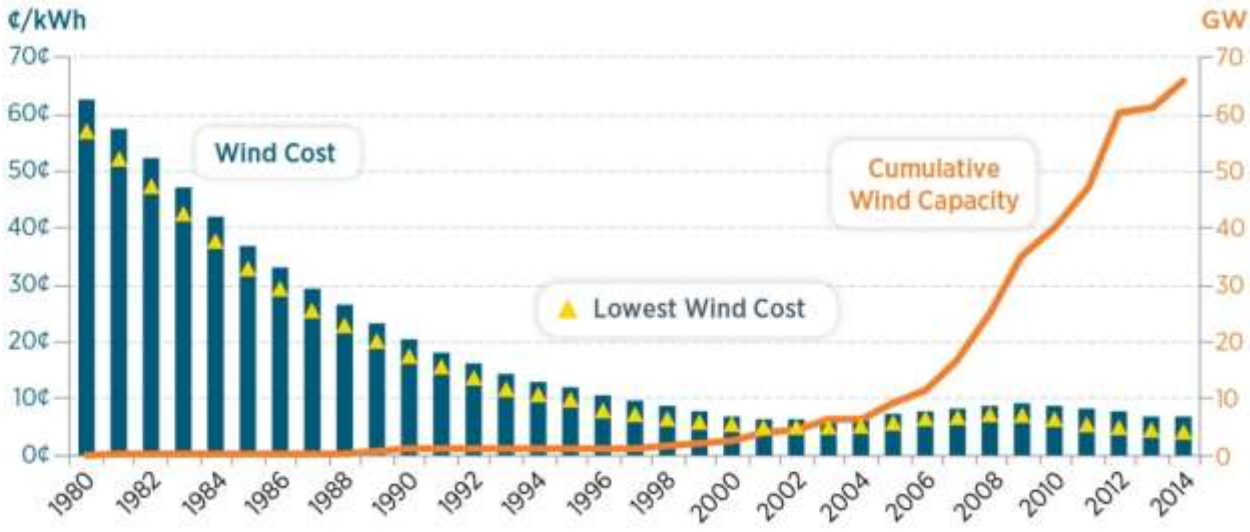

Figure A-1. Onshore wind capacity and cost

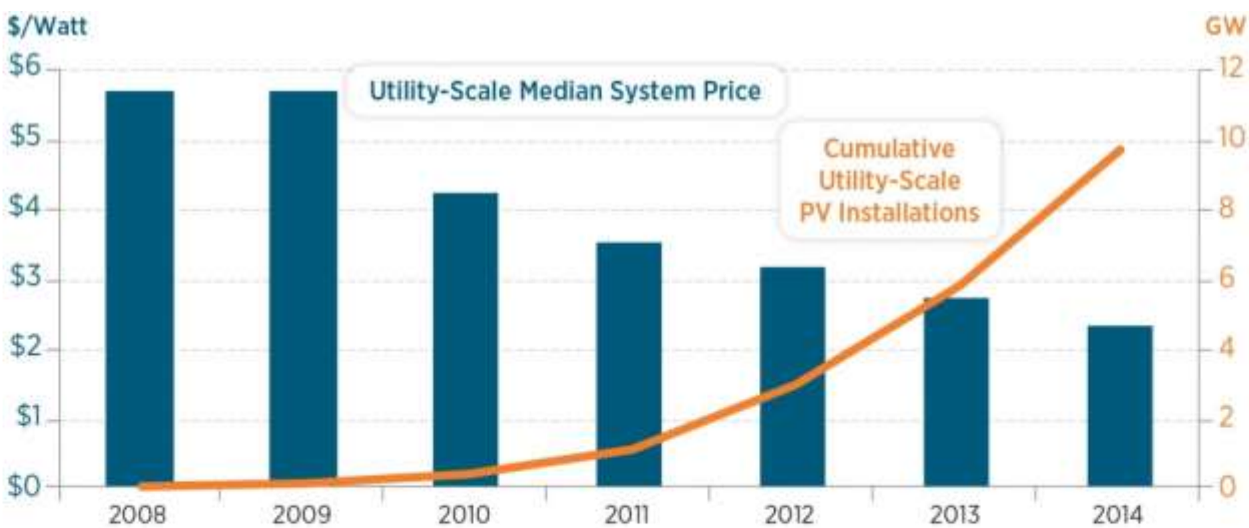

Figure A-2. Utility-scale solar capacity and cost

Figure A-3. Distributed solar capacity and cost

Figure A-4. LED lighting capacity and cost

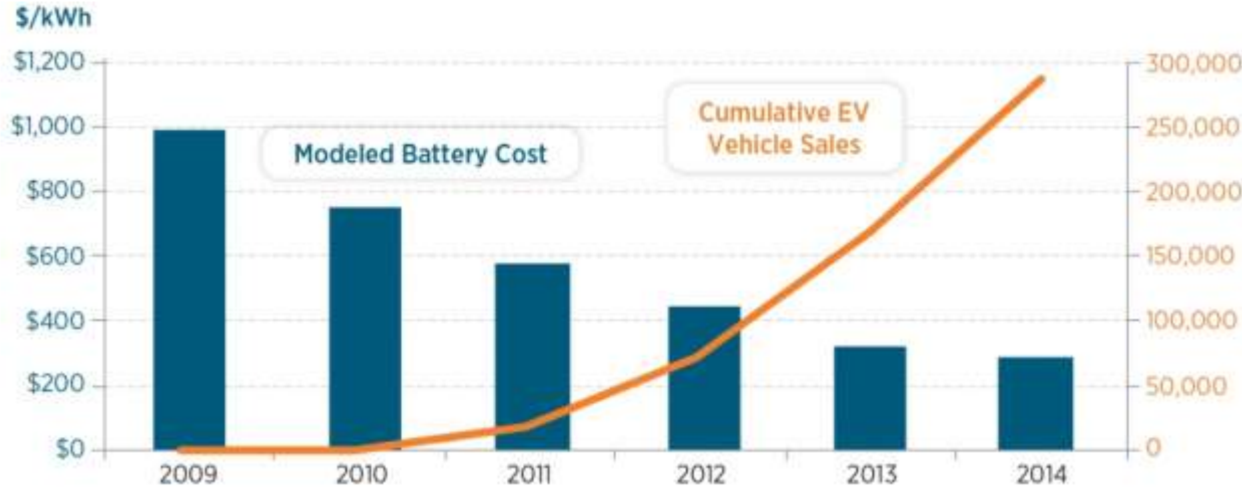

Figure A-5. Vehicle battery cost and electric vehicle sales

Next we present some other work on battery costs that include some forward cost projections.

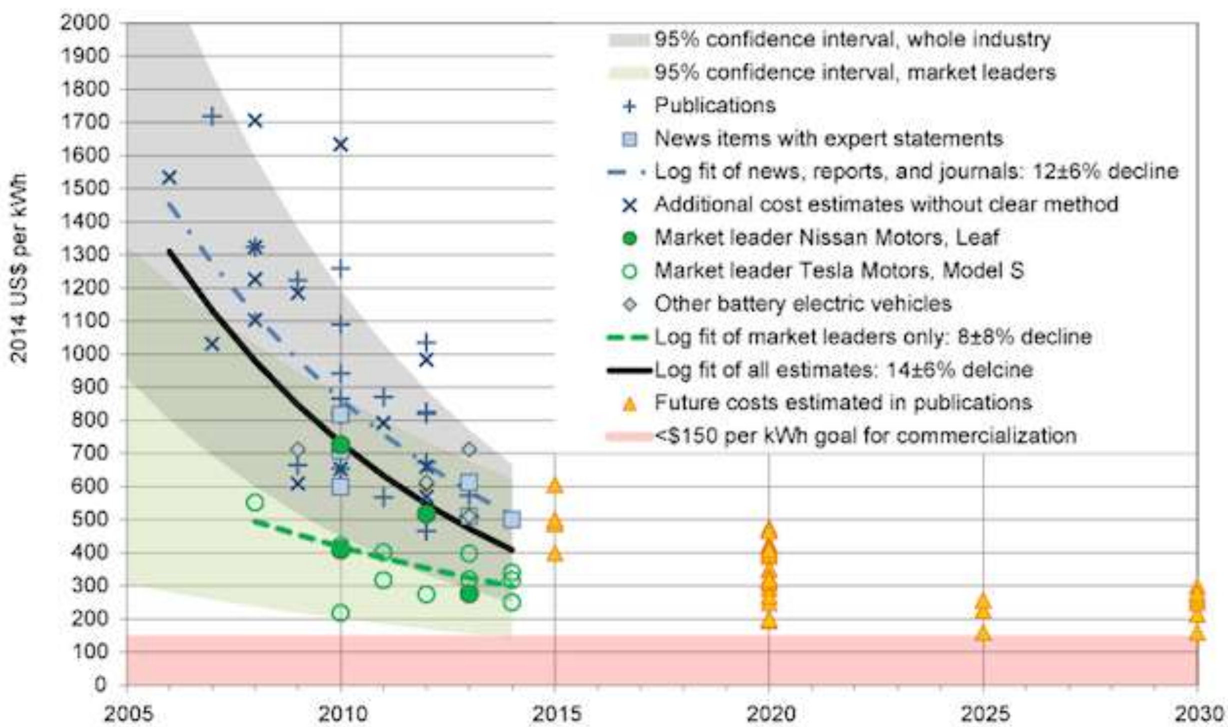

Figure A-6. Cost estimates of lithium-ion batteries for use in electric vehicles

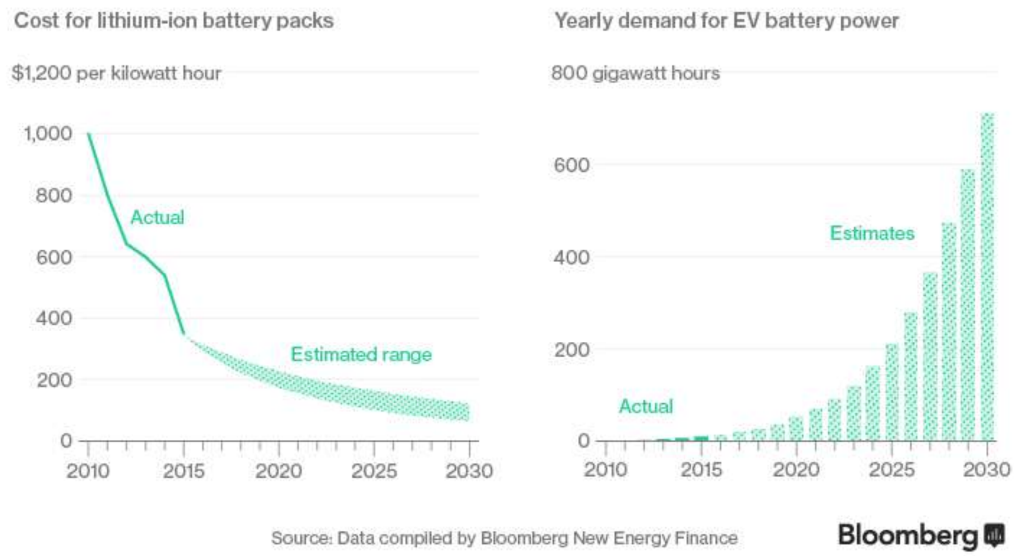

Figure A-7. Bloomberg New Energy Finance estimates on battery costs and electric vehicle sales (Source: BNEF)