

CALIFORNIA CLIMATE POLICY TO 2050

Pathways for Sustained Prosperity

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Research Papers on Energy, Resources, and Environmental Economics

This report contributes to the basis of evidence on alternative climate policy pathways for the California economy. In addition to presenting original research findings, it is intended to support policy dialogue and public awareness about environment-economy linkages and sustainable growth. All opinions expressed here are those of the authors and should not be attributed to their affiliated institutions.

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ABSTRACT

It is becoming apparent to many that California can achieve its climate policy milestone at the end of this decade, reducing GHG emissions to levels not seen in two and a half decades. The fact that we have also more than doubled the size of the state economy during the same period sets the Golden State apart as a new global example for sustainable prosperity. Having said this, optimism for 2020 is somewhat tempered by uncertainties regarding the next phase of climate action, which calls for GHG emissions to fall 80% from their 1990 levels by 2050. The first phase of AB32 compliance was, frankly speaking, easier than many imagined, but looking ahead, we must acknowledge that even greater determination and creativity will be needed to reach the 2050 milestone. This report elucidates some of the challenges and opportunities ahead, with special reference to the goals of economic growth and environmental quality. The main message of our analysis is that these goals can be reconciled; indeed we show that climate action can be a potent catalyst for innovation and growth of the California economy.

Our study uses a long-term dynamic forecasting model, combined with the latest technology and economic data, to evaluate alternative policy mixes from now to 2050. Updating earlier contributions made to the original Scoping Plan, we explicitly model existing California climate policies, as well as some alternatives under active discussion such as intermediate GHG targets for 2030. Our results reveal how policies can be combined to account for diverse institutions and behavior, and how these can be complementary and improve policy effectiveness. We also show the importance of recognizing uncertainty and creating mechanisms to accommodate this during a long and pervasive structural adjustment process. As most experts already acknowledge, a truly low carbon economy will be very different from today's California economy. Our analysis reveals that this future pathway will not only be more environmentally sustainable, but also more prosperous.

EXECUTIVE SUMMARY

California's commitment to reduce Greenhouse Gas (GHG) emissions has made the world's seventh largest economy a leader in global climate policy. The first major milestone for its path breaking Global Warming Solutions Act (AB32) will come at the end of this decade, when the state is targeting emission levels not seen in thirty years. Given that California's 2020 real gross state product (GSP) is also expected to be more than double its 1990 counterpart, this will be a great achievement in delivering prosperity while reducing environmental risks. Looking further ahead, California's long-term climate goals will require that the rate of GHG reduction be significantly accelerated. Emissions from 2020 to 2050 will have to decline at more than twice the rate needed today to reach the 2050 statewide emissions limit.

Table ES 1: Main Findings

1. California can meet its 2050 climate goals in ways that achieve higher growth and employment, including GSP growth of over \$300 billion and about a million additional jobs.
2. To do this will require a fundamental restructuring of the state's energy system, including electrification of the vehicle fleet.
3. 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.
4. With complementary policies, average long term industry compliance costs appear to be quite low.

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To support a robust and informed examination of these ambitious policies, this report assesses the economic implications of alternative pathways to the 2050 targets, including compatible intermediate (2030) milestones. While substantive mitigation policy must entail some direct and indirect costs, the benefits from greater energy efficiency and improved environmental conditions can significantly outweigh these. The goal of this report is to strengthen the basis of evidence in this area, identifying policy alternatives and estimating their attendant costs and benefits.

Economic Assessment of Climate Action

This study uses a long-term dynamic forecasting model, combined with the latest economic and technology data, to evaluate alternative policy mixes from now to 2050. Updating earlier contributions made to the original Scoping Plan, we explicitly model existing California climate policies, as well as some alternatives being discussed for intermediate GHG targets and pathways. Our results reveal how policies can be combined to account for diverse institutions and behavior, and how these can be complementary and improve policy effectiveness. We also show the importance of recognizing uncertainty and creating mechanisms to accommodate this during a long and pervasive structural adjustment process. As most experts already acknowledge, a truly low carbon economy will be very different from today's California. Our analysis indicates that this future can be not only more environmentally sustainable, but also more prosperous.

As part of their advanced Scoping Plan and implementation activities, CARB and CalEPA organized a comparison project featuring the leading economic assessment tools applied to AB32 since its passage in 2006. Included among these was the same Berkeley Energy and Resources (BEAR) model used in the

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present study. Eight years ago, BEAR predicted that the state's unprecedented Cap and Trade program would not only be feasible, but affordable in terms of its market-based mitigation costs. In particular, BEAR predicted carbon permit prices well below \$20/MTCO_{2e}. Some other studies also predicted carbon permit prices in this range, while some industry-sponsored estimates in some cases exceeded \$100. Today, even after incorporating all transport fuels in the cap, California's carbon prices are in the low teens, a reminder of the importance of independent research to the public interest.

To assess prospects for the next three decades, BEAR has been completely updated and re-calibrated to the latest economic data and policy information. The model itself has been peer reviewed and fully documented elsewhere, and we summarize its main findings below.

Scenarios Evaluated

For purposes of policy comparison, BEAR was used to evaluate a variety of generic scenarios reflecting different degrees of climate action and combinations of instruments (Table ES 2). In addition to reference cases of no action (BAU), a Baseline incorporating existing policies, and an extrapolation of historical efficiency trends, we looked at three policy instruments: An enhanced (50%) Renewable Portfolio Standard, Cap and Trade, and tradable Mitigation Credits (defined below). Finally, we look at a scenario that assumes complete electrification of the state's light duty vehicle fleet by 2050.

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Table ES 2: Policy Scenarios

Name	Description	Post-2020 C&T target	Mitigation credits	Complementary policies
1. BAU	Business as Usual	No	N/A (not applicable if no post-2020 C&T target)	Frozen at current levels
2. Baseline	Existing Complementary Programs	No	N/A	Existing with AB 32 plus others
3. EffTrend	Continued efficiency trends	No	N/A	Adds new EE
4. RPS50	Extend RPS to 50% by 2030	No	N/A	New EE plus 50% RPS
5. Incremental C&T	Cap and Trade - Fixed increments after 2020	Linear trend to 2050	No	New EE plus 50% RPS
6. Progressive C&T	Cap and Trade - Fixed Percent (5.2) from 2020	Accelerated reductions to 2050	No	New EE plus 50% RPS
7. Deferred C&T	Cap and Trade - Delayed response after 2020, but attaining to the 2050 target	Delayed reductions, symmetric with accelerated scenario	No	New EE plus 50% RPS
8. Mitigation Credits	Allowances from outside the system, equal to the difference between the Deferred and Progressive Pathways	Accelerated reductions to 2050 (Progressive plus credits)	Yes	New EE plus 50% RPS
9. EV Adoption	Phase out ICE and PHEV with BEV by 2050.	Accelerated reductions to 2050 (Progressive plus credits)	Yes	Adds transportation electrification to new EE plus 50% RPS

Renewables Deployment

Renewable energy is playing a rapidly growing role in climate policy, and California set an ambitious 33% Renewable Portfolio Standard as part of its

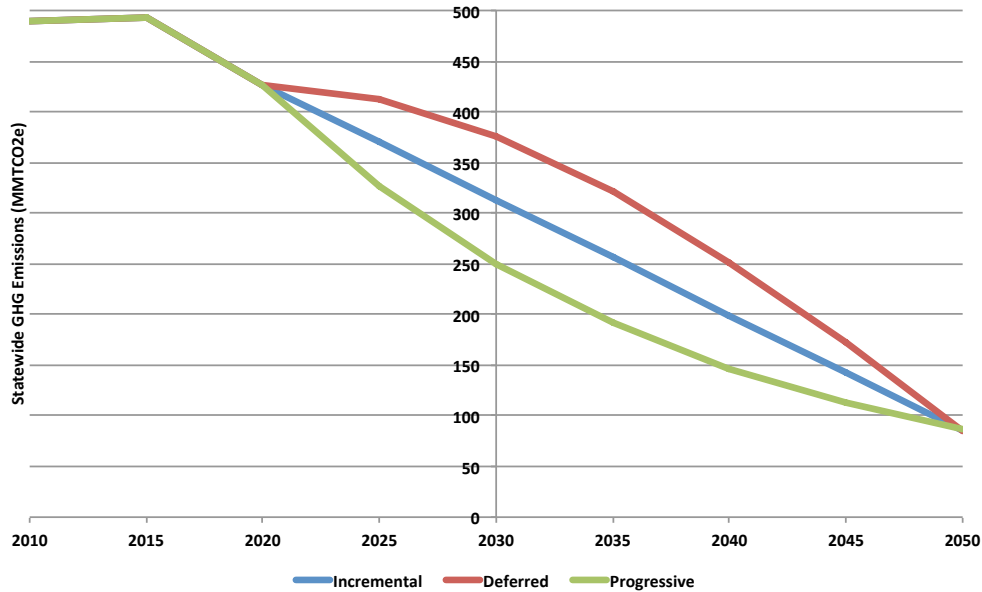
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AB32 initiative. A large part of the renewable energy mix: solar, wind, and geothermal, represents a fundamentally new energy supply paradigm. Because they are exhaustible resources, fossil fuel supplies and prices are determined primarily by scarcity, while these renewables represent essentially boundless resources relative to today's energy requirements. In the latter case the constraint to supply is not scarcity, but technological change. Recent trends in renewable technology show that these costs can fall dramatically with scale and learning. For our 4th and subsequent scenarios, we assume California steps up its RPS to achieve 50% renewable sourcing of electric power by 2030. Our cost assumptions are detailed in the full report.

Cap and Trade Pathways

Although the policy has a brief history, California's Cap and Trade program has been quite successful, providing market based incentives for mitigation and innovation at relatively modest cost across a very diverse economy. Going forward, we assume that the cap will be the primary indicator of the state's mitigation targets, leading us to an 80% GHG reduction from 2020 to 2050. While the destination of 2050 is an ambitious focal point, the pathway getting there is of course more relevant to most decision making. As the following figure suggests, that pathway can also make a big difference to the primary determinant of global warming, the stock of GHG in the atmosphere. If we follow the Progressive rather than the Deferred pathway, California will contribute up to 30% less global warming pollution to the atmosphere. The question we ask is, can this environmental benefit be achieved at reasonable cost? Scenarios 5-7 evaluate a simple linear (Incremental) pathway and compare this to more (Progressive) and less (Deferred) ambitious GHG reduction strategies.

Figure ES -1: Cap and Trade Pathways



Mitigation Credits – An important source of flexibility

Flexibility is one of main attractions of market-based emission reduction mechanisms like Cap and Trade, permitting covered entities a choice between direct spending on permits and investments that would lead to lower emissions. While this encourages more efficient firms to innovate, it is important to recognize that, because of progress already made, the marginal cost of mitigation in California is high by global standards. Given that the global warming impact of a 1MTCO₂e emission reduction is the same regardless of where it is realized, it is reasonable to ask if there are more cost-effective ways for Californians to reduce global GHG stocks.¹ In scenarios 8 and 9, we consider a prominent example of one such policy, allowance for out-of-state mitigation credits against in-state emissions above the cap.

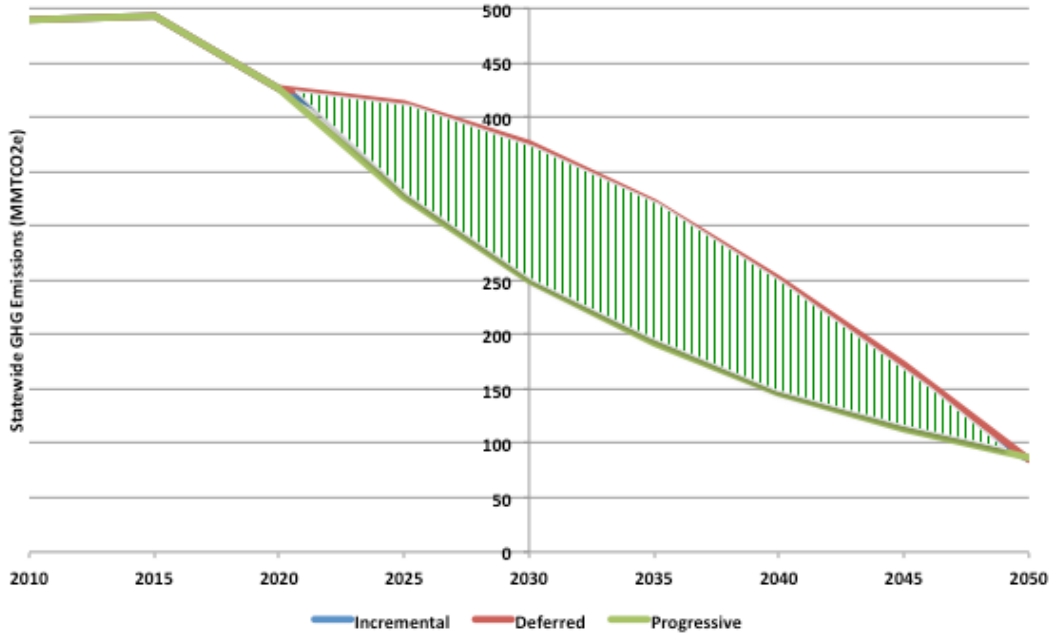
¹ It should be emphasized that we only consider global GHG benefits in this case. Offsets may lead to higher local pollution costs, as well as outsourcing of innovation benefits that might arise from more stringent local emission standards.

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Sometimes referred to as offsets, mitigation credits in these scenarios are assumed to be available at the same price as permits (although they would generally be cheaper). In addition we assume they are verifiable, additional, and tradable on an annualized basis, representing (e.g.) 1MTCO_{2e} of annual reduction in an atmospheric flow (mitigation) or stock (sequestration). Such credits could be made available through a variety of mechanisms, but this is the subject of a separate study. For the moment, we merely assume there exists an international financial market for sovereign mitigation certificates, like the sovereign bond market. These “climate bonds” would trade at prices reflecting the underlying costs of providing mitigation/sequestration services, with appropriate risk discounts that reflect the credibility of the issuer.²

² International instruments like this, if effectively supported by financial markets, could be a substantial improvement over more ad hoc negotiated arrangements like CDM, Debt for Nature, REDD, etc. The latter tend to be plagued by moral hazard and other agency problems. Given cost advantages for lower income countries in both mitigation and sequestration investments, this market could also become a very important source of North-South transfers to support climate adaptation.

Figure ES-2: Mitigation Credit Allowances (shaded area)



For our sample scenarios, we look at allowances of credits equal to the difference between the Progressive and Deferred emission pathways (Figure ES-2). Obviously, an infinite variety of allowance schemes are possible, but the importance of this one is that, while offering flexibility over the transition period, it leads to the same 2050 emission target (flow) and achieves the same global GHG stock reduction as the Progressive pathway. Thus we achieve both the state's ultimate goal and a more ambitious mitigation pathway for overall GHG reductions. As we shall see, we also do this much more cost effectively.

It should also be noted that mitigation credits, by outsourcing emission reductions, might forsake opportunities for in-state innovation. Local pollution is an important issue because of the unequal distribution of many criteria emissions around the state, but these are also being targeted at specific mitigation policies that look to be at least as stringent as overall GHG emission standards. The foregone innovation issue may also be an important drawback for a higher income,

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technology-intensive economy like California. The primary drivers of the Golden State's superior growth over the last two generations have been education and innovation, going hand-in-hand to make the state a knowledge-intensive leader in the global economy. First in information and communication technology (ICT), then in biotech, and now with clean technology, the state's R&D supply chain has delivered solutions for the most dynamic and profitable sectors of modern times. With the benefits of local environmental quality and innovation in mind, perhaps a modest premium on abatement cost could be justified.

Uncertainty

A final issue addressed in this analysis is the role of uncertainty. In the past, most economic assessments are delivered as point estimates, implying somehow that the forecasting profession can offer deterministic guidance. Particularly when looking at dynamics in energy markets and long term adjustment processes, such a perspective is increasingly untenable. For this reason, we implement an explicit Monte Carlo framework, evaluating each of our scenarios repeatedly under varying assumptions about three important data uncertainties: energy prices, technology costs, and price sensitivity of electricity demand. The technical details of this approach are set forth in the full report, but suffice for the present to say that each scenario was evaluated in 1000 replications around a distribution of the three variables just mentioned.

Electric Vehicle Adoption

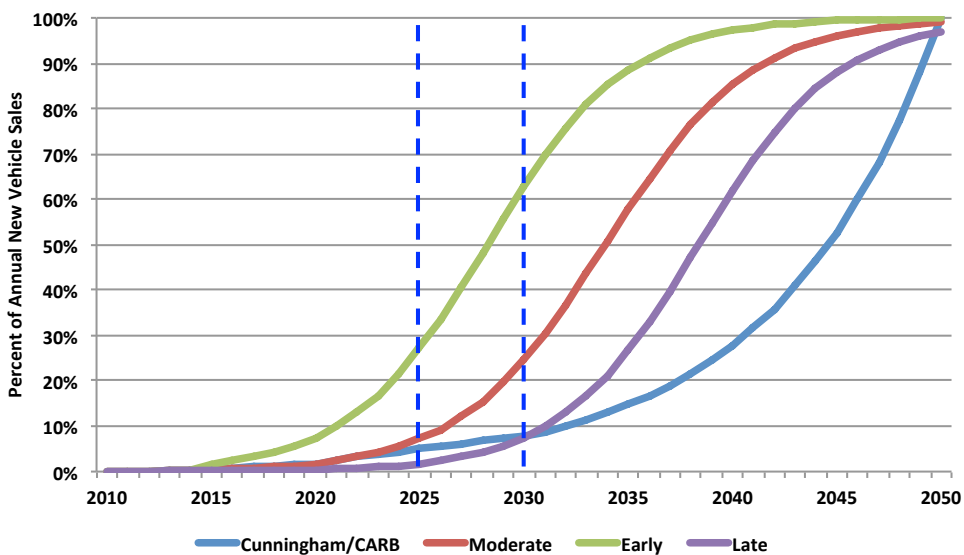
Most informed observers now recognize that California cannot realistically expect to achieve 80% decarbonization without a fundamental transition of its transportation system to electric power. Alternative fuels can be important sources of mitigation in the near term, but they cannot displace enough conventional fuel emissions to get us to 2050 with current population growth

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trends and known technologies for biofuel production and distribution. Hydrogen is an emerging technology that may play an important role, but we do not evaluate it here.

Our last scenario considers one of many possible adoption pathways for 100% light duty vehicle fleet electrification, or Battery Electric Vehicle (BEV) adoption, the Moderate profile in Figure ES-3. This calls for about 7% of new vehicles sales to be EV by 2025, increasing to 25% by 2030 and 100% by 2050. For comparison, we also illustrate a CARB proposal for more gradual early adoption, rapidly accelerating in the final decade.

Figure ES-3: Scenarios for Battery Electric Vehicle Adoption

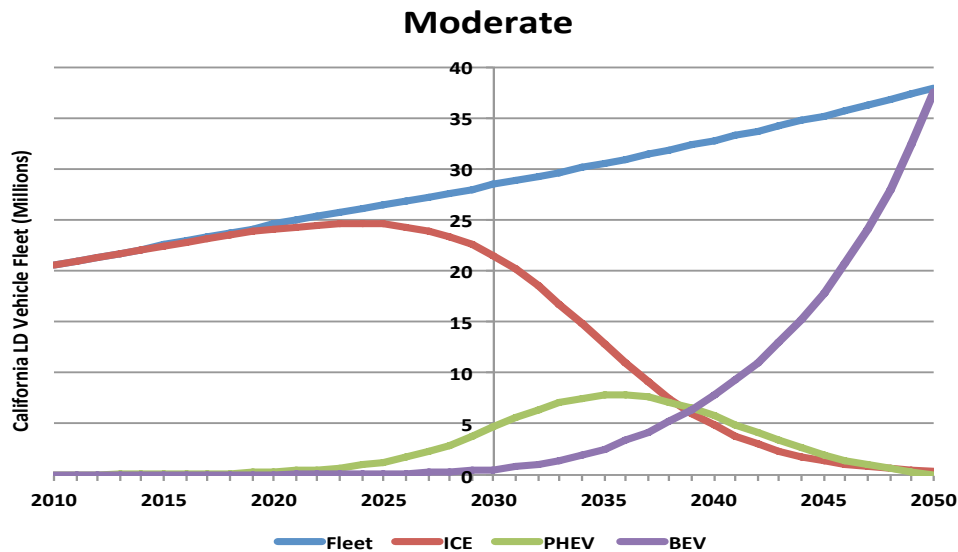


Assuming the Moderate adoption profile for BEVs, along with an assumption of phasing out hybrid vehicles, we obtain the vehicle fleet transition implemented in Scenario 9 and illustrated in Figure ES-4. With respect to current levels of BEV market penetration, this is obviously a very different transportation sector, with far reaching implications for complementary technologies, infrastructure, electric power capacity, etc. All these issues require detailed evaluation to be most

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effectively supported by public policy and, in turn, for leading private stakeholders to effectively support climate policy. The state's ambitious goals have the best chance of success if they are based on this kind of constructive engagement.

Figure ES-5: California Vehicle Fleet – Moderate BEV Adoption Profile



Source: Author estimates. Vehicle classes are Internal Combustion Engine (ICE), Plug-in Hybrid Electric Vehicles (PHEV), and 100% electric or Battery Electric Vehicles (BEV)

Aggregate Economic Impacts

When the BEAR model was applied to the nine scenarios, aggregate economic impacts indicate that the state can achieve its medium and long term climate goals while promoting economic growth. Put differently, the aggregate net economic benefits are positive under all seven climate action scenarios considered. As will be apparent in the discussion below, the primary driver of these growth dividends is multiplier effects from economy wide energy savings. In the medium and long term, these savings outweigh the costs of new

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technology adoption, and those net savings are passed on by households and enterprises to the rest of the state economy, stimulating indirect income and job creation. Because aggregate gains are based on the scope of distributed efficiency measures, the benefits increase with time and with the degree of emission reduction, conferring the largest dividends by 2050.

The role of uncertainty in our results is indicated by the color of the cells for changes in real Gross State Product (GSP). A cell colored green contains a result that, subject to 1000 randomized experimental variations in energy costs and behavioral parameters are positive with probability exceeding 95%. Thus the pure efficiency scenario, which essentially extrapolates the state's past trends of "no regrets" efficiency improvements, is extremely likely to be growth positive. Also, if Californians actually do transition to a pure electric light vehicle fleet, the aggregate efficiency gains are virtually certain to outweigh AB32 compliance costs.

For the middle scenarios, the average economic impact across 1000 replications is positive, but not so strongly that they could not be reversed by large swings in energy policy or behavior. As a practical matter, this uncertainty has important implications. It means, for example, that we need to better understand the non-economic benefits that motivate climate policy, as these might justify zero or even positive net costs for the policies considered. These include, for example, induced innovation and other technological change, climate benefits or reduced damages, co-benefits, and national/international leadership. Another immediate implication of the uncertainty in the C&T scenarios is that we need complementary policies, especially to move behavior (like BEV adoption) in directions that make net growth more likely.

Table ES 3: Macroeconomic Impacts

2030							
	Efftrend	RPS50	Incremental	Deferred	Progressive	Offset	EV Mod
GSP	1%	1%	1%	1%	1%	2%	2%
Consumption	2%	2%	1%	1%	1%	1%	2%
Employment	1%	1%	2%	2%	2%	2%	2%
FTE ('000)	203	244	273	270	275	281	341
CPI	0%	-1%	-1%	-1%	-1%	-1%	-1%
GHG(MMTCO2e)	557	429	394	313	376	250	250

2050							
	Efftrend	RPS50	Incremental	Deferred	Progressive	Credits	EVMod
GSP	2%	2%	3%	3%	3%	4%	6%
Consumption	3%	3%	3%	2%	3%	3%	6%
Employment	2%	2%	3%	3%	3%	3%	4%
FTE ('000)	406	457	738	729	747	767	915
CPI	0%	-1%	-1%	-1%	-1%	-1%	-1%
GHG (MMTCO2e)	644	384	328	85	85	85	85

Notes: All impacts except GHG represent changes from Baseline in the year indicated, in percentage or the units given in parantheses. GSP and Consumption are measured in constant (2010) dollars. Employment chages are measured in Full Time Equivalent (FTE) annual jobs. GHG measures the level of annual emissions for the given year and scenario.

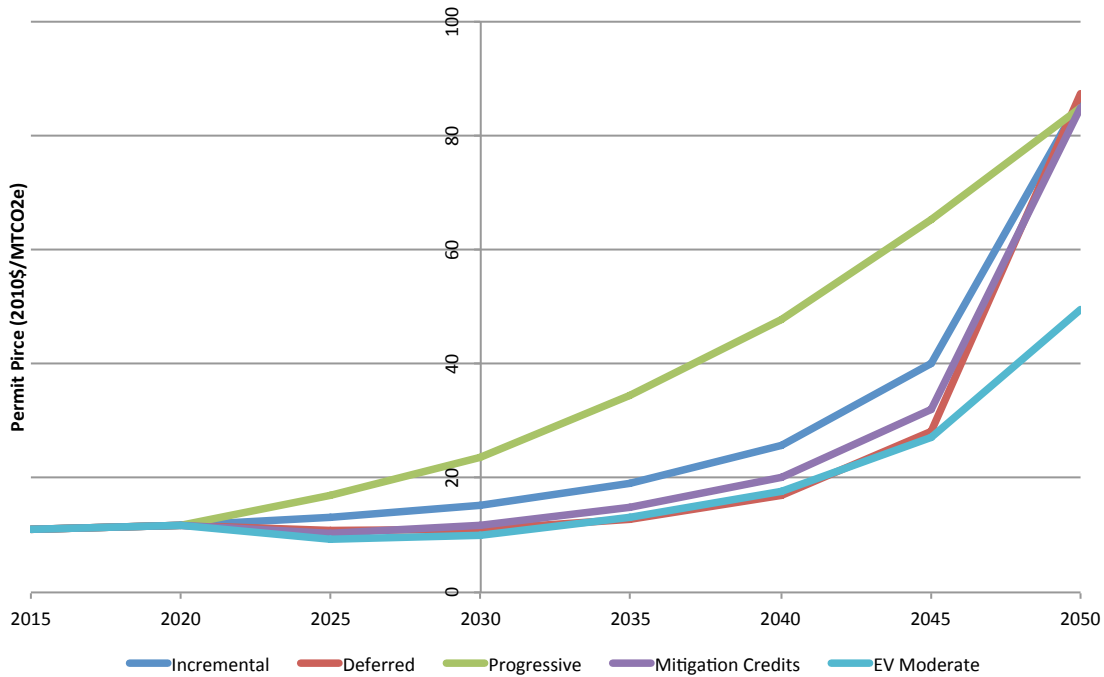
High Confidence	$P(x>0)>0.95$
Uncertain	

Generally speaking, complementary policies fall into three categories. The first are policies targeting specific behavior, e.g. sector-specific incentives for compliance like the decoupling policies developed in collaboration with California utilities decades ago. A second category addresses situations where prices alone cannot achieve the intended mitigation, such as mpg and other efficiency standards. Finally, a broader set of complementary policies, such as the proposed mitigation credits, creates system flexibility that can push down allowance prices and help preserve the competitiveness of California goods and

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services in the national economy. It is not difficult to develop a laundry list of such measures, but careful research is needed to determine their real potential and appropriate implementation.

Figure ES-6: Estimated Permit Prices



Another important feature of our results is explicit projection of permit prices that would result from Cap and Trade operating under the scenarios considered. Figure ES-6 illustrates these in 2010 dollars per MTCO_{2e}, and several salient findings are immediately apparent. Firstly, permit prices are generally relatively low, extending the current state of this market and suggesting that direct (permit) and indirect (investment) compliance costs are manageable even under the more ambitious Progressive mitigation pathway. Depending on discount rates, however, an investment approach to compliance would seem to be increasingly attractive, which should provide impetus to the innovation community. Finally,

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these results do not take explicit account of the current commitment to a price floor of \$26.50 in 2030, but all our scenario results are below this level.

Secondly, it is clear that a more flexible approach to recognizing mitigation can be cost effective for California. Even in the (unlikely) event that mitigation credits are the same price as AB32 auction permits, access to the former would reduce direct compliance costs by about half for the Progressive policy scenario. Third, note that permit prices rise sharply for the less ambitious pathways because they share the same 2050 target. The same is true as mitigation credits are ended by 2050 (Scenario 8), although this is by assumption and in principle the credits could be continued. The Deferred pathway sees the biggest jump because it has more catching up to do, Progressive prices smooth compliance costs, and the incremental approach falls in between. Finally, large scale BEV adoption makes a substantial and lasting contribution to statewide GHG mitigation, reducing the burden of emission reduction that must be achieved by Cap and Trade.

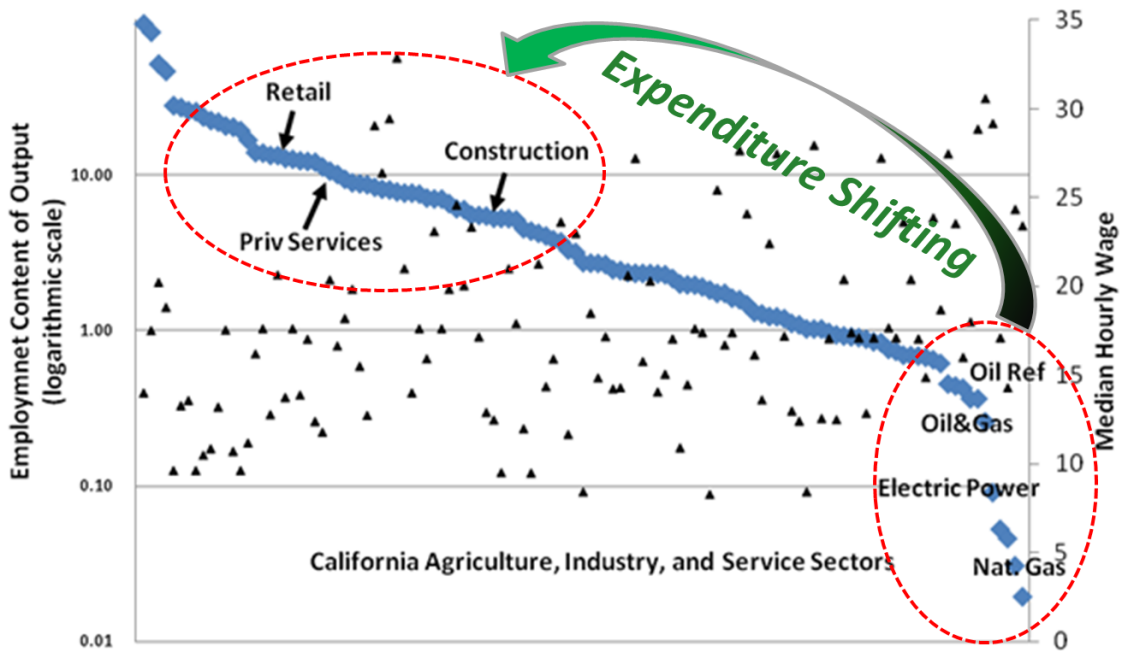
How AB32 Promotes Growth

The BEAR model may be a highly complex research tool, but it is not a Black Box. Using a state-of-the-art behavioral model, BEAR is calibrated to the most up-to-date information on the California economy, emissions, and technology costs. This forecasting tool tracks interactions between 50 sectors and attendant patterns of demand, supply, employment, trade, investment, and many other variables, forecasting annually over a 40-year period. Despite many technical details, however, the macroeconomic impacts we estimate from climate action can be explained with the simplest economic reasoning: Enterprises and households save money on conventional energy resources, and these savings are recycled to stimulate more job-intensive employment and income growth.

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Energy efficiency results in economic savings if the economic benefit reduced energy use outweighs the cost of adopting the more efficient technology. The best evidence available on this is California itself, which has maintained a combination of appliance and building standards and utility incentive programs since the early 1970's. In response to this, and even before AB32, the state went from parity to household electricity use levels that were 40% below the national average. These savings diverted household and enterprise expenditure from the carbon fuel supply chain to (mainly) services and manufactures, both of which significantly more employment intensive (Figure ES-7).

Figure ES-7: How Energy Efficiency Creates Jobs



Source: Roland-Holst:2008, "Energy Efficiency, Innovation, and Job Creation in California," Next10.org.

To assess the economy wide impacts of our efficiency and electric vehicle scenarios, we calibrated our model to the most recent information on present and

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future energy technology costs. These estimates, produced by ICF (2014) and E3 (2015), show net long term savings for both those who adopt electric vehicles and, because of capacity grid adjustments resulting from large scale EV adoption, reduced system wide electricity rates. Including their estimates of these incremental microeconomic benefits in our economy wide model leads to gains for individual households and enterprises, amplified by multiplier effects from recycling their energy savings into other expenditures. Taken together, these effects make out long term climate policy scenarios growth positive for California. Simply put, if you take a dollar out of the gas pump and give it to an average California household, they will spend it on goods and services that average 16 times the employment potential in terms of jobs per dollar of revenue.

Trade Issues

Lower expenditures on conventional energy reduce California's dependence on imports of raw energy fuels from other states and overseas. This trade effect has aroused concern that our export opportunities might likewise be reduced. The fact is that lowering conventional energy fuel imports will increase state employment as long as it results from efficiency. California transport fuels are only partially traded. Not only does California produce 20% of its own oil, but imported transport fuels add two-thirds of their final value inside the state. Unfortunately, however, these activities (refining and distribution) have extremely low employment potential. For example, dollar spent on California gasoline generates less than 10% as many jobs as the average dollar of consumer spending (\$.70 of which go to services). Even if California's exports fell by an amount equal to the reduction in raw energy fuel imports, the net job creation effect would be strongly positive.

The mercantile criticism also ignores three other effects of fuel savings to households and enterprises:

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1. Spending fuel savings creates its own import demand. If CA imports are about 15% of GSP (US average, but probably higher), this would offset about half the trade effect of reduced energy imports.
2. Service spending has larger in-state multipliers than energy fuel spending.
3. Innovation benefits of new fuel and vehicle technologies.

Market Failure Issues

Another type of skepticism regarding the benefits of AB32 and other climate policies is based on a presumption of market efficiency. Simply put, this perspective holds that to justify intervention, we must identify specific market failures that are inhibiting otherwise voluntary mitigation efforts and/or technology adoption. Otherwise, markets know best and we are already using or pursuing the most cost-effective solutions.

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. For example, CEC estimated that electric appliance standards netted California households a dividend of \$54 Billion over thirty years, and an early

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Next 10 report (Roland-Holst: 2008) showed how this created multiplier benefits of almost equal magnitude, contributing an additional 1.4 million FTE jobs to the state's long term growth.

Employment Issues

The positive job creation resulting in our scenarios of course requires that supply conditions are conducive to new hiring. To be clear, BEAR is not a “full employment” model because California historically as had an elastic supply of labor. Coming out of an adverse national macro cycle, the state happens to have structural unemployment now and, like most economies, this will likely continue intermittently. Over the long term, however, California has a higher than average elasticity of labor supply because of sustained inward migration. We take explicit account of this and, while it may not benefit the national economy, this kind of job and income creation has always benefitted California.³

³ Borenstein: 2015 is among prominent experts who caution about the risk of overestimating national benefits from state-specific job creation. This skepticism is certainly well founded, but states tend to place self-interest first when it comes to jobs and income growth.

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California Climate Policy to 2050: Pathways for Sustained Prosperity

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1 INTRODUCTION

The Golden State has been a source of economic inspiration for generations. Beginning with gold and agriculture, California's dynamism has continued as the state economy matured into a service and technology intensive powerhouse. Local, regional, national, and even global adversities have been taken in stride, and each time the state has emerged stronger, more diversified, and more creative. Indeed, California's innovation is as much admired as the superior growth and living standards it sustains. As we face a new global challenge from climate change, the state is again responding proactively and offering leadership to the nation and the world. California's landmark Global Warming Solutions Act (AB32) and a wide array of complementary policies (dating back four decades) have established the most ambitious public commitment in the United States to energy efficiency, pollution mitigation, and long term environmental security. These policies have done more than directly limit resource waste and climate risk, however, they have made the California economy, the world's seventh largest, into an incubator for the next generation of clean and energy efficient

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technologies. In light of global climate risk, these technologies hold the promise to deliver California's next breakout knowledge-intensive sector, following IT and Biotech to sustain the state's superior growth for another generation.

The first major milestone for AB32 will come at the end of this decade, when the state economy is targeted greenhouse gas (GHG) emission levels not seen in twenty-five years. Given that California's 2020 real gross state product (GSP) is expected to be more than double its 1990 counterpart, this will be a great achievement the state that has worked so hard to deliver prosperity while reducing risks to public health and the environment. The next established milestone for GHG reductions, 80% below 1990 levels by 2050, is even more ambitious. To reach this, the state will have to reduce emissions about twice as fast as we did from 2010 to 2020. In this report, we examine alternative policy scenarios that could achieve the 2050 goal, assessing their economic impacts and implications for technology adoption. Generally, we find that while substantive mitigation policy must entail some direct and indirect costs, the benefits from greater energy efficiency can significantly outweigh these.

Our approach, which integrates the latest available technology information with a long term economic forecasting model, shows how innovations in the transportation and electric power sector can facilitate GHG reductions in ways that confer economic savings on households and enterprises across the state. These savings, made possible by rapid innovation and a pervasive restructuring of the light vehicle fleet and electric power system, offer a pathway to our emission goals that promotes higher economic growth and employment than continuing the status quo. While we cannot predict the details of individual behavior and enterprise decision making, our results clearly reveal the potential of technology adoption and diffusion to reconcile the state's ambitious climate goals with economic growth objectives.

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In terms of the pathway to 2050, we also show that more aggressive technology adoption would permit the state to set more ambitious intermediate (2030) emissions targets. While the 2050 goals would be met under all the scenarios we consider, a more progressive approach to medium term GHG reduction would reduce total state emissions, and thereby the stock of global warming gases in the atmosphere, significantly. At the same time, more progressive intermediate GHG targets increase California's opportunities for innovation and technology leadership. For these reasons, the state should seriously consider such targets and how to promote constructive engagement with leading stakeholders to achieve them.

2 POLICY SCENARIOS FOR CLIMATE ACTION

This study uses a long-term dynamic forecasting model, combined with the latest economic and technology data, to evaluate alternative policy mixes from now to 2050. Updating earlier contributions made to the original Scoping Plan, we explicitly model existing California climate policies, as well as some alternatives being discussed for intermediate GHG targets and pathways. Our results reveal how policies can be combined to account for diverse institutions and behavior, and how these can be complementary and improve policy effectiveness. We also show the importance of recognizing uncertainty and creating mechanisms to accommodate this during a long and pervasive structural adjustment process. As most experts already acknowledge, a truly low carbon economy will be very different from today's California. Our analysis indicates that this future cannot only be more environmentally sustainable, but substantially more prosperous.

As part of their advanced Scoping Plan and implementation activities, CARB and CalEPA organized a comparison project featuring the leading economic assessment tools applied to AB32 since its passage in 2006. Included among

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these was the same Berkeley Energy and Resources (BEAR) model used in the present study. At that time, BEAR predicted that the state's unprecedented Cap and Trade program would not only be feasible, but affordable in terms of its market-based mitigation costs. In particular, BEAR predicted carbon permit prices well below \$20/MTCO_{2e}, while other estimates in some cases exceeded \$100. Eight years later, California's carbon prices are in the low teens. This fact reminds us of the importance of independent research to the public interest.

In the same study, both CARB's EDRAM and the BEAR model found that the combined policies of AB32 could achieve the state's 2020 GHG targets with a positive impact on the overall economy. At the time, critics argued that intervening in markets could not confer a growth dividend (or "negative net cost" in their rather perverse terminology), unless it were correcting for some structural distortion. A longer term debate has persisted about what and where there might be market "failures" that the state's energy and climate policies are rectifying and, absent such failures, continued skepticism about the policies, particular among industry groups and their advisors.

These differences of opinion are better understood for reasons of political economy than by observing economic reality, however, since it's easy for even casual observers to find market failures in this context. The main one, of course, is the most dangerous pollution externality of all time, unregulated GHG emissions and their attendant global warming impacts. In California, this problem is complemented by a broad spectrum of local public health risks that arise from imperfect competition, imperfect regulation, and related problems. Beyond this, we can include monopoly local electricity markets, oligopolistic energy fuel and vehicle sectors, etc. This is fertile ground indeed for the public interest to take root.

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Beyond the supply side, we can also acknowledge myriad imperfections of individual decision making. A large but still rapidly growing literature, emanating from inspired work of Kahneman and others, identifies and quantifies significant and pervasive aspects of individual decisions that underestimate subjective net benefit, risk, and a variety of other conceptual and hedonic implications of choice. Among the most relevant aspects of this for climate policy relates to individual adoption of technology and its diffusion throughout society. We have long known that individuals defer material gains because of subjective factors (e.g. “taste”), bounded rationality, and risk aversion. To the extent, however, that this is due to information failures or supply side imperfections, again intervention may be justified.

Just this kind of intervention was behind California’s pioneering energy efficiency policies. Implemented the last four decades, the “command and control” measures mandated appliance and their technical efficiency standards. Since then, California has gone from parity with national household per capita electricity use to about 40% below the national average, saving over \$50 billion in the process. In an earlier study (Roland-Holst: 2008), we showed how these historical savings were recycled through the economy to stimulate additional income and job growth. In the present study, we take a forward looking perspective, translating savings from the latest estimates of technical potential into economy wide growth drivers.

To assess prospects of determined California climate initiative over the next three decades, the BEAR model was been completely updated and re-calibrated to the latest economic data and policy information. The model itself has been peer reviewed and fully documented elsewhere, and we summarize its main findings below.

Table 2.1: Policy Scenarios

Name	Description	Post-2020 C&T target	Mitigation credits	Complementary policies
1. BAU	Business as Usual	No	N/A (not applicable if no post-2020 C&T target)	Frozen at current levels
2. Baseline	Existing Complementary Programs	No	N/A	Existing with AB 32 plus others
3. EffTrend	Continued efficiency trends	No	N/A	Adds new EE
4. RPS50	Extend RPS to 50% by 2030	No	N/A	New EE plus 50% RPS
5. Incremental C&T	Cap and Trade - Fixed increments after 2020	Linear trend to 2050	No	New EE plus 50% RPS
6. Progressive C&T	Cap and Trade - Fixed Percent (5.2) from 2020	Accelerated reductions to 2050	No	New EE plus 50% RPS
7. Deferred C&T	Cap and Trade - Delayed response after 2020, but attaining to the 2050 target	Delayed reductions, symmetric with accelerated scenario	No	New EE plus 50% RPS
8. Mitigation Credits	Allowances from outside the system, equal to the difference between the Deferred and Progressive Pathways	Accelerated reductions to 2050 (Progressive plus credits)	Yes	New EE plus 50% RPS
9. EV Adoption	Phase out ICE and PHEV with BEV by 2050.	Accelerated reductions to 2050 (Progressive plus credits)	Yes	Adds transportation electrification to new EE plus 50% RPS

For purposes of policy comparison, BEAR was used to evaluate a variety of generic scenarios reflecting different degrees of climate action and combinations of instruments (Table 2.1). In addition to reference cases of no action (BAU), a

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Baseline incorporating existing policies, and an extrapolation of historical efficiency trends, we looked at three policy instruments: An enhanced (50%) Renewable Portfolio Standard, Cap and Trade, and tradable Mitigation Credits. Finally, we look at a scenario that assumes complete electrification of the state's light duty vehicle fleet by 2050.

2.1 Renewables Deployment

Renewable energy is playing a rapidly growing role in climate policy, and California set an ambitious 33% Renewable Portfolio Standard as part of its AB32 initiative. A large part of the renewable energy mix: solar, wind, and geothermal, represents a fundamentally new energy supply paradigm. Because they are exhaustible resources, fossil fuel supplies and prices are determined primarily by scarcity, while these renewables represent essentially boundless resources relative to today's energy requirements. In the latter case the constraint to supply is not scarcity, but technological change. Recent trends in renewable technology show that these costs can fall dramatically with scale and learning. For our 4th and subsequent scenarios, we assume California steps up its RPS to achieve 50% renewable sourcing of electric power by 2030. Our cost assumptions are detailed in the full report.

2.2 Cap and Trade Pathways

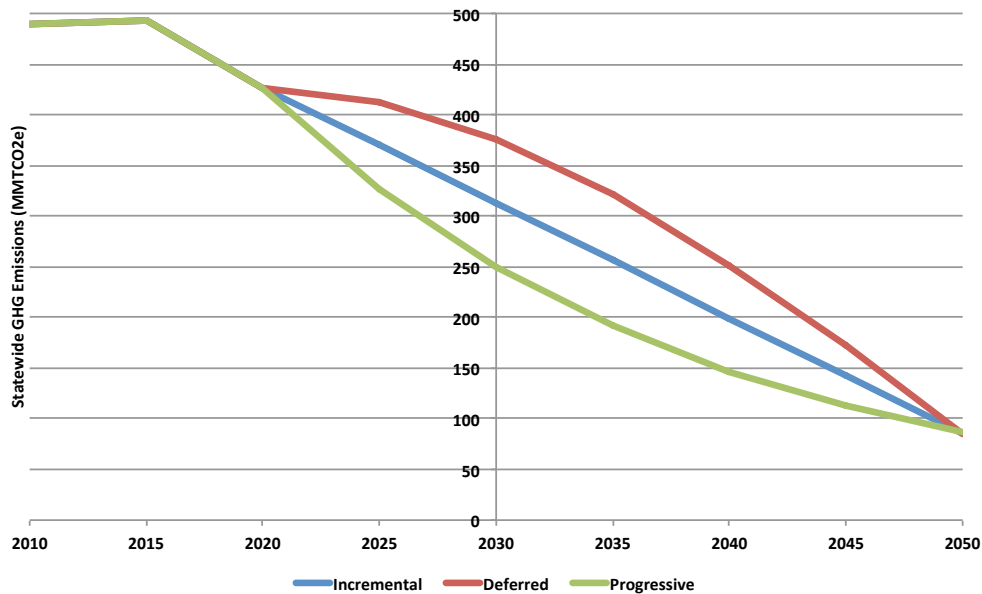
Although the policy has a brief history, California's Cap and Trade program has been quite successful, providing market based incentives for mitigation and innovation at relatively modest cost across a very diverse economy.⁴ Going forward, we assume that the cap will be a leading policy instrument to meet the

⁴ In fairness, it should be noted that compliance costs implied by today's Cap and Trade auction prices may be artificially low because of exceptional allocation measures. According to independent estimates (Busch: 2015), this could lead to banking of up to 100MT of emissions by 2020.

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state’s mitigation targets, combining with sector and other complementary policies to achieve 80% GHG reductions from 2020 to 2050. While the destination of 2050 is an ambitious focal point, the pathway getting there is of course more relevant to most decision making. As the following figure suggests, that pathway can also make a big difference to the primary determinant of global warming, the stock of GHG in the atmosphere. If we follow the Progressive rather than the Deferred pathway, California will contribute up to 30% less global warming pollution to the atmosphere. The question we ask is, can this environmental benefit be achieved at reasonable cost? Scenarios 5-7 evaluate a simple linear (Incremental) pathway and compare this to more (Progressive) and less (Deferred) ambitious GHG reduction strategies.

Figure 2.1: Cap and Trade Pathways



3 ASSESSMENT RESULTS

Our assessment of the nine policy scenarios set forth above, evaluated over the the period 2015-2050, yields four primary insights, summarized in the following table.

Table 3.1: Main Findings

<ol style="list-style-type: none">5. California can meet its 2050 climate goals in ways that achieve higher growth and employment, including GSP growth of over \$300 billion and about a million additional jobs.1. To do this will require a fundamental restructuring of the state's energy system, including electrification of the vehicle fleet.2. 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.3. With complementary policies, average long term industry compliance

3.1 Macroeconomic Impacts

When the BEAR model was applied to the nine scenarios, aggregate economic impacts indicate that the state can achieve its medium and long term climate goals while promoting economic growth (Table 3.2). Put differently, the aggregate net economic benefits are positive under all seven climate action scenarios considered. As will be apparent in the discussion below, the primary driver of the these growth dividends is multiplier effects from economy wide energy savings.

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In the medium and long term, these savings outweigh the costs of new technology adoption, and those net savings are passed on by households and enterprises to the rest of the state economy, stimulating indirect income and job creation. Because aggregate gains are based on the scope of distributed efficiency measures, the benefits increase with time and with the degree of emission reduction, conferring the largest dividends by 2050.

Table 3.2: Macroeconomic Impacts

2030							
	Efftrend	RPS50	Incremental	Deferred	Progressive	Offset	EV Mod
GSP	1%	1%	1%	1%	1%	2%	2%
Consumption	2%	2%	1%	1%	1%	1%	2%
Employment	1%	1%	2%	2%	2%	2%	2%
FTE ('000)	203	244	273	270	275	281	341
CPI	0%	-1%	-1%	-1%	-1%	-1%	-1%
GHG(MMTCO2e)	557	429	394	313	376	250	250

2050							
	Efftrend	RPS50	Incremental	Deferred	Progressive	Credits	EVMod
GSP	2%	2%	3%	3%	3%	4%	6%
Consumption	3%	3%	3%	2%	3%	3%	6%
Employment	2%	2%	3%	3%	3%	3%	4%
FTE ('000)	406	457	738	729	747	767	915
CPI	0%	-1%	-1%	-1%	-1%	-1%	-1%
GHG (MMTCO2e)	644	384	328	85	85	85	85

Notes: All impacts except GHG represent changes from Baseline in the year indicated, in percentage or the units given in parantheses. GSP and Consumption are measured in constant (2010) dollars. Employment chages are measured in Full Time Equivalent (FTE) annual jobs. GHG measures the level of annual emissions for the given year and scenario.

High Confidence	P(x>0)>0.95
Uncertain	

The role of uncertainty in our results is indicated by the color of the cells for changes in real Gross State Product (GSP). A cell colored green contains a result

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that, subject to our experimental variations in energy costs and behavior are positive with probability exceeding 95%. Thus the pure efficiency scenario, which essentially extrapolates the state's past trends of "no regrets" efficiency improvements, is extremely likely to be growth positive. Also, if Californians actually do transition to a pure electric light vehicle fleet, the aggregate efficiency gains are virtually certain to outweigh AB32 compliance costs.

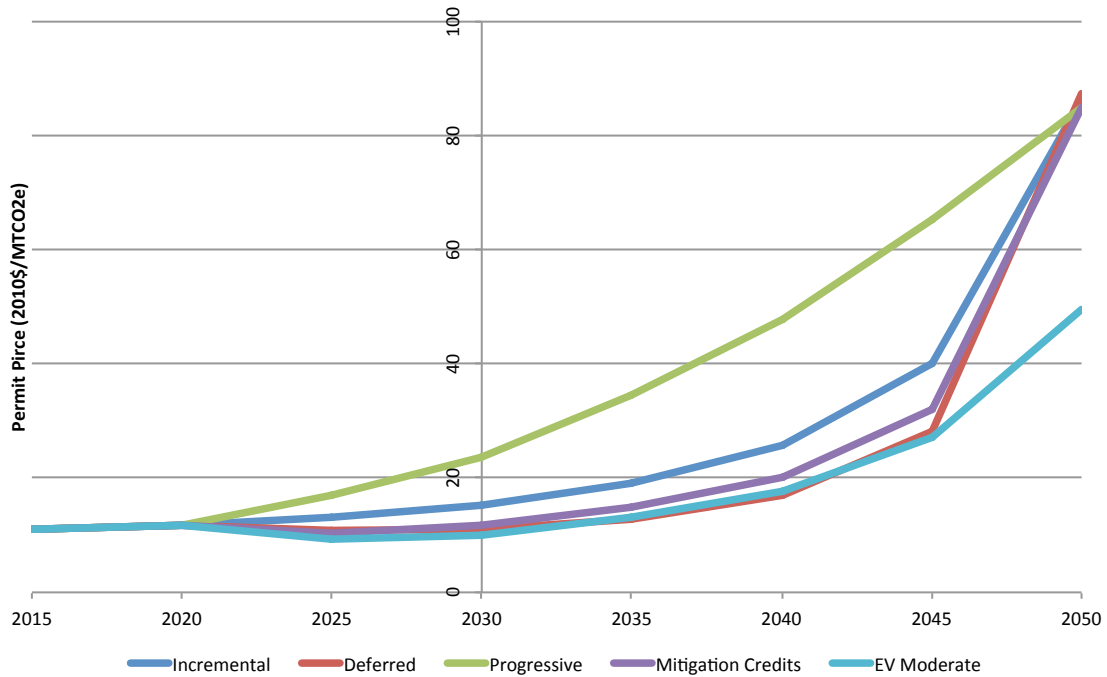
For the middle scenarios, the average economic impact across 1000 replications is positive, but not so strongly that they could not be reversed by large swings in energy policy or behavior. As a practical matter, this uncertainty has important implications. It means, for example, that we need to better understand the non-economic benefits that motivate climate policy, as these might justify zero or even positive net costs for the policies considered. These include, for example, induced innovation and other technological change, climate benefits or reduced damages, co-benefits, and national/international leadership. Another immediate implication of the uncertainty in the C&T scenarios is that we need complementary policies, especially to move behavior (like BEV adoption) in directions that make net growth more likely.

Generally speaking, complementary policies fall into three categories. The first are policies targeting specific behavior, e.g. sector-specific incentives for compliance like the decoupling policies developed in collaboration with California utilities decades ago. A second category addresses situations where prices alone cannot achieve the intended mitigation, such as mpg and other efficiency standards. Finally, a broader set of complementary policies, such as the proposed mitigation credits, creates system flexibility that can push down allowance prices and help preserve the competitiveness of California goods and services in the national economy. It is not difficult to develop a laundry list of such

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measures, but careful research is needed to determine their real potential and appropriate implementation.

Figure 3.1: Estimated Permit Prices



Another important feature of our results is explicit projection of permit prices that would result from Cap and Trade operating under the scenarios considered. Figure 3.1 illustrates these in 2010 dollars per MTCO_{2e}, and several salient findings are immediately apparent. Firstly, permit prices are generally relatively low, extending the current state of this market and suggesting that direct (permit) and indirect (investment) compliance costs are manageable even under the more ambitious Progressive mitigation pathway. Depending on discount rates, however, an investment approach to compliance would seem to be increasingly attractive, which should provide impetus to the innovation community. Finally, these results do not take explicit account of the current commitment to a price floor of \$26.50 in 2030, but all our scenario results are below this level. Among

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other things, this suggests that mitigation credit allowances can be more limited than modeled in our scenarios.

Secondly, it is clear that a more flexible approach to recognizing mitigation can be cost effective for California. Note that we have assumed for the sake of this scenario that mitigation credits are relatively costly, i.e. equal to the price of in-state emission permits obtained at auction. In reality, there are likely to be abundant sources of international mitigation that are much cheaper than GHG reductions in California. This would be especially true in emission-intensive developing economies and countries with low marginal forestation costs. Even in the (unlikely) event that mitigation credits are the same price as AB32 auction permits, access to the former would reduce direct compliance costs by about half for the Progressive policy scenario.

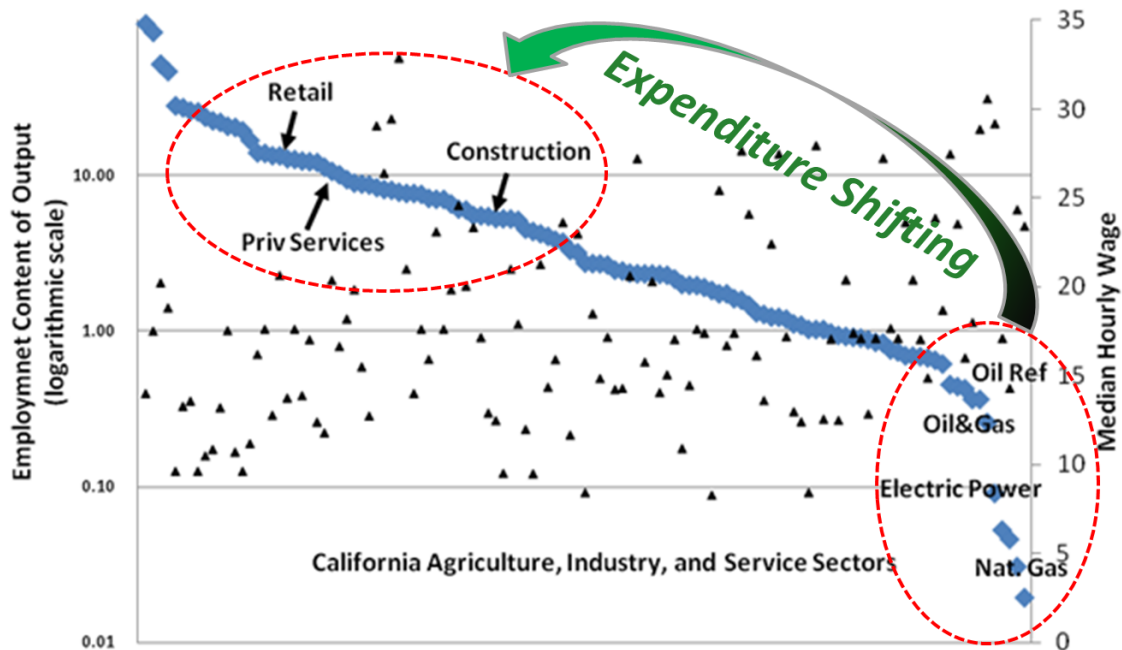
The reason auction prices are lower, even though external credits are priced at parity to them, is because the credit allowances effectively loosen the cap by diverting permit demand, increasing availability for those who ultimately buy in-state permits. Of course it should be emphasized that the same GHG mitigation is achieved globally, and we have chosen to eliminate credit allowances by 2050, meaning California meets its ultimate mitigation goal within the state.

Third, note that permit prices rise sharply for the less ambitious pathways because they share the same 2050 target. The same is true as mitigation credits are ended by 2050 (Scenario 8), although this is by assumption and in principle the credits could be continued. The Deferred pathway sees the biggest jump because it has more catching up to do, Progressive prices smooth compliance costs, and the incremental approach falls in between. Finally, large scale BEV adoption makes a substantial and lasting contribution to statewide GHG mitigation, reducing the burden of emission reduction that must be achieved by Cap and Trade.

3.2 How AB32 Promotes Growth

The BEAR model may be a highly complex research tool, but it is not a Black Box. Using a state-of-the-art behavioral model, BEAR is calibrated to the most up-to-date information on the California economy, emissions, and technology costs. This forecasting tool tracks interactions between 50 sectors and attendant patterns of demand, supply, employment, trade, investment, and many other variables, forecasting annually over a 40-year period. Despite many technical details, however, the macroeconomic impacts we estimate from climate action can be explained with the simplest economic reasoning: Enterprises and households save money on conventional energy resources, and these savings are recycled to stimulate more job-intensive employment and income growth.

Figure 3.2: How Energy Efficiency Creates Jobs



Source: Roland-Holst:2008, "Energy Efficiency, Innovation, and Job Creation in California," Next10.org.

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Energy efficiency results in economic savings if the economic benefit reduced energy use outweighs the cost of adopting the more efficient technology. The best evidence available on this is California itself, which has maintained a combination of appliance and building standards and utility incentive programs since the early 1970's. In response to this, and even before AB32, the state went from parity to household electricity use levels that were 40% below the national average. These savings diverted household and enterprise expenditure from the carbon fuel supply chain to (mainly) services and manufactures, both of which significantly more employment intensive (Figure 3.2).

To assess the economy wide impacts of our efficiency and electric vehicle scenarios, we calibrated our model to the most recent information on present and future energy technology costs. These estimates, produced by ICF (2014) and E3 (2015), show net long term savings for both those who adopt electric vehicles and, because of capacity grid adjustments resulting from large scale EV adoption, reduced system wide electricity rates. Including their estimates of these incremental microeconomic benefits in our economy wide model leads to gains for individual households and enterprises, amplified by multiplier effects from recycling their energy savings into other expenditures. Taken together, these effects make out long term climate policy scenarios growth positive for California. Simply put, if you take a dollar out of the gas pump and give it to an average California household, they will spend it on goods and services that average 16 times the employment potential in terms of jobs per dollar of revenue.

3.2.1 Trade Issues

Lower expenditures on conventional energy reduce California's dependence on imports of raw energy fuels from other states and overseas. This trade effect aroused concern that our export oportunities might likewise be reduced. The fact is that lowering conventional energy fuel imports will increase state employment

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as long as it results from efficiency. California transport fuels are only partially traded. Not only does California produce 20% of its own oil, but imported transport fuels add two-thirds of their final value inside the state. Unfortunately, however, these activities (refining and distribution) have extremely low employment potential. For example, dollar spent on California gasoline generates less than 10% as many jobs as the average dollar of consumer spending (\$.70 of which go to services). Even if California's exports fell by an amount equal to the reduction in raw energy fuel imports, the net job creation effect would be strongly positive.

The mercantile critique also ignores three other effects of fuel savings to households and enterprises:

1. Spending fuel savings creates its own import demand. If CA imports are about 15% of GSP (US average, but probably higher), this would offset about half the mercantile effect of reduced energy imports.
2. Service spending has larger in-state multipliers than energy fuel spending.
3. Innovation benefits of new fuel and vehicle technologies.

3.2.2 Market Failure Issues

Another type of skepticism regarding the benefits of AB32 and other climate policies is based on a presumption of market efficiency. Simply put, this perspective holds that to justify intervention, we must identify specific market failures that are inhibiting otherwise voluntary mitigation efforts and/or technology adoption. Otherwise, markets know best and we are already using or pursuing the most cost-effective solutions.

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

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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. For example, CEC estimated that electric appliance standards netted California households a dividend of \$54Billion over thirty years, and an early Next 10 report (Roland-Holst: 2008) showed how this created multiplayer benefits of almost equal magnitude, contributing an additional 1.4 million FTE jobs to the state's long term growth.

3.2.3 Employment Issues

The positive job creation resulting in our scenarios of course requires that supply conditions are conducive to new hiring. To be clear, BEAR is not a "full employment" model because California historically as had an elastic supply of labor. Coming out of an adverse national macro cycle, the state happens to have structural unemployment now and, like most economies, this will likely continue intermittently. Over the long term, however, California has a higher than average elasticity of labor supply because of sustained inward migration. We take explicit account of this and, while it may not benefit the national economy, this kind of job and income creation has always benefitted California.⁵

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4 MODELING CAP AND TRADE

California's Cap-and-Trade Regulation has the broadest scope of climate policy in the AB32 package. As of early this year, when fuels were incorporated, Cap-and-Trade covers the sources for around 80% of the state's GHG emissions and provides flexibility for companies to reduce their emissions. The Cap-and-Trade program works in concert with other areas of policy by creating a price signal to drive long-term investment in efficiency measures and low-carbon sources of energy. For example, Cap-and-Trade will likely raise the cost of electricity for industries, which encourages industries to invest in energy efficiency technologies (Cook, 2013). As Cap-and-Trade is applied to transportation fuels and the compliance costs for oil companies are passed on to consumers, it is reasonable to expect behavior change among Californian drivers, which will help accomplish some of the policy goals of the transportation sector (such as SB 375).

The program opened in January 2013 covering just electric utilities and large industrial facilities and expanded in 2015 to cover transportation fuels and natural gas. The 2013 cap was set at 2% below 2012 emission levels. From there, the cap decreased by 2% in 2014 and will decrease 3% annually from 2015 to 2020. California policy makers consider the cap as an economically efficient mechanism for lower GHG emissions that relies on trading between firms to achieve optimal allocations of emissions and on market forces to drive innovation and investment. California's program has been linked to Quebec's and negotiations are in the works to link it to other Canadian provinces through the Western Climate Initiative.

The first year of emission permit trading under the Cap-and-Trade system showed several signs that the policy is functioning as intended and headed

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towards long-term stability. That all available 2013 vintage and 2016 vintage permits sold suggests that participants have high confidence that the carbon market should continue to function for several years. The secondary market for permits also stabilized very near to the floor price, indicating that companies found the marginal cost of abatement in the first compliance period to be sufficiently low (Hsia-Kiung, 2014). According to the Environmental Defense Fund, auction results so far have shown that California “Is decoupling economic growth from emissions growth, creating less demand for allowances than expected.” The March 16, 2014 auction had 74 qualified participants from all sectors covered by the program and raised \$71.1 million for the state (EDF, 2014).

4.1.1 Offsets and Mitigation Credits

Under the Cap-and-Trade Regulation 8% of a company’s emission abatement can be met by purchasing offsets from another project within the United States. This provides an important mechanism for (at least temporary) cost containment of the program by providing companies some flexibility about how and when they adopt emission reduction measures. Offsets are expected to play a large role in the later years of the program and there are already indications that the availability of certified offset credits could become a problem (CARB, 2014a).⁶

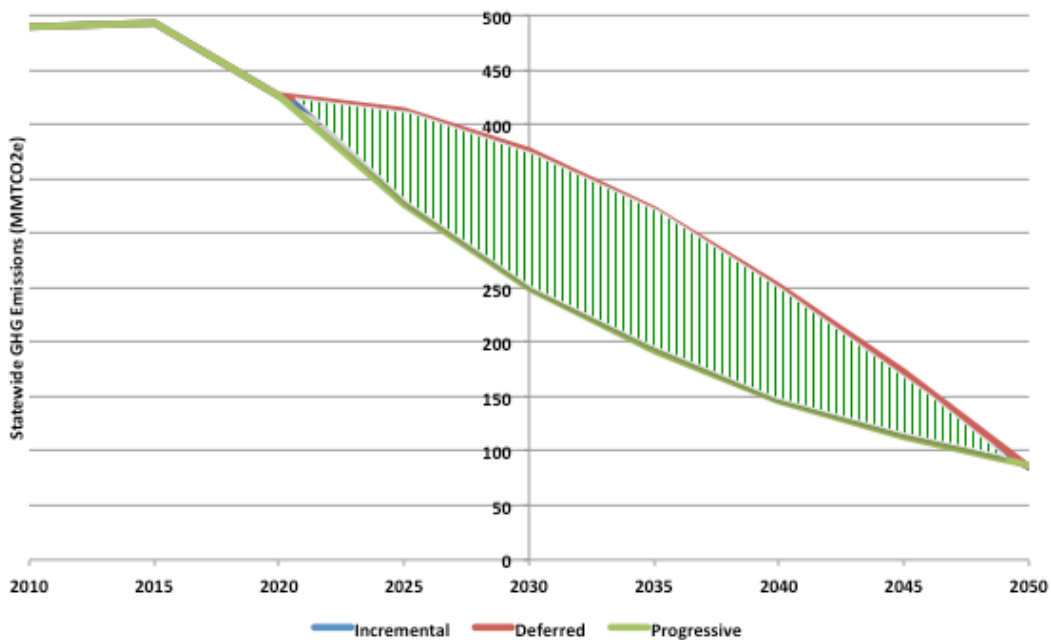
In addition to calibrating our model to the 8% offset allowance, we include an additional opportunity for flexibility – certified mitigation allowances. One of main attractions of market-based emission reduction mechanisms like Cap and Trade is flexibility permitted covered entities a choice between direct spending on permits and investments that would lead to lower emissions. While this encourages more efficient firms to innovate, it is important to recognize that,

⁶ Most recent indications suggest a pickup in offset supply, with 14.7MMT approved and 10MMT actually used in 2014 (Busch: 2015).

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because of progress already made, the marginal cost of mitigation in California is high by global standards. Given that the global warming impact of a 1MTCO_{2e} emission reduction is the same regardless of where it is realized, it is reasonable to ask if there are more cost-effective ways for Californians to reduce global GHG stocks.⁷ In scenarios 8 and 9, we consider a prominent example of one such policy, allowance for out-of-state mitigation credits against in-state emissions above the cap.

Figure 4.1: Mitigation Credit Allowances (shaded area)



Sometimes referred to as offsets, mitigation credits in these scenarios are assumed to be available at the same price as permits (although they would generally be cheaper). In addition we assume they are verifiable, additional, and tradable on an annualized basis, representing (e.g.) 1MTCO_{2e} of annual reduction in a flow (mitigation) or stock (sequestration). Such credits could be

⁷ It should be emphasized that we only consider global GHG benefits in this case. Offsets may lead to higher local pollution costs, as well as outsourcing of innovation benefits that might arise from more stringent local emission standards.

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made available through a variety of mechanisms, and we make this the subject of a separate study. For the moment, however, we assume that there exists an international financial market for sovereign mitigation certificates, like the sovereign bond market. These “climate bonds” would trade at prices reflecting underlying costs of providing mitigation/sequestration services, with appropriate risk discounts that reflect the credibility of the issuer.⁸

For our sample scenarios, we look at an allowance of credits equal to the difference between the Progressive and Deferred emission pathways (Figure 4.1). Obviously, an infinite variety of allowance schemes are possible, but the importance of this one is that, while offering flexibility over the transition period, it leads to the same 2050 emission target (flow) and achieves the same global GHG stock reduction as the Progressive pathway. Thus we achieve both the state’s ultimate goal and a more ambitious mitigation pathway for overall GHG reductions. As we shall see, we also do this much more cost effectively.

It should also be noted that mitigation credits, by outsourcing emission reductions, forsake an opportunity for in-state innovation. For higher income, technology-intensive economies like California, this may be a serious drawback. The primary drivers of the Golden State’s superior growth over the last two generations have been education and innovation, going hand-in-hand to make the state a knowledge-intensive leader in the global economy. First in information and communication technology (ICT), then in biotech, the state’s R&D supply chain has delivered solutions for the most dynamic and profitable sectors of modern times. Certainly, the co-benefits of mandating in-state mitigation deserve

⁸ International instruments like this, if effectively supported by financial markets, could be a substantial improvement over more ad hoc negotiated arrangements like CDM, Debt for Nature, REDD, etc. The latter tend to be plagued by moral hazard and other agency problems. Given cost advantages for lower income countries in both mitigation and sequestration investments, this market could also become a very important source of North-South transfers to support climate adaptation.

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further research. Having said this, it should be emphasized that, in all our C&T scenarios, mitigation credits are reduced to zero by 2050.

5 MODELING THE TRANSPORTATION SECTOR

The transportation sector was the largest source of GHG emissions in 2012, constituting more than 36% (167.4MMT_{CO2e}) of California's overall GHG emission inventory (459MMT_{CO2e}). On-road vehicles constituted over 92% of transportation sector emissions. These emissions declined 5% between 2000 and 2012, and annually in each year since 2007, with the greatest decrease occurring at the time of the recession. In the summer of 2008, fuel prices reached a historic maximum, followed by a dramatic decrease in the consumption of gasoline and diesel fuel. Total transportation fuel consumption declined in 2008, and even with modest increases in 2009 and 2010, on-road emissions continued to decrease, remaining below pre-recession levels as the economy improved. (CARB, 2014).

An overwhelmingly large majority of emissions from this sector is due to on-road transportation (90%). The on-road category also accounts for more than 33% of the statewide 2012 greenhouse gas emissions. Of the on-road vehicles, light duty passenger vehicles accounted for approximately 69% of the total sector emissions in 2012. Figure 17 shows the trend in emissions for this sector from 2000 through 2012. Transportation emissions showed a marked decline since 2007 (from a high of 192 MMT_{CO2e} in 2007 to 171 MMT_{CO2e} in 2012, CARB: 2014b).

5.1 Electrification of the Light Duty Vehicle Fleet

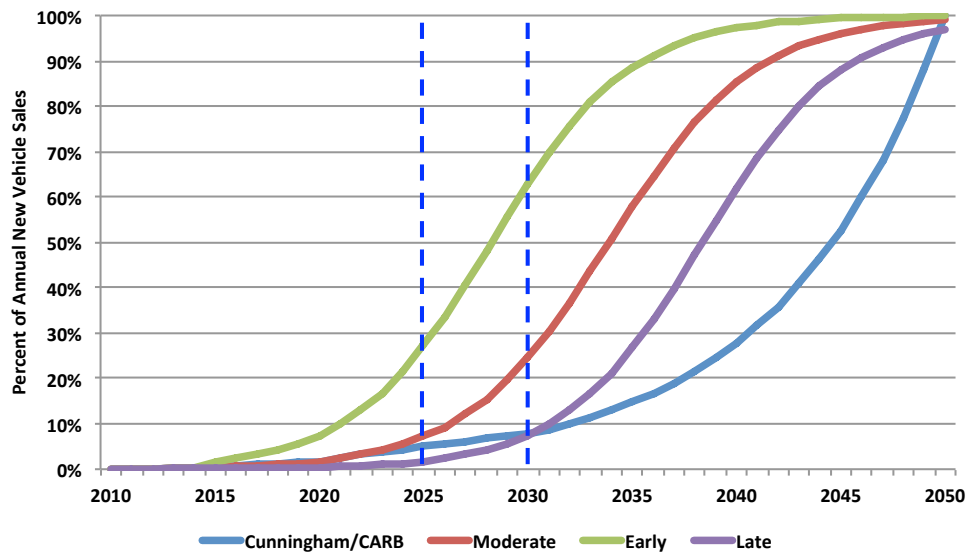
Most informed observers now recognize that California cannot realistically expect to achieve 80% decarbonization without a fundamental transition of its

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transportation system to electric power. Alternative fuels can be important sources of mitigation in the near term, but they cannot displace enough conventional fuel emissions to get us to 2050 with current population growth trends and known technologies for biofuel production and distribution. Hydrogen is an emerging technology that may play an important role, but we do not evaluate it here.

We begin this section with a description of our modeling approach and assumptions regarding electrification of the light vehicle fleet. This is followed with an overview of prospects and challenges for leading California policies toward this important sector.

Figure 5.1: Scenarios for Battery Electric Vehicle Adoption



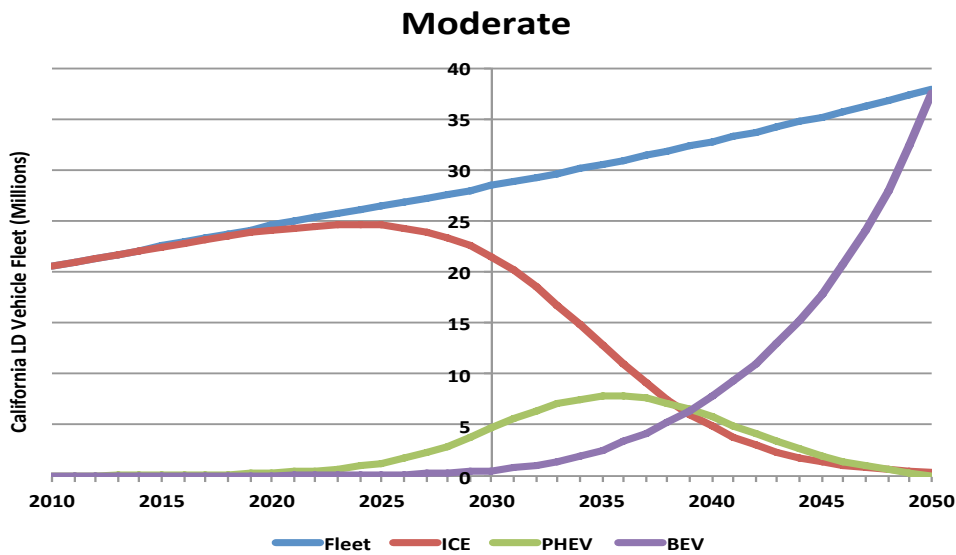
Our last scenario considers one of many possible adoption pathways for 100% light duty vehicle fleet electrification, or Battery Electric Vehicle (BEV) adoption, the Moderate profile in Figure 5.1. This calls for about 7% of new vehicles sales to be EV by 2025, increasing to 25% by 2030 and 100% by 2050. For

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comparison, we also illustrate a CARB proposal for more gradual early adoption, rapidly accelerating in the final decade.

Assuming the Moderate adoption profile for BEVs, along with an assumption of phasing out hybrid vehicles, we obtain the vehicle fleet transition implemented in Scenario 9 and illustrated in Figure 5.2. With respect to current levels of BEV market penetration, this is obviously a very different transportation sector, with far reaching implications for complementary technologies, infrastructure, electric power capacity, etc. All these issues require detailed evaluation to be most effectively supported by public policy and, in turn, for leading private stakeholders to effectively support climate policy. The state’s ambitious goals have the best chance of success if they are based on this kind of constructive engagement.

Figure 5.2: California Vehicle Fleet – Moderate BEV Adoption Profile



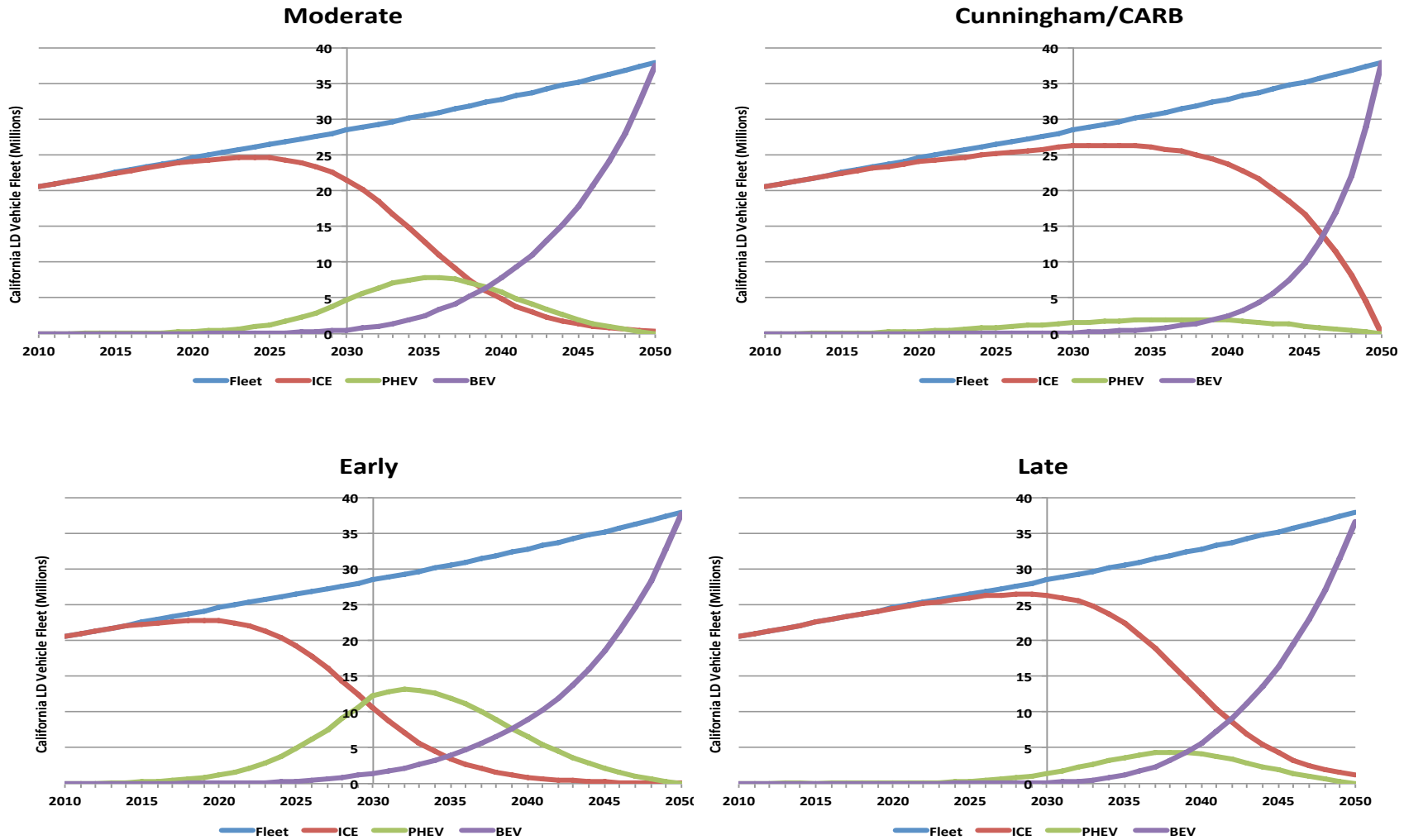
Source: Author estimates. Vehicle classes are Internal Combustion Engine (ICE), Plug-in Hybrid Electric Vehicles (PHEV), and 100% electric or Battery Electric Vehicles (BEV)

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We now provide an overview of climate related policies directed at transportation. Generally, California's long-term criteria pollutant and GHG emissions goals will require four transportation-oriented strategies: (1) improve vehicle efficiency and develop zero emission technologies, (2) reduce the carbon content of fuels and provide market support to get these lower-carbon fuels into the marketplace, (3) plan and build communities to reduce vehicular GHG emissions and provide more transportation options, and (4) improve the efficiency and throughput of existing transportation systems (CARB, 2014).

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Figure 5.3: Alternative Scenarios for EV Diffusion in the California Light Duty Fleet



5.2 Vehicle Efficiency standards

As noted early, many researchers have concluded that reaching the state's 2050 goals will be impossible without maximizing energy efficiency. With transportation being the largest category of emissions, vehicle efficiency plays a critical role.

5.2.1 Progress

California is already demonstrating considerable progress as the California EPA, reports that expected annual emission reductions of 29.9 MMTCO_{2e} in 2020, which includes their expected gains from ZEV. This represents more than one-third of 86.1 MMTCO_{2E} in emission reductions that CARB's forecasts for 2020 across all of the state's policies (or 3.3% of California's total 2012 emissions) (CalEPA, 2013). However, most of these gains are from improvement in internal combustion vehicles which is the most cost-effective way to reduce emissions. Since consumers save at the pump, there is policy support, and no major technical barriers, 100% fleet adoption by 2050 appears reasonable (with fleet averages perhaps 50-60 mpg among combustion vehicles). While this technological change pathway may be appealing because of established policy support, the maximum expected efficiency from internal combustion cars is still expected to fall considerably short of enabling AB32 compliance. Success will ultimately rely on adoption of electric vehicles and possibly hydrogen vehicles.

To date, the majority of progress has been made in light-duty passenger vehicles, which can lead to very substantial reductions since they accounted for 71.1% of emissions in 2012 (CARB, 2014). However, reaching 80% reductions by 2050 will require significant advances to the heavy-duty road vehicles (20.7% of 2012 emissions) as well as rail, aviation, and water vehicles (9.9% of 2012 emissions – this does not add up there is a flaw in CARB's data). In these

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sectors there are significantly higher technology barriers and less progress has been made.

PEVs entered the California market in 2011 Chevy Volt and Nissan Leaf. About 11,000 are sold per year. A rapid increase in growth rates is needed to meet targets and would likely need policy assistance for more recharging stations and purchasing support. To this end, the California Vehicle Rebate Program has already provided \$44 million toward rebates for more than 10,000 zero-emission vehicles and more than 9,000 plug-in hybrid electric vehicles.

Many fuel cell vehicles (FCVs) have been developed and are expected to hit the California market in 2015. 37 public hydrogen fueling stations will be in operation in 2015 with 68 planned by 2016. This is enough to support 20,000 FCVs (Yang, 2011).

5.2.2 Outlook for 2050

Travel demand is expected to increase 50-100% by 2050. LDV sales are expected to be approximately 2.7 million vehicles/year with the fleet of LDVs expected to rise to 40-45 million. It is difficult to anticipate how PEV or FCV adoption will be influenced by low carbon fuels. If second generation fuels become widely available, it maybe possible to meet AB32 targets with existing hybrid vehicle technology. This modeled by a team of researchers who said it is possible but would require that, “Transitions in vehicle technology, energy supply, and transportation infrastructure must begin soon and progress rapidly” (Leighty, 2012).

5.2.3 Policies

5.2.3.1 Advanced Clean Car Program, AB 1493 (2004)

The Pavley Regulation (AB 1493) sets fuel economy regulations for model years 2012-2016 in California and is the primary policy instrument for lowering emissions from new automobiles. This was extended in 2012 with the passage of the Advanced Clean Car Program which covers model year 2017-2025. The program includes the following features:

- Reducing GHG emissions from light-duty (passenger) vehicles by about 4.5% per year from 2017-2025.
- Combining both smog pollutants and GHG emissions into a set of standards known as LEVIII.
- Measures to support the Zero-Emission Vehicle.

The Air Resources Board anticipates that by 2025 new cars will produce 34% fewer GHG emissions and 75% fewer smog emissions. They also estimate that this will save consumers \$6000 on average over the life of the car while only increasing the upfront cost \$1900.

The federal government has taken its most dramatic step toward climate change mitigation by setting national vehicle emission standards. The first rule, adopted in April 2010, raises the average fuel economy of new passenger vehicles to 34.1 miles per gallon (mpg) for model year 2016, a nearly 15% increase from 2011. The second rule, finalized in August 2012, will raise average fuel economy to up to 54.5 mpg for model year 2025, which has adopted as well.

5.2.3.1.1 Compliance

The fleet average CO₂ emission for cars in California decreased from 323 to 205 g CO₂/mi for passenger car and light duty trucks (class 1) from model years 2009

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to model years 2016. They also improved gas millage from 27.6 to 43.4 MPG on the same time period. The California EPA reported that the emission reductions from these efforts were 2.2 MMTCO₂E for the year 2011 (Cal EPA, 2013).

5.2.3.1.2 Outlook

The California EPA, based on data provided by responsible government agency, reported expected annual emission reductions of 29.9 MMTCO_{2e} in 2020, but this includes their expected gains from ZEV. This represents more than one-third of 86.1 MMTCO₂E in emission reductions that CARB's forecasts for 2020 across all of the state's policies (Cal EPA, 2013).

5.2.3.2 Zero Emission vehicles program (2012)

This program, which is technically a sub policy of the Advanced Clean Car Program, requires about 15% of new cars sold in California in 2025 to be a plug-in hybrid, battery electric, or fuel cell vehicle. Executive Order B-16-12 added to this by mandating that 1.5 million ZEVs on California's roadways by 2025 (CARB, 2014). This program provides incentives for purchasing ZEVs and assists in building VEZ fueling infrastructure, as outlined by the Zero Emission Vehicle Action Plan the

5.2.3.2.1 Compliance

There are currently 60,000 ZEVs on the road in California (CARB, 2014). From a July 22, 2014 news release, the California Energy Commission also claims to have given final approval for, "Nearly \$50 million in construction projects to advance the consumer market for zero-emission electric vehicles... \$46.6 million in grant agreements for 28 hydrogen refueling stations and one mobile refueler were awarded" (CEC, 2014).

5.2.3.3 Heavy-duty vehicle regulations

There are at least three separate policy efforts – standards, aerodynamics and hybrid efficiency - that I am combining here. The aerodynamics program is making the most short-term gains, but will soon hit the ceiling for potential emission reductions. The hybrid efficiency program is likely to be critical in reaching AB32 target but so far has seen insignificant reductions.

Standards – In 2011 CARB adopted new heavy duty vehicle standards that are compliant with federal EPA regulation currently in “phase I.” The regulations require a 4-5% reduction in emissions each year from 2014-2018 for class 8 vehicles (CARB, 2014).

Aerodynamics – Long-haul trucks are required to be U.S. EPA SmartWay certified and equipped with low rolling resistance tires (Cal EPA, 2013).

Hybridization – An incentive program started in 2010 to provide funds for purchasing hybrid and zero-emission trucks and is available to a wide variety of trucks including parcel delivery, utility trucks, garbage trucks, and transit buses.

5.2.3.3.1 Compliance

As of 2013, the hybridization program had invested more than \$60 million in demonstration and deployment projects. This was only enough for a handful of demonstration projects of ZEV and hybrid vehicle and providing the initial funding to develop electric trolley truck infrastructure along Interstate 710 near the ports of Los Angeles and Long Beach (CEC, 2013).

The California EPA, based on data provided by responsible government agency, reported expected emission reductions of 0.7 MMTCO_{2e} in 2012 for the aerodynamics buy negligible savings for hybridization (CalEPA, 2013).

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5.2.3.3.2 *Outlook*

ARB is currently engaged in developing standard beyond 2018 for heavy duty vehicles.

5.2.3.4 Minor policies

The Tire Pressure Program requires specified automobile servicing businesses to ensure proper tire inflation at the time of service, as well as public education about proper tire inflation. The California EPA, reported emissions savings of 0.6 MMTCO₂E in 2012, and expected annual emission reductions of 0.7 MMTCO₂E for 2020 (CalEPA, 2013). Which suggests the policy is already achieving maximum emission reductions.

Several policies similarly max out on emission reduction at a level that makes an insignificant contribution to reaching 2050 target, such as Cargo Handling, Cargo Refrigeration, and various Anti-Idling programs.

5.3 Low Carbon Fuels

Low carbon fuels are without a doubt critical in meeting AB32's 2050 targets. In their research series "California's Energy Future" the California Council on Science and Technology developed multiple scenarios that applied also viable efficiency measures, maximized fleet electrification, reduced demand as much feasible. Their findings suggested this would, "Reduce demand to roughly 75% of 2005 levels for gaseous fuels and 66% for liquid fuels" (CCST, 2013). Therefore, even under the most optimistic scenarios 2050 it will likely be impossible to meet 2050 emission reduction targets without substantially decarbonizing fuel.

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5.3.1 Progress

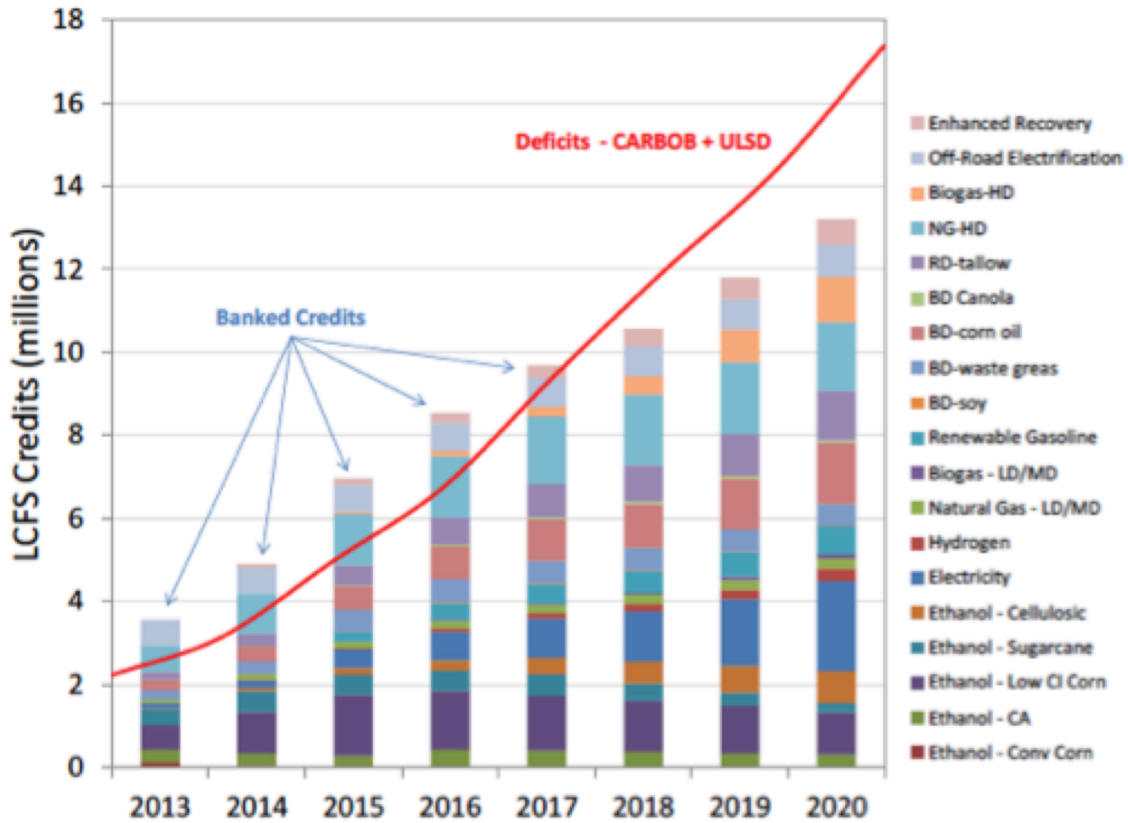
The Low Carbon Fuel Standard (LCFS) is the dominant policy drive in this space. So far under the LCFS program alternative fuels have increased from 6.3% of total transport energy use in California in 2011 to 6.8% in the first half of 2013. Fuel suppliers have also banked excess LCFS credits in every quarter since regulation began, totaling 1.64 MMTCO_{2e} by June 2013, or 61% more credits than required (Yeh, 2014). Despite this early success, there are concerns about reaching the target of reducing the state-wide carbon intensity of fuel by 10% by 2020, with possible implications for the ability to reach long-term AB32 targets. Researchers at UC Davis Institute of Transportation Studies, for example, summarize that concerns as follows: “Given the unpredictable nature of new technologies and the scale at which alternative fuels will need to be produced in order to maintain compliance across all obligated parties, there is reasonable concern regarding the potential for high and volatile costs of the program in coming years” (Lade, 2013). Similarly, in a review of available research on the topic the Consumer Alliance for Responsible Fuel Policies concludes that, “California’s LCFS is unrealistic and likely to become infeasible and unworkable well before the 2020 compliance date because the LCFS technology is unproven and experimental, LCFS fuels will be too costly and lead to economic loss, and the LCFS timeline is too aggressive” (CARFP). Some reports suggest that failure to comply due to lack of fuel availability will be forced as early as 2015.

LCFS still has some grounds for support however. From a technology standpoint ICF International believes reaching the 2020 target is possible. Furthermore, their research finds that, “By spurring greater use of clean alternative fuels and vehicles, the LCFS will result in \$1.4 – \$4.8 billion in societal benefits by 2020 from reduced air pollution and increased energy security.” Other predictions from the study (which was commissioned by a coalition of interest groups such as the

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Advanced Biofuels Association) include: 9,100 new jobs for California and LCFS compliance costs of only \$0.06 to \$0.19 per gallon for producers (ICF, 2013). LCFS compliance, however, also relies on investments beyond fuel production. To meet targets for ethanol consumption, will require as much as \$7.2 billion invested in E85 dispensing infrastructure and at 5 million flex-fuel vehicles on the road by 2030 (Schremp, 2011). Even the ICF International report concedes that investment across all of the available technologies is not likely to be sufficient to reach targets as LCFS exists now. The ICF International's projections are shown in the following graph.

Figure 5.4: Balance of Credits and Deficits in the Enhanced LCFS Scenario



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Some concern has been expressed that the price of LCFS credits could jump, and several academics have advocated for cost containment mechanisms, such as a cap on credit prices to guard against the LCFS system collapsing (Yeh, 2014 and Lade 2013). Meeting LCFS through electricity for transportation has seen steady, though comparative modest, progress as well with the increase in electric vehicles with 0.35 million gasoline gallon equivalent (GGE) provided in 2011, 1.22 million GGE in 2012, and 1.19 million GGE in just the first six months of 2013 (Yeh, 2014, Malins et al: 2014). The use of natural gas for vehicle fuel has been mostly limited to heavy utility vehicles with slow turn over rate and has not seen significant change.

5.3.1.1 Low carbon fuel standard (2009)

The Low Carbon Fuel Standard (LCFS) is administered by the California Air Resources Board (CARB) and sets the goal of reducing the average fuel carbon intensity by 10% in 2020 as measured on a lifecycle basis. LCFS requires regulated parties (fuel producers and importers to California) to meet annual targets for their fuel mix, starting with only a 0.25% reduction in 2011 and escalating rapidly to 10% by 2020.

LCFS is a “technology neutral approach “ and “performance-based” measure that allows regulated parties to choose the most cost effective way to achieve compliance. LCFS is also considered a market-based system since companies that meet their energy needs by coming in under carbon emission targets are issued credits that can be traded to companies that are running a deficit. This gives companies two pathways to being LCFS compliant: lowering their carbon intensity, or purchasing LCFS credits.

Proponents of LCFS claim that by efficiently incentivizing the adoption of cleaner technologies LCFS fosters innovation while attracting a nascent low carbon fuels

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industry to California, creating jobs and building energy security. Findings from ICF International summarize the LCSF as “delivering cleaner fuels, insulation from gas price spikes, cuts in greenhouse gas emissions, and healthier air while our economy continues to grow – and it’s helping California maintain its leadership position in the fast-growing clean energy sector.”

However, LCSF has faced much controversy and opponents have challenged that the technologies are not developed enough to make 2020 compliance viable and the regulations place an unnecessary cost burden on industry in California that will be detrimental to the overall economy. In 2012 the U.S. District Court in Fresno ruled LCFS unconstitutional because it violates the Commerce Clause of the U.S. Constitution by discriminating against interstate commerce by assigning higher carbon scores to Midwest ethanol than identical California ethanol (this ruling is currently being held up in appeals).

5.3.1.1.1 Compliance

The California EPA, based on data provided by responsible government agency, reported 2011 Emission Reductions of 0.7 MMTCO_{2e} (CalEPA, 2013). A majority of the gains in carbon reduction have been made through ethanol, which is primarily blended in reformulated gasoline, with nearly 1.5 billion gallons consumed in 2010 (Smith, 2013). This is compared to a total of about 14.8 billion gallons of gasoline consumed in the same year. Currently, ethanol in standard vehicle gasoline is limited to 10% (called E10 fuel). However, flex-fuel vehicles are capable of running 85% ethanol (E85). In 2010, about 10 million gallons of E85 was sold to service California’s 450,000 flex-fuel vehicles, which accounts for 1.5% of California’s fleet. The limited progress of E85 is due to a 10-25% higher price on an energy equivalent basis, few stations selling E85, and the small number of flex fuel vehicles.

5.3.1.1.2 Outlook

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The California EPA, based on data provided by responsible government agency, reported expected annual emission reductions of 15 MMTCO_{2e} in 2020, but this includes their expected gains from ZEV (CalEPA, 2013).

5.3.1.2 Advanced renewable Fuel and vehicle technology program, ab118 (2007), ab8 (2013)

The Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP), a voluntary incentive program administered by the California Energy Commission that provides approximately \$100 million annually to develop fueling infrastructure for alternative and low-carbon fuels, including biofuels, natural gas, propane, electricity and hydrogen. It is funded by vehicle licensing fees. Programs also under AB 118 included: Clean Vehicle Rebate Project; Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project; Advanced Technologies Demonstration Project; and the Truck Loan Assistance Program.

5.3.1.2.1 Compliance

By June 2013 the ARFVTP had funded 233 projects for more than \$400 million. These investments will add 7,200 electric vehicle-charging stations, 205 E85 fueling stations, 50 natural gas stations, and 24 hydrogen fueling stations. Roughly one-third of funds went to electric vehicle technologies and one-third went to biofuel production technologies (CEC, 2013).

5.3.1.3 Minor policies

Other legislation in this space includes **Assembly Bill 523** (2012), which prohibits funding for ethanol production that is derived from the edible plant portions of corn. As well as the **Clean Fuels Outlet (CFO) Regulation** of 1990 which required the provision outlets of clean fuel to meet the service needs of alternative fuel vehicles of Californian roadways. CFO was designed to provide

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sufficient fuel stations for methanol, ethanol and compressed natural gas and has recently been modified to focus on hydrogen vehicles.

At the federal level, the **Energy Policy Act of 2005** established the Renewable Fuel Standard Program (RFS), which was revised under the Energy Independence and Security Act of 2007 into the RFS2 and mandates 36 billion gallons of renewable fuel to be blended into transportation fuels nationwide by 2022. RFS2 establishes four specific types of renewable fuel, each with its own target for 2022. Of the four types, the largest volume of renewable fuel is expected from cellulosic biofuel (15 billion gallons by 2022) and conventional, starch-derived biofuel (15 billion gallons by 2022). Regulated parties (such as refiners, importers, and blenders) have minimum yearly calculated blending obligations that gradually rise through 2022 (Smith, 2013).

Executive Order S-06-06 sets the target for 40% of biofuels consumed in California to be produced in-state by 2020, increasing to 75% by 2050 (CCST, 2014).

5.3.1.4 Technology options

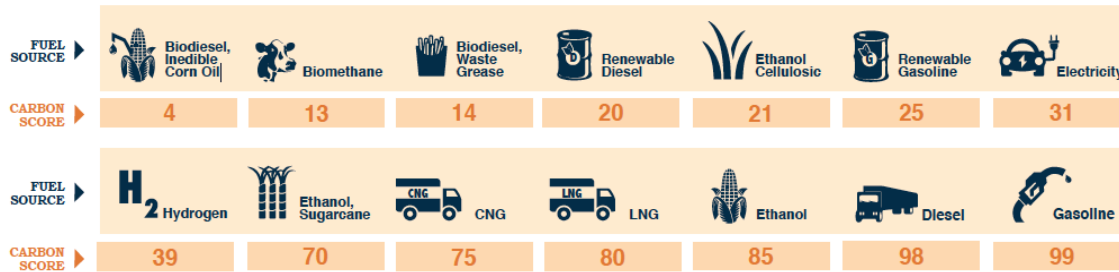
As of June 2013, there were 201 fuel pathways for LCFS compliance, 50 from CARB and 151 provided by regulated parties (Yeh, 2014). One type of alternate fuel may have several pathways with different scores (e.g. natural gas from landfills may have a significantly different carbon score than natural gas from food production waste). For example, CARB has received from producers more than 20 requests for approval of pathway for ethanol each with distinctive production processes (ICF 2013).

Each fuel's carbon score is measured "well-to-wheels." This means it combines the greenhouse gas emissions associated with all the steps in its extraction, production, refining, and final use. The lower the score, the cleaner the fuel.

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These values are not static and the carbon intensity of a pathway can vary according to changes such as upgrading transmission infrastructure, or developing feedstock production closer to refineries.

Figure @@: Carbon Scores by Fuel Source.



Source: ICF International fact sheet.

Note that traditional ethanol is only 85. Even if the transportation sector switched to 100% ethanol by 2020, it would still be 5 points off of LCFS targets. This puts the comment “LCFS technology needed to comply by 2020 is currently undeveloped, therefore experimental and unproven. There is no certainty that low-carbon fuels will be ready to meet demands within the current LCFS timeline.” (CARFP)

5.3.1.5 Cellulosic ethanol

Cellulosic ethanol is made from wood fiber or other waste plant materials which gives it a much lower carbon intensity than corn ethanol. However, production of cellulosic ethanol is more difficult and has not yet reached commercial scale.

The federal Renewable Fuel Standards requires the adoption of cellulosic ethanol, but it is unlikely that sufficient infrastructure will be developed to meet targets. The U.S. Environmental Protection Agency set the cellulosic biofuel standard each year for RFS based projected production and was forced to revise targets downwards in both 2011 and 2012 (Schremp, 2011).

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By 2013, in California, 27 facilities were in an “advanced stage” of development. If completed they would add between 337 and 512 million gallons of annual capacity (ICF 2013).

5.3.1.6 Sugarcane ethanol

“Sugarcane ethanol has lower carbon intensity than corn-based ethanol and up to 2.73 billion gallons per will be available for use in California by 2020. Virtually all sugarcane ethanol comes from Brazil and according to CEC (California Energy Commission) data no Brazilian ethanol has been exported to the U.S. since 2009” (CARFP).

5.3.1.7 Hydrogen

“Hydrogen has the potential to be a common alternative fuel. Although it does not occur free in nature, it can be reformed from natural gas and any renewable biogas or landfill gas and can be derived through the electrolysis of water. It is produced in mass quantities and is trucked or piped for use in food processing and in petroleum refining processes. Used in fuel cell passenger vehicles and forklifts, it reduces well-to-wheel criteria pollutant and greenhouse gas emissions relative to all internal combustion engine cars on the road today” (Schremp, 2011). Survey of automaker’s strategy for compliance with the zero emission vehicle mandate showed an anticipated 53,000 fuel cell vehicles are expected on the road by 2020.

5.3.1.8 Biomethane

Biomethane is a well-established fuel that is a perfect substitute for natural gas, and therefore has potential for displacing diesel fuel. However, “There have not been any known commercial transactions within California: all biomethane currently used as transportation fuel is consumed by the producer” (Schremp,

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2011). While this gas will certainly be valuable for enterprise-level application (particularly in agriculture), aggregation costs may inhibit its development as a statewide commercial fuel.

5.3.1.9 Natural Gas

Natural gas is the second most used alternate transportation fuel in California behind ethanol. “The number of natural gas powered buses in California rose from just under 1,400 in 2000 to over 11,000 in 2009. In 2009, roughly 10% of all buses were powered by natural gas” (Schremp, 2011).

5.3.1.10 Renewable gasoline

Renewable gasoline refers to processes such as gasification, pyrolysis, or biochemical processes that turn biomass to liquid processes to create a transportation fuel.

“Renewable gasoline is chemically similar to conventional gasoline, and in principle, can be distributed and combusted in the existing infrastructure and vehicles... Companies such as Dynamic Fuels, KiOR, Sundrop, and UOP all are building commercial plants to manufacture these types of biomass-to-liquid fuels... the long-term viability of renewable gasoline will be largely dependent on the ability of biofuel producers to reduce the costs of producing a stable oil for processing” (ICF, 2013).

5.3.1.11 Renewable diesel

“Renewable diesel is similar to renewable gasoline in that it is produced via biomass-to-liquid processing. Renewable diesel, however, is currently being produced, primarily via hydrogenation of bio-oils, in commercial quantities and being consumed in California... Neste Oil has been the most aggressive producer shipping renewable diesel to California. In 2010, Neste invested billions

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of dollars to build renewable diesel production plants in Singapore and Rotterdam (the Netherlands), in addition to facilities in Finland. All four of these facilities are operational; the Singapore plant is well situated to deliver renewable diesel fuel to California. It has been estimated that Neste will deliver about 100 million gallons of renewable diesel to consumers in California in 2013” (IFC, 2103).

5.3.1.12 Biodiesel

“Biodiesel consumption, mandated through RFS2, was 800 million gallons and one billion gallons in 2011 and 2012, respectively. Biodiesel production has exceeded these targets in both years the upper limit of nationwide production is about 720 million gallons in 2020 according to the EIA. By the end of 2011, approximately 40% of ethanol production facilities in the US had corn oil extraction in place, and this likely increased further in 2012. ICF research indicates that nearly every corn ethanol production facility that can be retrofitted for corn oil extraction will have done so by the end of 2014” (ICF 2013).

5.3.1.13 Natural Gas

Natural gas can be used as a transportation fuel both as a compressed natural gas (for light duty applications such as a fork lifts the do not require frequent refueling) and liquid natural gas (mostly used for long-haul trucking). Although most natural gas consumed now is non-renewable and has carbon intensity insufficient to reach long-term targets, its position in California’s energy mix has been solidified by recent large investments in refueling infrastructure and the development of shale gas production in the Monterey and San Joaquin Basins. “Clean Energy Fuels has teamed up with Pilot Flying J truck stops to create a nationwide network of natural gas refueling stations called America’s Natural Gas Highway. As of February, the first 70 of the planned 150+ stations have been constructed” (ICF 2013).

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Several automakers are also scaling up their model offerings for light duty consumer vehicles. GM, for example, is introducing natural gas versions of both the Silverado and Sierra starting around \$9,500. At this price, and with natural gas at two-thirds the cost of diesel, forecasts suggest as two-to-three year payback period, leading to significant adoption of natural gas vehicles (IFC 2013).

5.4 Urban and Regional Planning

This policy component, which I will refer to as “city planning,” includes the entire suite of policy options for designing communities in a way that reduces vehicle miles traveled (VMT). The majority of action in this component typically revolves around public transportation and residential density/mixed use planning. Other types of policies in this category capable of reducing VMT include road and parking pricing schemes, pedestrian and bicycle strategies, incentivized telecommuting, and behavior change programs. This policy component is dominated by SB375, the Sustain Communities and Climate Protection Act. Policies such as railway modernization efforts have developed independently of SB375 but state agencies and municipal planning organizations (MPOs) tend to role them into their Sustainable Community Strategies as part of SB375 compliance.

As the section on efficiency and low-carbon fuels highlighted, reaching 2050 goals will require extremely aggressive action, some of it dependent on uncertain technological development. The expected 3.0 MMTCO₂E in emissions reduction by 2020 from transportation planning may seem modest, but reducing vehicle miles travels can provide some critical relief where other measure fall short. So far planning effort appear to have significant buy in from municipalities and with expected demographic shifts to a more urban lifestyle, gains past 2020 could be sizable.

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In California transportation, particularly in urban areas, is the primary contributor to smog-forming and toxic air pollution, which have considerable negative impacts on health and living standards. That reducing VMT through planning also results in health benefit has helped city planning efforts gain political traction (Eaken, 2012). In addition to public health, other commonly cited public benefits include resource conservation, land preservation, and fiscal savings. With trips of less than 50 miles in urban areas account for 72% of VMT in California (CEC, 2013), transportation planning efforts and SB375 give municipalities a powerful tool for reducing a significant amount of emissions.

5.4.1 Progress

To date, only 7 MPOs have developed and adopted a SCS, but all seven have met or exceeded the ARB-set targets (CARB, 2014). The size of the regional transportation investment programs associated with SCSs for California's 4 largest MPOs were \$31.4 billion (L.A.), \$11.1 (Bay Area), \$10.1 billion (San Diego), and \$3.3 (Sacramento). Researchers have observed a tendency for SCS funds to be almost entirely used for capital investment (such as rail lines), opposed to planning investments (such as network connectivity), due to "biases built into the programs' underlying funding sources" (Sciara, 2013).

For an example of SB375 compliance, take the San Diego Association of Governments (SANDAG), the first MPO to adopt a SCS. The strategy commits significantly higher levels of funds to transit and planning than has previously been seen in the region and outlines a clear path for meeting 2020 and 2035 emissions reduction targets. One key feature is canceling plans to add extra lanes to Interstate 5 and instead use the \$800 million to fund transit, active transportation, and smart growth programs. It also calls for 84% of new residential growth to come from multi-family housing, and for 80% of it to be near transit stations. In spite of early accomplishments, commentators remain

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skeptical about the longevity of SANDAG's emission reductions as models suggest that after achieving short-term goals the plan will result in VMT increasing once again (Eaken, 2012).

For another example of progress, take the Southern California Association of Governments (SCAG), the country's largest MPO representing more than 18 million people and covers the greater Los Angeles region. In April 2012 members unanimously adopted a \$524 billion strategy that includes plans to invest \$246 billion in public transportation, \$6.7 billion in walking and bicycling infrastructure, and place 87% of all new jobs within a half-mile of a public transit stop (Eaken, 2012). Examining SCAG's plan, however, makes compliance seem far from assured. At \$110 billion, the largest anticipated source of revenue for the plan is a user tax of \$0.05 per mile that the plan claims will be implemented in 2025 (SCAG, 2012).

A study of the impact of Culver City's new rail system is one of the very few examples of rigorous investigation on the impacts of planning efforts on VMT and provides insight into the potential impacts of SCAG's future investments. In a difference-in-difference study of 204 residents from 2011 to 2013 researchers from UC Irvine and USC found a reduction in average VMT from about 32 to 22 miles per day for residents near the new transit stations (Boarnet, 2013).

At the state level, the Strategic Growth Council (SGC) provides coordination between agencies and financial services for helping SCS implementation. Over the next two years the SGC is using \$200 million in cap-and-trade revenue to create a Sustainable Communities Implementation Program (PIEEE, 2014).

Apart from actions within the SCS framework, California has made progress in reducing VMT (probably, but again, sufficient data to be certain probably do not

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exist) by starting to implement its rail modernization program, which includes the nation's first true high-speed rail (HSR) system (CARB, 2014).

A few incidental trends appear to be working in SB375's favor. These include: high gasoline prices; traffic congestion; demographic trends; changing attitudes towards driving; denser urban areas through infill development.

5.4.2 Policies

5.4.2.1 Sustainable communities and climate protection act, sb 375 (2008)

The piece of legislation that dominates this policy component is the Sustainable Communities and Climate Protection Act of 2008. SB375 requires the 18 local planning agencies, called metropolitan planning organizations (MPOs), to adopt Sustainable Communities Strategies (SCS) that reach transportation emission reduction targets set by the California Air Resources Board that range from 5 to 8% by 2020 and 10 to 16% by 2035 (PIEEE, 2014). The state supports MPOs by providing resources such as access to financing, planning tools, land use models, and housing certification.

5.4.2.2 California Freight mobility plan (2014)

These planning efforts will need to identify the infrastructure, including fueling and intelligent transportation infrastructure, needed to support full-scale deployment of advanced technologies, improved throughput, and expanded access to rail, public transit, and active transportation.

5.4.2.3 Rail modernization plan

California is implementing the nation's first true high-speed rail system. Signed the first construction contract in August 2013. Plans also include the electrification of existing rail infrastructure by 2019 (CARB, 2014). Completion of

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the a HSR line from San Francisco to Los Angeles is scheduled to be completed by 2029.

5.5 System efficiency

This component covers the myriad policy options beyond vehicle efficiency standards that improve the efficiency of vehicle travel. According to the CARB's AB32 scoping document this includes: redesigning road for multimodal use, eco-routing smart phone apps, vehicle automation, asphalt improvements, ship electrification at ports, tire pressure, fuel-efficient tires, and low friction motor oils.

The only real action that California has taken in this component is in multimodal use (which doesn't even really seem to fit the definition of "system efficiency to me" and might be better categorized under transportation planning), which is likely to make extremely meager contributions to reaching AB32 goals. There has been some minor action in other aspects of system efficiency, but legislation so far appears limited in scope and I have found no indication that it is resulting in significant emissions reductions. I have also found very little useful research on the potential for emissions reductions from these policy options. This appears to be a relatively minor policy component.

5.5.1 Progress

At least 70 jurisdictions in California have adopted "complete streets" plans. However, we cannot find any research that can attribute emission reductions from increased pedestrian or bicycle activity to complete street activities (like improved bicycle lanes) as opposed to planning activities (like mixed-use neighborhoods). The lack of information about successful implementation of complete street plans suggests to me that this policy promises only meager long-term emission reductions.

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As part of AB1358 compliance the Caltrans has enacted a statewide Complete Streets Implementation Action Plan in 2012, however, this appears to have resulted in little more than developing road improvement manuals for municipal transportation agencies to use. The California EPA report no recorded emission reductions from this policy, but does claim ship electrification at ports have made a minute (<0.2 MMTCO₂E) amount of reductions.

Vehicle automation has perhaps the largest potential impact on emissions. As required by Senate Bill 1298, the California Department of Motor Vehicles has created rules regulating the testing of autonomous vehicles in California. However, whether automation will result in emission increases or decrease is yet to be determined.

Several of the interventions that improve vehicle efficiency that CARB lists under “system efficiency” such as tire pressure, low-friction engine oil, and low-resistance tire are become popular independent of policy efforts. A simple Google search reveals a plethora of actors in the auto industry advocating for or adopting these strategies. For an example of the possible impact from these strategies, research on passenger vehicles found that fuel economy decreases 0.32% for each 1 psi drop in tire pressure (Evans, 2013). The extent to which the general public has changed its behavior around tire pressure, however, is of course unknown.

5.5.2 Outlook for 2050 and key issues

Unlikely to make sizable contributions to statewide emission reductions.

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5.5.3 Policies

5.5.3.1 California complete streets act, ab1358 (2008)

The AB 1358 requires cities and counties to integrate complete streets policies into their transportation planning. “Complete streets” is defined as, “A transportation facility that is planned, designed, operated, and maintained to provide safe mobility for all users, including bicyclists, pedestrians, transit vehicles, truckers, and motorists, appropriate to the function and context of the facility. Complete street concepts apply to rural, suburban, and urban areas” (Caltrans, 2012).

5.5.3.2 Ship electrification (2007)

This policy requires cargo ships to shut off their auxiliary engines while in port and switch to grid power.

5.5.3.2.1 Compliance

The California EPA, reported 2011 Emission Reductions of 0.1 MMTCO_{2e} (CalEPA, 2013).

5.5.3.2.2 Outlook

The California EPA reported expected annual emission reductions of 0.2 MMTCO_{2e} in 2020 (CalEPA, 2013), which suggested there will not be sizable future gains.

5.5.3.3 Other

Port Drayage Trucks: “This regulation requires the reduction of GHG, diesel PM, and NO_x emissions from drayage trucks operating at California’s ports and rail yards through retrofits and turnover of pre-1994 trucks” (Cal EPA, 2013).

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Transport Refrigeration Units Cold Storage Prohibition: Transport Refrigeration Units (TRUs) are powered by external combustion engines. This measure would limit the amount of time TRU engines could run for extended cold storage at facilities including distribution centers and grocery stores. ” (Cal EPA, 2013).

Cargo Handling Equipment, Anti-Idling, Hybrid, Electrification: This measure proposes to require ARB to investigate and potentially develop a new measure to restrict unnecessary idling of cargo handling equipment, which would reduce fuel consumption and associated greenhouse gases, criteria pollutants, and toxic air contaminants” (Cal EPA, 2013).

5.5.3.3.1 Compliance

The California EPA, reported 2011 Emission Reductions of 0.1 MMTCO₂e (CalEPA, 2013).

5.5.3.3.2 Outlook

The California EPA reported expected annual emission reductions of 3.5 MMTCO₂e in 2020 from the combination of these three policies (CalEPA, 2013). Presumably the large expected gains over the next decade are mostly from hybridizing handling equipment, which has not started yet.

5.6 Integrated policy planning and the Sustainable Freight strategy

Within the transportation sector 23% of emission currently come from heavy-duty trucks, 1.4% from rail, and 2.2% from water-borne transport, making the movement of freight a significant source of emissions. The Sustainable Freight Strategy (SFS), started in 2014 by ARB Resolution 14-2, is the first step in a board, as of yet undefined, Sustainable Freight initiative. Its goal is to transition

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California, “From a diesel-dependent system into one with significant numbers of zero and near-zero emission engines for trucks, locomotives, cargo-handling equipment, ships, and aircraft.” According to ARB this will be a, “broad, multi-decade effort to develop, fund, and implement the changes necessary” (CARB, 2014).

For the sake of this project, SFS require no specific attention since most, or all, of the emissions reductions that result from this strategy would be attributed to other policy components. For example, the Strategy aims to accelerate zero or near-zero emissions heavy-duty vehicles, which would fall under assisting the Advance Clean Car Program and the Heavy-Duty Vehicles Regulations. Other objectives include: improving dock-to-rail connection (which would fall under AB1358); coordinating the modernization of railway (which would fall under the Rail Modernization Plan); improving state-wide transportation system efficiency (which would be done largely by MPOs under SB375); and developing various other efficiency technologies (which would be part of the numerous efficiency policies in the vehicle efficiency section).

The primary mechanism the CARB talks about making these changes through is incentive program and research and development financing – particularly the Alternative and Renewable Fuel and Vehicle Technology Program which is part of (AB118, efficiency section).

The meaningful addition of SFS might be the “integrate policy planning” aspect, which is modeled after the cross-agency jurisdiction of SB375 (which has also been cited as a weakness by city planners). SFS for now seems to have significant political support. If it is successful at catalyzing political momentum and generating funds to other programs, it could provide a serious boost to other policy areas. Furthermore, it is plausible dedicating efforts at this high level of oversight could enable synergies between policy areas that lead to deeper

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reductions. After all, CARB does state that SFS intends to integrate with national and international freight systems, which is beyond the scope of most other policy areas (LCFS and Cap and Trade excepted). However, that CARB state near-zero-emission aircraft as a goal of SFS makes suggests to me that SFS is far from being connected to the operational realities that might affect serious changes.

5.6.1 Outlook for 2050 and key issues

SFS could provide political momentum and financial support to the Advanced Clean Car Program, SB375, AB118, and several other initiatives. Reducing emissions from water-borne transportation and aviation is talked about in other policy areas, but has little invested in it through state policies. SFS's emphasis on these two may generate some emission reductions that are actually attributable to this policy.

5.7 Supporting planning and market Development through Targeted investments

In the AB32 Scoping document, ARB list three programs in this policy area: Proposition 1B, the Carl Moyer Program, and AB118. There is probably nothing relevant for our project in this policy area since all of the emissions reduction would be attributed to other policy areas. AB118 is covered in detail elsewhere in this document, but I will provide brief detail on the other two.

Started in 1998, the Carl Moyer Program is a voluntary grant program that aims to reduce vehicle emissions through incentive funds to private companies and public agencies to purchase emission reduction technologies. Specifically, they work with ARB to target emissions reductions opportunities that go beyond regulation requirements. The project is funded through tire fees and smog impact vehicle registration fees and pays out \$60 million annually (CARB, 2013).

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Proposition 1B, also known as the Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act, was passed in 2006, \$4.5 billion of funding for the Corridor Mobility Improvement Account (CMIA). The funding is designed to, “Provide demonstratable congestion relief, enhanced mobility, improved safety, and stronger connectivity to benefit traveling Californians” (CARB website).

5.8 System efficiency

This component covers the myriad policy options beyond vehicle efficiency standards that improve the efficiency of vehicle travel. According to the CARB’s AB32 scoping document this includes: redesigning road for multimodal use, eco-routing smart phone apps, vehicle automation, asphalt improvements, ship electrification at ports, tire pressure, fuel-efficient tires, and low friction motor oils.

The only real action that California has taken in this component is in multimodal use (which doesn’t even really seem to fit the definition of “system efficiency to me” and might be better categorized under transportation planning), which is likely to make extremely meager contributions to reaching AB32 goals. There has been some minor action in other aspects of system efficiency, but legislation so far appears limited in scope and I have found no indication that it is resulting in significant emissions reductions. I have also found very little useful research on the potential for emissions reductions from these policy options. This appears to be a relatively minor policy component.

5.8.1 Progress

At least 70 jurisdictions in California have adopted “complete streets” plans. However, I cannot find any research that can attribute emission reductions from increased pedestrian or bicycle activity to complete street activities (like improved bicycle lanes) as opposed to planning activities (like mixed-use neighborhoods). The lack of information about successful implementation of complete street plans

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provide safe mobility for all users, including bicyclists, pedestrians, transit vehicles, truckers, and motorists, appropriate to the function and context of the facility. Complete street concepts apply to rural, suburban, and urban areas” (Caltrans, 2012).

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For the sake of this project, SFS require no specific attention since most, or all, of the emissions reductions that result from this strategy would be attributed to other policy components. For example, the Strategy aims to accelerate zero or near-zero emissions heavy-duty vehicles, which would fall under assisting the Advance Clean Car Program and the Heavy-Duty Vehicles Regulations. Other objectives include: improving dock-to-rail connection (which would fall under AB1358); coordinating the modernization of railway (which would fall under the Rail Modernization Plan); improving state-wide transportation system efficiency (which would be done largely by MPOs under SB375); and developing various other efficiency technologies (which would be part of the numerous efficiency policies in the vehicle efficiency section).

The primary mechanism the CARB talks about making these changes through is incentive program and research and development financing – particularly the Alternative and Renewable Fuel and Vehicle Technology Program which is part of (AB118, efficiency section).

The meaningful addition of SFS might be the “integrate policy planning” aspect, which is modeled after the cross-agency jurisdiction of SB375 (which has also been cited as a weakness by city planners). SFS for now seems to have significant political support. If it is successful at catalyzing political momentum and generating funds to other programs, it could provide a serious boost to other policy areas. Furthermore, it is plausible dedicating efforts at this high level of oversight could enable synergies between policy areas that lead to deeper reductions. After all, CARB does state that SFS intends to integrate with national and international freight systems, which is beyond the scope of most other policy areas (LCFS and Cap and Trade excepted). However, that CARB state near-zero-emission aircraft as a goal of SFS makes suggests to me that SFS is far

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from being connected to the operational realities that might affect serious changes.

5.9.1 Outlook for 2050 and key issues

SFS could provide political momentum and financial support to the Advanced Clean Car Program, SB375, AB118, and several other initiatives. Reducing emissions from water-borne transportation and aviation is talked about in other policy areas, but has little invested in it through state policies. SFS's emphasis on these two may generate some emission reductions that are actually attributable to this policy.

6 ENERGY POLICY MEASURES

As has already been emphasized, California has a very long and activist history of energy sector regulation. In addition to the usual commercial, public health, and safety measures, California has long recognized the environmental importance of the energy sector. This recognition is reflecting in an array of public interest regulations and standards, expanding significantly with the recognition of climate risk. In this section, we provide an overview of the state of implementation for those policies of greatest relevance to AB32, now and in the future.

6.1 Energy Efficiency

This policy area is among the most important as 2050 emission targets are almost certainly unattainable without maximizing gains from energy efficiency. In California, energy efficiency is considered the "highest priority energy resource" and with two pieces of legislation - Assembly Bill 1890 (1996) and Assembly Bill

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995 (2000) – mandates that utilities pursue all cost-effective efficiency resources for meeting new energy demands before adding new capacity to the grid.

Energy efficiency is also, perhaps more than any of the other critical steps, a policy story more than a technology story. The technology to make deep carbon reductions, in the ballpark of 70%, already exists and is easily scalable. Moving beyond these smaller gains, California faces some enormous challenges for developing the optimal policy to fund, measure, monitor, and incentivize energy efficiency. Among the key activities that CPUC has identified for itself are: information campaigns; coordinating research, development, and demonstration; providing technical assistance and workforce development; and designing incentive structures (CPUC, 2008 and 2014).

For residential and commercial buildings, the technology exists to get close, but not all the way to the AB 32 target. However, at this point it is far from financially viable. The state may accomplish its goal of achieve zero-net emissions among new residential and commercial construction by 2020, but achieving 2050 targets will not happen with extraordinary levels of investment and voluntary participation in retrofitting houses for the 55% of residential buildings and 40% of nonresidential buildings that were built before energy efficiency standards were passed (CARB, 2014). This will be an especially daunting task for the high percentage of low-income households and renters.

The CPUC is taking several steps to address this, such as the Whole House Retrofit Program, which provides up to \$4,000 per home for installation energy savings retrofits such as insulation and light fixtures (CPUC, 2011). However, 42% of California residents rent their homes, and efficiency have been particularly inaccessible for California's low-income residents. So far 90% of residential energy efficiency has been concentrated with single-family homeowners (CPUC, 2012b). Providing enough incentives to reach lower-income households could put a serious strain

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on California's energy efficiency budget. The CPUC also notes that programs focused on market transformation or longer-term reductions so far have only had limited penetration (CPUC, 2012b).

The state has several ambitious legislative efforts in play including incentives for retrofit homes and plans to escalate standards. These efforts are chronically hampered by a lack of data, unstandardized methods of measuring efficiency gains, and the challenges relate to coordinating the wide array of stakeholders involved in building construction (financial institutions, contractors, local permitting agencies, technology firms, etc). The current retrofit rate is far below what is necessary to meet targets.

A complication for commenting on the future of energy efficiency for buildings is that all of California's long-term plans hinge on the idea of net-zero building. This means paring building with distributed generation renewable resources to compensate for their energy consumption. This makes the accounting for emissions reductions overlap with renewable energy projections. It is difficult to disentangle expected emission reduction from renewable energy and from home efficiency is problematic, making it impossible to speculate what the future of energy savings might be strictly from efficiency measures. However, as California continues with the net-zero framework, and natural gas is progressively phased out for home heating, in the long-run the proliferation of renewable grid energy may compensate for slow retrofit rates and result in the emissions associated with buildings being within 2050 targets.

The complex policy landscape, many customer segments, diverse actors, evolving technology, budgetary uncertainties, and challenges calculating energy savings make it extremely difficult to estimate how large a role efficiency will play in accomplishing 2050 emission reduction targets. In a 2012 report, the California Council on Science and Technology attempted to calculate to maximum

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technologically feasible efficiency measures by 2050 based on a literature review and expert opinions but still but still admitted that, “Due to the scarcity of real-world data, so these estimates were fairly crude.” The analysis concluded that an 80% reduction in emissions from the residential and commercial sectors was technically possible but far from financially viable. They find it technically viable to make similar reductions in the industrial sector (Greenblatt, 2012b).

6.1.1 Types of efficiency programs

California has a vast array of efficiency programs that can be grouped in the following categories:

Standards and codes – Standards are the by far the most cost effective way for the state to achieve emissions reductions from efficiency. They generally do not require subsidies and incentive programs to maintain and apply to the entire population. In the 2010 – 2012 portfolio cycle, statewide Codes and Standards Program used less than 1% of the energy efficiency portfolio budget, but delivered 22% of the total electricity savings and 25% of the natural gas savings (CEC, 2012b). Technology can only be included under standards once it has become cost effective enough that it is viable for everyone in the state to adopt, so government agencies have a variety of other policy mechanisms to incentive the early adoption of technologies to help advance them to the point they can become standards.

Utility Programs – As a primary instrument for driving efficiency adoption, the state uses public utilities to administer rate-payer funded efficiency programs. Investor owned utilities are decoupled so that their profits are not related to the amount of energy their customers consume and are heavily incentivized by the state to push energy efficiency programs. The CPUC is responsible for approving energy efficiency budgets, setting savings targets, providing oversight, and verifying savings.

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State Programs – The California Clean Energy Jobs Act of 2012 is the largest example in this policy category. A large portion of the \$2.5 billion budget over five years is designated for supporting energy efficiency projects. Since building retrofits are typically less cost-efficient and relying on voluntary participation, the state government has used its funds to catalyze the retrofit market by leading the way with retrofitting government buildings. Executive Order B-18-12, for example, mandates that government buildings reduce their emissions 20% by 2018.

Local Government Programs – Many communities in California have created property-assessed clean energy financing districts (PACE programs) that provide property with financing for energy efficiency improvements. Local governments also have a wide array of highly targeted incentive programs.

Coordinating across government agencies, the numerous stakeholders, and private interest groups in order to ramp up or optimize energy efficiency is exceedingly difficult. For many types of energy efficiency technology, particularly with buildings, the techniques for calculating energy efficiency are often disputed or still evolving. Some sectors, publicly owned utilities, and government agencies also neglect to properly monitor and report on efficiency savings. No single government agency is responsible for aggregating data of efficiency or overseeing compliance across all policy areas. Plus, independent actions by individuals and companies not influenced by policy also contribute to efficiency gains. All of these factors combine to make it exceptionally difficult to quantify what the total savings from energy efficiency are or speculate on the future.

As the broadest-reaching and most cost-efficient type of regulations, the end-goal for most efficiency technologies is to move them into codes and standards. However, as efficiency technologies emerge it is rarely economically viable to include them in standards and the businesses and expertise need to be developed to facilitate statewide adoption. For this reason, energy efficiency

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measures typically follow a trajectory from research and development (sometime financed by policy), to being supported by utility and state incentive programs, and finally transitioning into state standards. The CPUC and CEC are stepping up leadership in this process and have outlined their efforts in the Energy Efficiency Strategic Plan.

6.1.2 Energy Efficiency Strategic Plan

The Energy Efficiency Strategic Plan is perhaps the single most important document in guiding California's energy efficiency efforts. According to the plan itself, it "Represents the state's first integrated framework of goals and strategies for saving energy, covering government, utility, and private sector actions, and holds energy efficiency to its role as the highest priority resource in meeting California's energy needs." The plan is guided by 4 programmatic goals, known as the "Big Bold Energy Efficiency Strategies" (BBEES):

- All new residential construction in California will be zero net energy by 2020
- All new commercial construction in California will be zero net energy by 2030
- Heating, Ventilation and Air Conditioning (HVAC) will be transformed to ensure that its energy performance is optimal for California's climate
- All eligible low-income customers will be given the opportunity to participate in the low-income energy efficiency program by 2020.

The Plan also sets near-term, mid-term and long-term goals for each economic sector to assist in achieving those goals.

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Since the many of the efficiency measures required for meeting 2050 are not viable to be included in state standards, the Strategic Plan is essentially an effort for overcoming the barriers for adoption and bringing down technology costs in a coordinated fashion. The CPUC and CEC have defined their role as facilitating “market transformation.” This involves engaging utilities, builders, investors, local governments, homeowners, technology companies, etc. in stakeholder workshops in order to “inspire independent action and provide a higher level of certainty and understanding for the market to build their own path to [energy efficiency]” (CPUC, 2011). The market transformation process must also be tailored for each sectors (commercial, residential, industrial, and agricultural) and system (HVAC, insulation, lighting, etc.).

The CPUC has very little authority over the array of stakeholders that require “coordinated efforts,” which can raise some skepticism for the lack specific mechanisms, details, or targets for “inspiring independent action.” The vagueness of the Strategic Pan is a reflection of the energy efficiency sector its. There is a large amount of uncertainty in the sector due to the uncertainty about how to measure or monitor efficiency, lofty policy goals without a clear path to implementation, a lack of coordination, and quickly evolving technology.

The plan also admits to two very important limitations: its development did not involve any cost-benefit analysis, and it does not cover the evaluation and measurement and verification of energy savings. These both present a hurdle for formulating appropriate policy to support energy efficiency.

6.1.3 Standards

6.1.3.1 Appliances

Energy efficiency standards for appliances have been regulated under Title 20 in California since 1980. Recent additions include standards for

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televisions (2009), and battery chargers (2012). The CEC is also currently considering other consumer electronics, lighting, and water appliances (CARB, 2014). The CEC estimates the energy saving from battery chargers alone will equal nearly 2,200 GWh per year (CEC, 2013).

The energy savings associated with appliance standards have been seeing steady improvement in recent years. According to Cal EPA data, using 2007 as a base year, electricity savings in 2009, 2010, and 2011 respectively were, 2,207 GWh, 3,813 GWh and 5,159 GWh in 2011. For natural gas they were 100, 77, and 113 million thermal units, respectively (Cal EPA, 2013).

6.1.3.2 Buildings

The incremental energy saving from California's building energy efficiency standards for 2009, 2010, 2011 were 389 GWh, 451 GWh, and 582 GWh respectively, using 2007 as a baseline (Cal EPA, 2013). These standards were upgraded in 2013 to be 25% more efficient. The CEC estimates the new standards will save Californians \$1.6 billion over the next 30 years (CEC, 2013a). The building energy efficiency standards only cover new construction, so they do not reduce previous emissions, only decrease the amount of added emissions.

The new building codes still fall significantly short of the zero-net-energy buildings that the CPUC and CEC hope to make the standard by 2020 (commercial) and 2030 (residential). In fact, the ZNE concept is not currently viable given current technology. Achieving AB 32 targets past 2020 is going to require significant EE advances that are currently highly questionable. However, the CEC remains optimistic and claims that, "Making ZNE operational will continue through the 2016 and 2019 code development cycles" (CARB, 2014a).

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6.1.4 Utility Programs

For investor owned utilities, which deliver about 75% of California's electricity supply, energy efficiency works on a two-year program cycle. The CPUC authorizes a budget for rate-payer funded efficiency programs and sets targets for emissions reductions. The utility then has flexibility to develop a portfolio of energy efficiency programs to meet these targets. The budget for the 2010-2012, the last completed cycle for which data has been released, the budget was \$3.1 billion. According to data from the utilities, which the CPCU works to verify, these programs saved 5,900 GWh in electricity, offsetting the need for 1,069 MW of new capacity. The combined cost effectiveness (the ratio of money spend to money saved) was slightly more than 2 (CPUC, 2012b).

California's POU's account for about 25% of the state's electricity and 2% of its natural gas supply. Most POU's have inconsistent evaluation, measure and verification methods and less than half have filed energy saving reports. This makes it quite difficult to comment on the progress made by the segment of utilities but they do lag considerably behind investor owned utilities. In 2012, publicly owned utilities reported declines in savings for the third consecutive year. Since 2006 POU's have only achieved around 2,700 GWh of energy efficiency savings, about half of the one year total for investor owned utilities (CEC, 2013a).

Due to the lack of available data for, the following sections will highlight progress in energy efficiency programs by investor owned utilities.

6.1.5 Commercial and Residential

The commercial sector accounts for 55% of the energy efficiency saving while the residential sector accounts for 34%. Together these two sectors represent 89% of California's energy savings (CPUC, 2012b).

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In the residential sector the Home Energy Efficiency Rebate (HEER) program is the single largest source of energy saving. The program offers rebates for high efficiency technologies such as insulation, water heaters, and appliances. Other programs include Appliance Recycling Program, the Home Energy Efficiency Survey and Universal Audit Tool, the HVAC Quality Installation and Quality Maintenance program, and multiple behavior change programs to encourage reduced consumption or self-installation of efficiency technologies. Most of the energy saving continue to be realized through long-running programs in lighting and appliances;

The commercial sector includes 5 billion square feet of building space and consumes 38% California's electricity, making it the largest customer segment. Commercial buildings also use a significant amount of natural gas at over 25% of California's total supply. The energy efficiency program for the commercial sectors are also much more numerous and diverse with 107 programs and sub programs tailored to specific customer segments. The programs include rebates, installation assistance, new construction design assistance, and no-cost assessments (CPUC, 2013c).

6.1.6 Industrial

The CPUC has 25 industrial programs in their portfolio administered by independent utility operators have. The programs are split between targeting specific industries and targeting specific technologies like boilers and usual incentivize process improvements or equipment upgrades. Energy savings for industrial programs are calculated on a custom basis (CPUC, 2012b).

These regulations do not represent a very robust strategy for reducing emissions from industry and it seems that government agencies are still struggling to develop appropriate policies. For example, the Regulation for Energy Efficiency

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and Co-Benefits Assessment of Large Industrial Facilities was passed in 2010 requiring the largest industrial facilities in California to conduct energy efficiency assessments of their emissions sources. Implementation is still in the first of three phases and ARB staff members are compiling the information in the reports from the industrial facilities. As of July 2014, only two reports were finished and published: for the cement industry and the refinery industry.

6.1.7 Other Efforts

6.1.7.1 Geothermal Heat Pumps

Assembly Bill 2339 requires the CEC to investigate policies for encouraging the use of geothermal heat pump (GHP) and ground loop technologies. GHP technology can use 25 to 50% less electricity than conventional HVAC systems have higher upfront cost and are not viable at every building site. While GHP is could potentially provide emission reduction, adoption has been held up by inconsistent permitting requirements and insufficient modeling software to demonstrate compliance (CEC, 2013a).

6.2 Renewable Energy

According to CPUC's website, 22.7% of the retail electricity served by California's largest 3 IOUs was produced by RPS-eligible electricity, exceeding the first RPS compliance target of 20% by the end of 2013. By the end of 2012, the latest publicly available data, a total of 7,267 MW of RE capacity had been added to the grid since 2003. The rate at which RE capacity has been added has seen steady acceleration but has leveled off recently with 2,769 MW of RE capacity added in 2013 and 2,721 MW scheduled for 2014. CPUC forecasts also show utilities should have no issues with compliance of the subsequent targets of 25% RE by 2016 and 33% by 2020 (CPUC, 2014b).

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The CEC also claims that California may actually be ahead of schedule to meet the 2020 targets and that all of the necessary projects are “in the pipeline.” In 2012, California generated 8,272 GWh through solar, 13,040 GWh through wind power, 12,790 GWh through geothermal, and 6,982 GWh through biofuels (CEC, 2013a). These figures, however, exclude any distributed generation that takes place on the customer side of the meter. It is important to note that figures such as these for renewables are frequently given as electrical energy (power per hour – how much has actually been generated) rather than power which is how the installed capacity of most power plants is talked about (MW for example – how much electricity could be generated at any one time). This is because renewables, being intermittent, will usually only have capacity factors of 25% or less (they only generate 25% of the electricity they would if they could run non-stop). Therefore, replacing 1 MW of natural gas turbines would require several MWs of solar plus a load balancing solution. While recent progress in developing renewable energy is encouraging, renewable energy is still not a perfect substitute for conventional energy and the grid needs to evolve considerably before adding renewable energy translates directly to reducing emissions. Currently, for example, the CEC laments that, since most renewable resources cannot be deployed anywhere, they often “make little difference in displacing capacity that must be located in transmission-constrained areas along the coast” (CEC, 2013a).

6.2.1 Distributed Generation Solar

Distributed generation (DG) refers to any small-scale energy generation at or near the site of consumption. Typically it is not utility owned or centrally planned. DG can be either a commercial venture where independent power providers supply power to the grid under an independent power provider agreement, or owned by residential consumers (“customer side of the meter” installations). DG can utilize any type of generating technology. Fuel cells, for example, are

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particularly popular with large data centers. While California does have many types of DG resources, DG is almost synonymous with residential roof solar as this represents the vast majority of DG capacity.

California has multiple programs encouraging customer side of the meter solar power. These include California Solar Initiative (\$2.2 billion budget), the New Solar Homes Partnership (\$400 million budget), and various publicly owned utility incentive programs (with an estimated total budget of \$784 million). Collectively these are known as Go Solar California! and are responsible for about 240,000 solar installations totaling 2,268 MW (Go Solar California! website). This rapid progress has largely been enabled by a rapid decline in the price of solar panels. In 2007 the average price per watt about \$10.50. In 2014 that number has fallen to around \$5.50 per installed watt (CA Solar Statistics).

The irony behind this progress is that DG actions on the customer side of the meter are largely invisible to utilities and the impact that these resources have on the grid, or on California's emissions, is highly questionable. In the Transmission Planning Process the California Independent System Operator (CASIO) found a very limited ability for the DG to be substituted for conventional power generation (CEC, 2013a). It is well established that DG capacity added at the wrong place at the wrong time can add overall costs to the system. While the normal problems with intermittency apply to distributed solar, the problem can be amplified by the fact that distributed solar is invisible to utilities and proper grid planning is not possible. It is very possible that at this time, lacking adequate storage or demand response, the rapid addition of distributed solar generation requires utilities to "cover" this intermittent capacity with an equal amount of traditional generation capacity.

In spite of these rapid gains, DG penetration level is still considered low by the CPUC. At current levels of penetration, utilities have been able to proactively

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mitigate for transmission and interconnection challenges. Successfully maintaining proactive management of distributed generation in the future is questionable as utilities continue to lack the necessary tools for determining the effects, both positive and negative, that DG is having on the grid. (CPUC, 2013d).

As with the load balancing problem for grid-scale intermittent generation, if energy storage achieves cost effective levels it could nullify many of the problems associated with DG. Additionally, there are several emerging technologies on the way that could smooth over DG integration. These include: smart inverters that prevent system disturbance from PV trips; smart grid technologies that improve DG management through data transparency; and micro grids that combine storage, sensing, distribution, and management being the meter at the household or community level.

6.2.2 Wind power

Despite the recent rapid growth in solar power, wind continues to be the largest contributor to renewable energy generation. Over the last 10 years, the amount of wind power added each year has increased steadily with more than 5,000 MW of nameplate capacity added in 2013. Looking forward to 2050, wind will almost certainly continue to play a leading role since wind, along with solar, is one of the only two renewable resources that California has in sufficient quantity to meet future demand.

From a cost perspective the continued supremacy of wind power seems uncertain. The levelized cost of wind turbines, which is influenced by both the capital costs and the performance of the turbine, saw around a three-fold reduction in the 1990s. This however has begun to turn around as the capital cost for wind turbines have begun to climb upwards since 2003 and performance improvements to turbines are starting to level off. Some research predicts that the price of wind power may actually increase in coming years (Lantz, 2012). The

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CEC meanwhile expects the cost of installing wind power to continue to decrease slightly but for this to be “offset by increases in the cost of land and transmission” (CEC, 2013a). This makes the future of wind energy seem uncertain in a time of abundant and cheap natural gas and plummeting solar PV technology costs.

From the perspective of attaining California’s policy goals, however, it seems unlikely that wind can be excluded from the mix. Unlike solar, wind continues to generate at night. Furthermore, while the whole state may be cloudy for an extended period, particularly in the winter when there are already shortened daylight hours, wind is almost always blowing somewhere in the state. Geographically dispersed wind resources can allow windy parts of the state to compensate for parts of the state that have prolonged stretches of calm winds. This gives wind tremendous load balancing advantages over solar. Recent studies demonstrate that a wind-to-solar of 2:1 may be optimal for reliability on a predominantly renewable energy grid. This is not likely to be feasible in California, which has vastly more solar resources. Importing wind energy from states like Wyoming may be necessary (Jacobson, 2014). The reliability of wind has been demonstrated to a limited degree by several areas in Europe where wind provides 20% of electricity “with no adverse effects on system reliability” (UCS, 2013).

While wind may face cost issues in the short-term, in the long-term wind resources may be limited as well. A recent Stanford study demonstrated that California’s technical potential capacity for locations with capacity factor greater than 30% (higher capacity factors make projects more financially viable), adjusted for land restrictions, is about 73.3 GW of delivered power. If fully developed, this would only provide roughly 40% of what they calculate to be California's 2050 all-purpose energy demand (Jacobson, 2014).

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6.2.3 Outlook for 2050 and key issues

A report from the California Council on Science and Technology series California's Energy Future provides a benchmark for assessing technological potential for achieving AB32 at 2050 targets. The report found that even under their high-demand scenario, building the capacity to meet 2050 demand (about 500 TWh/yr) with just renewable energy is viable. All of the technologies they used in their modeling are commercially viable in their present state and have been deployed. This would be conditional on solving the load balancing problem, which is discussed more in the storage and demand response sections, as well as prices for RE technology dropping. (Greenblatt, 2012c).

6.2.3.1 Demand

In the CEC's latest ten-year energy demand forecast, they calculated 2024 based on the average of a range of demand and efficiency scenarios. By their estimates, efficiency will counteract growing demand for a "remarkably flat" demand growth only 0.2% annually (CEC, 2013a).

To get demand forecasts past 2024, as part of CCST's "California's Energy Future," Jane Long developed an electricity demand model by working backwards from scenarios that actually accomplish 2050 emissions reduction targets. The model assumed a 2050 population of 55 million Californians, 60% of the fleet being PEVs or HPEVs, aggressive efficiency measures in all sectors, and partial electrification of industrial and heating processes. From this she projected a 2050 energy demand 510 TWh/yr, almost twice the 270 TWh/yr consumed in 2005 (Long, 2011).

6.2.3.2 Nuclear Energy

Although not a renewable energy, nuclear energy is the only established zero-emission technology capable of supply many gig watts a day power. This makes

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future nuclear policies highly relevant to any discussion of emission reductions. The recent closure of the San Onofre Nuclear Generation Station (SONGS) and the Diablo Canyon Power Plant, create both a threat and opportunity for renewable energy. In 2011 nuclear energy provided 18% of California's electricity. Filling this void in has likely helped fuel the recent influx of investment in solar energy and distributed generation. However, adding intermittent energy resources to the grid before the zero-emission load balancing resources are in place to compensate may force investment in natural gas turbines to fill the need (CEC, 2013a).

On the generation side, from a technology stand there are no major hurdles to meeting capacity demand with renewable energy. From an economic standpoint, adding the capacity is to become economically viable without subsidies in the near future as well. The big uncertainty lies in what will happen to the financial equations as the demands for loading increase with added renewable energy capacity.

Energy storage, and to a lesser extend demand response, offer considerable promise for making loading balancing technologically feasible (discussed in more detail in the following sections), but here timing is everything. The advances in storage technology need to take place fast enough to for it to be commercially viable to accommodate a highly intermittent grid. Approximately 4 GW of storage is needed by 2020 to accommodate 33% renewable energy (MSF website and DoE, 2013b). This number is likely to climb steeply after that as the grid approaches having a majority of its power coming from intermittent renewables. If the costs of energy storage are not drastically reduced on a similar timescale, it could make the true cost of solar and wind infeasible.

Enormous changes in transmission, policy, and grid management need to happen in concert as well. Transitioning the grid to ubiquitous distributed

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generation, automated demand response, ubiquitous storage, and intermittent renewable energy resources will require a drastic overhaul. CEC admits that significant planning is still needed to “help increase the resiliency of the energy system while transforming it dramatically” (CEC, 2013a). This evolution will entirely change the way the grid functions. The process will require the collaboration of a wide variety of stakeholders, technological advance, and massively complex administrative challenges. All of these add to the uncertainty of renewable energies future.

6.2.3.3 Biofuel for Electricity

AB1900 requires the creation on a “bioenergy action plan” and an investigation into how biomethane can be procured in California for renewable energy generation. So far the Commission has conducted workshops and stakeholder sessions but no actions have been taken towards developing biomethane production capacity. The Commission’s work appears to taking biofuels off the table for the short-term as a renewable energy resource. Based on an assessment of competition for California’s biomass resources the Commission stated that California “Must recognize the limits to energy production from this resource.” Only 0.02% of available renewable energy resources are currently from biomass (CEC, 2013a). However, SB1122 requires that the California’s three biggest utilities procure 250 MW of small-scale bioenergy through feed-in tariff starting in 2013. Procurement must come from a mix of municipal waste water, dairy farms, and forest byproducts.

6.2.4 Key Policies

6.2.4.1 Renewable Portfolio standard, SB 1036 (2002)

The Renewable Portfolio Standard (RPS) requires California’s investor-owned and publicly owned electric utilities to procure 33% of their from renewable

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sources by 2020 (CEC, 2013). A 2011 decision amended RPS to allow for tradable renewable energy credits (TRECS) to be used for up to 25% of RPS compliance.

6.2.4.2 Clean Energy Jobs Plan, Proposition 39

Proposition 39 set the target of adding 8,000 MW of centralized renewable energy to the grid by 2020. To do this, \$2.5 billion was allocated over 5 year to be made available for eligible renewable energy project (CPUC, 2013c).

6.2.4.3 California Solar Initiative, SB1 (2006)

In 2006 the California Solar Initiative (SB1) set a target for 3,000 MW of self-generation solar, including solar water heating, by 2017. The initiative created a rebate program for the customers of the state's three largest utilities.

6.2.5 Compliance

According to CPUC by the end of the first quarter of 2014, 2,139 MW of solar capacity was installed at 227,141 customer sites. The California Solar Initiative General Market Program has already reached 83% of its target by funding the installation of 1,455 MW. Cal EPA estimates that this resulted in 0.26 MTCO₂e of emission reductions for PG&E customers, 0.32 MTCO₂e for SCE customers, and 0.35MTCO₂e for SDG&E (Cal EPA, 2013).

6.3 Industrial

Of the 459 MMTCO₂e of emission recorded in 2012, 89.2 were from the industrial sector, representing 19.4%. This sector emitted 6.2% less in 2012 than 2000 (CARB, 2014b). The sector is included in the energy section of the Scoping Plan because a majoring of its emissions to come from energy use. However, the vast majority of its emissions reductions area expected to come from cap and trade

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(CARB, 2014a). Other major sources of emission reductions come from efficiency measures and combined heat and power improvements. All three of these programs are covered in other section of this report and will be excluded here.

What remains to be highlighted in this section are the suite of regulations that CARB has developed for specific industries to cover fugitive emissions, but so far very little has moved to action.

In 2010, ARB a regulation requiring many large industrial facilities in California to conduct a one-time assessment of energy consumption and emissions. According to the Scoping Plan, four years later CARB is “currently developing public reports for each industrial sector, summarizing the information provided by the facilities” (CARB, 2014a). Only two industries have seen specific regulation placed on their fugitive emissions.

First is the oil and gas extraction industry, the states second-most emitting industry. Two bills have been passed to requiring the upgrade of many of the pipes and pumps involved in extraction and transmission, but as with the Scoping Plan, this is discussed in a separate section.

The second industry to receive targeted regulations is the Landfill Methane Control Measure, which was passed in 2010 and is currently in the “Discrete Early Action” phase. The regulation requires municipal solid waste operators to install gas collection and control systems and implement advanced methane monitoring. The expected emissions reductions from this regulation are 1.5 MMTCO_{2e} per year by 2020 (Cal EPA, 2013).

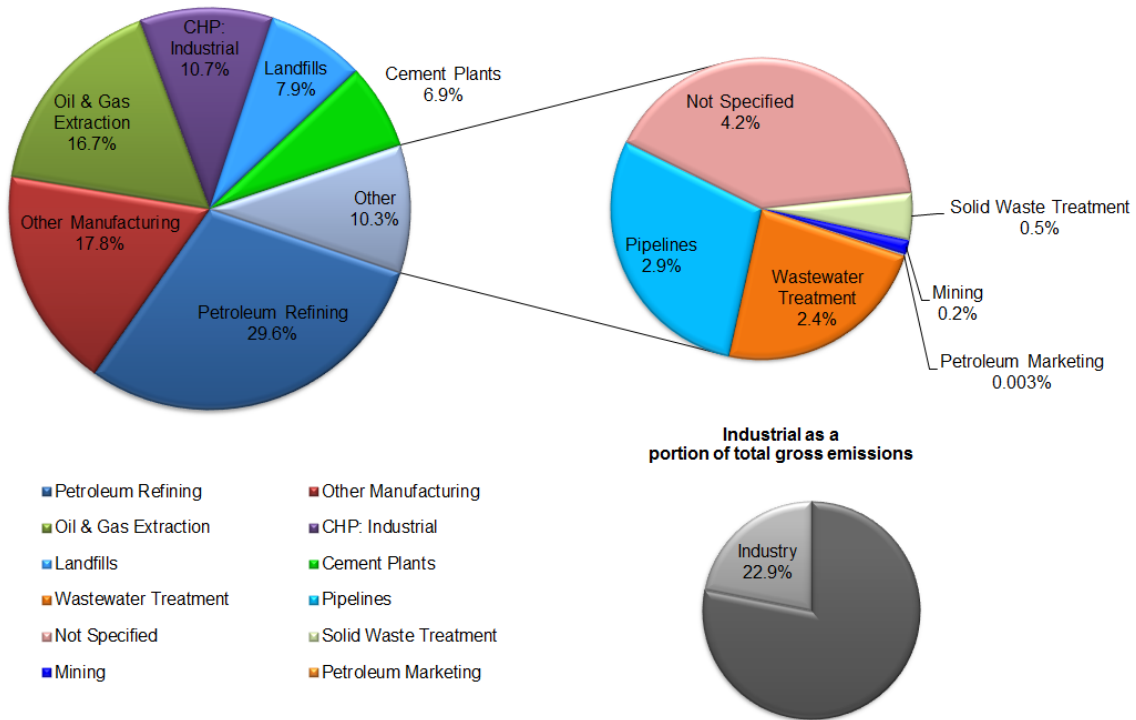
As an indication of how much CARB’s efforts are lagging in fugitive emissions, the “Industry and Manufacturing” section of their webpage only has links for two

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industries that have seen “GHG reduction activities”: cement (last update 2008) and glass manufacturing (last updated 2010).

A breakdown of emissions by each industry is shown in the following graphs.

Figure 6.1: Estimated Fugitive Emissions by Sector



Source: CARB, 2014b

The Air Resources Board recently produced a detailed study of cement sector efficiency and co-benefits (CARB (2013a)). This report summarizes the data provided to the Air Resources Board (ARB or Board) by cement manufacturing facilities subject to the Energy Efficiency and Co-Benefits Assessment of Large Industrial Facilities Regulation (EEA Regulation). The 8 cement-manufacturing facilities subject to the EEA Regulation identified 79 energy efficiency improvement projects specified as either completed/on-going, scheduled, or under investigation. The total greenhouse gas (GHG) reductions associated with

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these projects is estimated to be approximately 0.68 million metric tonnes carbon dioxide equivalent (MMTCO_{2e}) per year.² Approximately 93.3% of the estimated GHG reductions (0.632 MMTCO_{2e} per year) are from completed and ongoing projects, with 92.8% (0.629 MMTCO_{2e} per year) of the reductions from projects completed and ongoing before 2010 (and therefore already accounted for in the 2009 emissions inventories) and 0.5% (0.0035 MMTCO_{2e} per year) of those reductions from projects completed during or after 2010. Approximately 6.7% of the estimated GHG reductions (0.046 MMTCO_{2e} per year) are from projects that are scheduled (0.5%) or under investigation (6.2%). Corresponding reductions of oxides of nitrogen (NO_x) are 4.88 tons per day (tpd), with approximately 96.8% for the reductions from projects completed and ongoing before 2010 and 3.2% of the reductions from projects completed during or after 2010, scheduled, or under investigation.

In its recent review of the refinery sector (CARB:2013b), CARB identified 12 refineries subject to the EEA Regulation identified over 400 energy efficiency improvement projects. The total greenhouse gas (GHG) reductions associated with these projects is estimated to be approximately 2.8 million metric tonnes carbon-dioxide equivalent (MMTCO_{2e}) per year. Approximately 78% of the estimated GHG reductions (2.2 MMTCO_{2e}) are from completed projects, with 63% (1.4 MMTCO_{2e}) of these reductions from projects completed before 2010 (and therefore already accounted for in the 2009 emissions inventories) and 37% (0.8 MMTCO_{2e}) of those reductions from projects completed during or after 2010. Approximately 22% of the estimated GHG reductions (0.6 MMTCO_{2e}) are from projects that are scheduled (7%) or under investigation (15%). Corresponding reductions of oxides of nitrogen (NO_x) and particulate matter (PM) are 2.5 tons per day (tpd) and 0.6 tpd, respectively, with approximately 50 to 60% of the reductions from projects completed before 2010 and 40 to 50% of the reductions from projects completed during or after 2010, scheduled, or under investigation.

6.4 Demand response

Demand Response (DR) one primary tools for enabling scaling up of highly intermittent RE resources. DR works by having adjusting when time-flexible electricity activities (like air-condition which could run for one hour out of three and still keep a building cool) are used.

The primary usefulness of DR is smoothing the daily load curve. If a grid is below 20 GW for 80%, but hits 30 GW at peak, that is 10 GW of capacity that needs to be built and maintain only to run below 20% capacity. For now, while load balancing is done primarily by natural gas, if DR can be used to flatten the daily demand frequency curve, it could save substantial emissions as well as cost. In the future, when load balancing is done by batteries, it's unclear what the emission reduction from demand response would be apart from improving the cost-effectiveness of batteries.

6.4.1 Progress

Although demand response, along with EE, is at the top of California's loading order (utilities must meet required grid-load with these resources before using natural gas), it has so far seen only limited progress and lags behind targets set in 2007 (CEC, 2013a). In California demand response is primarily driven by utilities and aggregators (although the 'utilitycentric' approach is not the DR pathway and the some commenters criticize California policy for relying too heavily on utilities). Efforts are supported by \$1 billion of ratepayer funding over three years. There is currently around 2,000 MW of available DR capacity (CARB, 2014).

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Under most existing programs, customers receive incentives for manually reducing their electricity use during certain peak times, an approach that does “not provide anything close to the response time and precision needed for DR to provide grid management support” (CEC, 2013a). Some utilities are piloting automated programs where the utility controls some of the electricity demand, which is one of the key steps in smart grid development. This, in theory, should greatly increase DR capacity. According to the California Council on Science and Technology, “there is an expectation that this capacity can be greatly increased in a future grid that is more automated” (Greenblatt, 2012c). However, efforts to develop a smart grid have stumbled considerably. As of 2013, California’s three largest investor owned utilities had a combine 250 MW of “AutoDR” capacity (CEC, 2013a).

6.4.2 Outlook for 2050 and key issues

The Demand Response Research Center at Lawrence Berkeley National Laboratories suggests that advance telemetry, communication, and measurement systems are on their way that will allow for broader and more cost effective automated control of demand response resources. DRRC research suggests that this advance have put the electricity market “on the verge of transformation” (DRRC, 2013). If their predictions are correct, the total capacity of demand response in California would grow considerably. This would allow load shifting on scale that could defer the need to build new power plants or transmission infrastructure upgrades, buying the utility planning a flexibility in re-engineering the grid for renewables.

There are also exciting possibilities with smart metering and PEVs when they become prevalent. With thousands of large car batteries dispersed throughout a

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community, the utility can use them the top 10% of the batteries to cover frequency regulation (Greenblatt, 2012c). It is likely however, that it becomes more cost effective to use batteries at distribution points to fill this need.

A fundamental crux of demand response is that requires consumer participation. In the car battery example, it is likely that the utility could only compensate the car owner a few dollars per month at most, which could be insufficient to induce participation. The realize value to utilities for most demand response programs may be less than the threshold incentive for consumers.

Further automation of the grid and integration demand-side resources seems inevitable. What impact this will have on California's emission reduction will be highly dependent of on several factor including: how fast DR capacity can be ramped up; how quickly grid-scale energy storage is developed and deployed; and how fast renewable energy is scaled up. It is very possible to imagine scenarios where the challenges of consumer participation, grid communication and integration, and policy reform persist into 2020, while in the meantime utilities are forces to deploy large-scale energy storage to meet the load flattening functions that DR is expected to fill.

6.5 Energy Storage

Energy storage has only recently been identifies a critical part of California's energy future. Only in 2013 was California loading order updated to include energy storage as a "preferred resource" along with EE, RE, and DR. (CPUC, 2013c). In the context of enabling RE, "energy storage" typically refers to batteries, but can be compressed air, fly wheels, or pumped hydropower. Battery storage provides multiple benefit to load balancing. Different battery technologies can be scaled to any almost any need ("giga-watt day problem" excepted), deployed anywhere, and optimized for frequency regulation serves (adjusting

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sub-second), load following (adjusting on the minute to hour scale), and ramping (compensating for multiple hour fluctuations). They are zero-emission, quiet, require no water resources, can be deployed in front of or behind the meter, and can negate the need for transmission investment.

More than demand response, energy storage is expected to provide the solution to load balancing. Demand response is much better suited to smoothing out the demand curve, which could greatly reduce the magnitude of peak demand and make it easier to meet load following needs with batteries, thereby significantly reducing costs. For load balancing demand response is flawed by being too slow to respond, extremely complicated to administer and calculate optimal compensation which makes it makes it questionably reliable, and most of all, at its best demand response will probably only be able to provide a fraction of the dispatchable power needed for load balancing on an RE grid.

6.5.1 Progress

The frontrunner in the technology race is the lithium ion battery, which is already ubiquitous in appliances. There have already been 15 deployments of more than 1 MW, with the largest being 40 MW (DOE, 2013). Successful trial demonstrations are underway in the 5-20 kW distributed systems, and 1 MW load following range. Chevron has deployed the first peak-shaving Li-ion system at 2 MW, and utilities are presently deploying some of the first megawatt-scale units specifically for PV integration (Akhil, 2013). The technology has been proven viable and only needs to drop in price for it to become widespread in the United States. This is expected to be helped along by PEVs and PHEVS which are now primarily using Li-ion batteries. Li-ion manufacturing scale is estimated to hit 30 GWh by 2015 (DoE, 2013).

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Lithium ion batteries, however, are only optimally suited for short discharge. Energy storage on the scale capable of reaching 2050 targets will require developing a more robust set of storage technologies, particularly with deep-discharge capabilities. Compressed air, sodium-sulfur, and flow batteries are among the other technologies receiving significant investment and are in the demonstration phases to meet this need (Akhil, 2013).

Pumped hydropower has so far been the dominated method of storage. However, for energy storage to replace natural gas turbines for energy storage, a large amount will need to be responsive in under a second, which hydropower cannot do. For this reason, hydropower was left out of AB2514 and the CPUC has started to pay for energy storage based on speed of electricity supply as well as volume.

6.5.2 Outlook for 2050 and key issues

The Department of Energy realistic “long term” technology development targets they expect to see by 2013 include levelized systems cost of under 10 ¢/kWh/cycle, which would make it easily economically scalable without subsidies. Their work indicates that value realization for utilities will surpass technology costs around 2018 (DoE, 2013).

AB2514 has kicked off a “gold rush” of technology development companies working to improve several types of battery technologies which industry experts expect to produce the robust set of needed technology options. AB2514 has also catalyzed a variety of storage service providers producing concern from utilities that supply of storage will outpace demand as RE is slowly added to the grid.

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The Department of Energy calculates that the Renewable Portfolio Standard of RPS 20% renewable generation by 2020 while require about 18.6 GW of storage for grid stability (DoE, 2013b). This is roughly proportional with the calculations done for California by Megawatt Farms Storage that finds 4 GW of storage is needed to accomplish the 33% RPS goal of 2020. Megawatt Farms Storage claims that they have, “Been told by industry analysts, utility executives and government officials that this is in line with their own estimates” (MSF website). All indications suggest that this is an attainable goal and energy storage should be a viable solution to load balancing requirements.

6.5.3 Policies

6.5.3.1 AB2514 (2010)

This bill instituted a framework that requires the investor-owned utilities to collectively procure 1,325 MW of energy storage by 2020. All major utilities have been given individual targets for both transmission and distribution storage. The bill also requires aggregators to acquire 1% of their peak load in storage. The CEC ruled that hydropower pumped storage would not we counted towards compliance (CEC, 2013a).

6.6 Combined Heat and Power

Combined heat and power, or cogeneration, is used primarily in industrial settings where both thermal energy and electrical power are needed. In 2012, 5.1% of California’s emissions, or 23.4 MMTCO_{2e}, were from CHP in the industrial sector, with a small amount from the commercial sector as well, but Cal EPA figure are slightly inconsistent (CARB, 2013). As part of the Clean Energy

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Jobs Plan, Governor Brown set a goal for 6,500 MW of added CHP capacity by 2030 (CARB, 2014).

6.6.1 Progress

AB1613 and AB2791 recently created standards and a tariff for new high efficiency CHP systems. Implementation however is pending litigation. (CARB, 2013a). The California EPA, based on data provided by responsible government agency, reported expected annual emission reductions of 4.8 MMTCO₂e in 2020 (CalEPA, 2013). This is mostly expected to come through a settlement agreement between CPUC and the largest investor owned utilities to procure 3000 MW of capacity by 2015.

6.6.2 Outlook for 2050 and key issues

As noted early, reaching 2050 targets will likely requiring electrifying as many industrial processes. Several industrial processes require “high quality heat” that is only possible through burning fossil fuels. It is unclear what percent of CHP operations fall into this category. Furthermore, while CHP systems can improve efficiency in a carbon economy, an analysis that seems to be missing from the conversation is where CHP still provide considerable efficiency gains in 20 years when renewable energy becomes more abundant. Given the efforts to phase out natural gas as much as policy, and the lack of political momentum on this topic, I am inclined to think it will not play a large role in long-term emission reductions. This may be supported by the Scope Plan which admits that “due to older system retirements, the State’s overall CHP capacity may be lower now than it was in 2008” (CARB, 2014). Similarly, in a market report on CHP commissioned by CEC, ICF International identified about 8,500 MW active CHP in California and more than 14,000 MW of addition technical potential. The CEC developed three

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scenario of CHP policy and market penetration and found CHP falling short of emission reduction targets in a forecast to 2030(CEC, 2012).

6.7 Oil and Natural Gas

This section appears to have little relevance to our project. The way that CARB calculated emissions, almost all of the actual combustion of natural gas falls into other policy areas. In 2012, 45% of the natural gas burned in California was used to produce electricity. 30% was used in the commercial and residential sectors and would be covered in the building efficiency and CHP sections. 21% was used in industry, much of it CHP.

Only 3.8% of California's emissions, or 17.6 MMTCO₂e are attributed to the actual extraction and transmission of natural gas and oil (Cal EPA, 2013). Nevertheless, CARB is devoted significant energy to this sector and they are developing "best-in-industry practices to minimize GHG, criteria and toxic pollutant emissions associated with the production and refining of oil and gas" through a series of proposed regulatory measures (CARB, 2014a).

6.7.1 Progress

According to the California EPA, regulation to minimize venting and fugitive emissions are expected to reduce emissions by 0.2 MMTCO₂e annually by 2020. Other regulations requiring the upgrading of pipes and compressor stations are expected to result in 0.9 MMTCO₂e annually by 2020 (CARB, 2014b).

6.7.2 Outlook for 2050 and key issues

Several trends such as EE for buildings, electrification of industrial processes, and transitioning from gas turbines to DR and ES for grid balancing, if successful, could substantially lower natural gas demand, and with it the 17.6 MMTCO₂e

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currently associated with its production. However, California currently imports 90% of its natural gas. It seems likely that a reduction in natural gas demand, California will import less but not change in-state production trajectories. Furthermore, with the development of the Monterey Shale Fields, in-state production is expected to ramp up, which will likely off-set the policy efforts to limit fugitive emissions and improve efficiency of extraction.

The rise in needed load balancing with increased renewables could also significantly drive up demand if energy storage and demand response are not successful. Natural gas is also currently the main source of hydrogen for FCVs. The FCV movement does intend to transition to biofuel-produced hydrogen, but that is still speculative. If FCV do become widely adopted, it could increase emissions from natural gas production.

6.7.3 Policies

6.7.3.1 SB4 (2013)

This bill increases regulatory oversight for fracking and will likely probably result in improved efficiency and lower fugitive emissions. In particular, Cement and monitoring standards can be expected to help, but DOGGR is counting primarily on CARB and CARB has stated it plans to put performance standards on oil and gas supply chains. Independent marginal abatement cost estimates (ICF: 2013) show significant opportunities for negative cost compliance.

7 MODELING UNCERTAINTY

Economic policy is subject to a broad range of systemic and exogenous uncertainties, during development, implementation, and beyond. In the past, most economic assessments are delivered as point estimates, implying

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somehow that the forecasting profession can offer deterministic guidance. Particularly when looking at dynamic issues like energy markets, and long term adjustment processes, such a perspective is increasingly untenable. In other human endeavors, uncertainty is also pervasive, but in some fields it has been effectively managed with statistical methods. For this reason, we implement an explicit Monte Carlo framework, evaluating each of our scenarios repeatedly under varying assumptions about three important data uncertainties: energy prices, technology costs, and price sensitivity of electricity demand.

In engineering, reliability analysis is critical to hedge against risks of uncertain specification, design, materials, and operating conditions. Indeed, there is a large literature on most components of modern energy systems, including generation technologies, transmission systems, etc.⁹ Likewise, markets manage extensive risk patterns with statistical methods, including the same Monte Carlo methods popularized by engineers. Simpler “stress test” models of stochastic net present value inform most large project investments, but the spirit of these approaches is the same. In economic forecasting, there is also a long Monte Carlo tradition of “sensitivity analysis”, mainly intended to overcome uncertainty in estimates of behavioral parameters.¹⁰

What has been largely missing is an efficient methodology for what might be terms “policy reliability analysis,” a tractable empirical framework that can quantify the potential costs of uncertainty facing economic decision makers. It is somewhat surprising that most forecasters still report point estimates for events in the distant future, using scenario analysis to compare seemingly deterministic differences in outcomes of qualitatively different policies or states of nature. In

⁹ See e.g. Mazumdar and co-authors, Snyder and Stremel (1990), Scully et al (1992), and others cited below.

¹⁰ See, e.g. Thissen (1998) for a survey, as well as Abler et al (1999), Belgodere et al (2011). In energy modeling, see also Borenstein and co-authors.

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reality, it is only possible to anticipate an interval of outcomes from any action, hopefully with a corresponding degree of confidence. This approach might be more responsible for those who forecast, but it offers an important degree of robustness against very real risks faced by those who enact and implement policies.

Until now, Monte Carlo methods would have been the tool of choice for this kind of policy research. Unfortunately, the statistical properties of this (randomized drawing approach) have many limitations, including resource requirements and instability in some applications. In this report, we apply a new generation of numerical integration methods from physics and applied mathematics promises to greatly improve both the efficiency and accuracy of stochastic methods, and we apply this in the present report. We document these methods in a separate technical report (Roland-Holst: 2015), but for the present suffice to say that our scenarios are evaluated with respect to uncertainty in conventional energy prices, technology costs, and salient demand parameters.

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APPENDIX I – OVERVIEW OF THE BERKELEY ENERGY AND RESOURCES (BEAR) MODEL

The Berkeley Energy and Resources (BEAR) model is in reality a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures A1.1 and A1.2 describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.¹¹ For the purposes of this report, the 2012 California Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 activity sectors and ten households aggregated from the original California SAM. The equations of the model are completely documented elsewhere (Roland-Holst: 2005), and for the present we only discuss its salient structural components.

1.1 Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation

¹¹ See Roland-Holst (2015) for a complete model description.

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system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new California SAM estimated for the year 2012.¹² The result is a single economy model calibrated over the thirty-five year time path from 2015 to 2050. Using the very detailed accounts of the California SAM, we include the following in the present model:

¹² See e.g. Meeraus et al (1992) for GAMS. Berck et al (2004) for discussion of the California SAM.

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1.2 Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) function.

Figure A1.1: Component Structure of the Modeling Facility

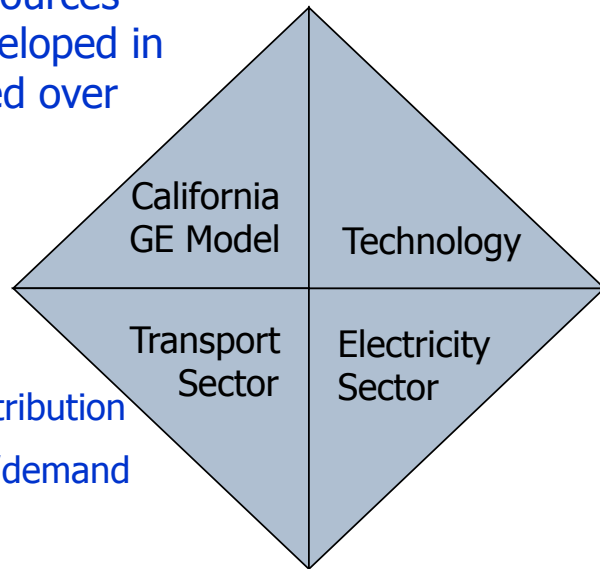
The Berkeley Energy and Resources (BEAR) model is being developed in four areas and implemented over two time horizons.

Components:

1. Core GE model
2. Technology module
3. Electricity generation/distribution
4. Transportation services/demand

Time frames:

1. Policy Horizon, 2015-2030
2. Strategic Horizon, 2015-2050



In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.¹³ The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.¹⁴ Once the optimal combination of inputs is

¹³ Capital supply is to some extent influenced by the current period's level of investment.

¹⁴ For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

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determined, sectoral output prices are calculated assuming competitive supply conditions in all markets.

1.3 Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a “good” and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified.¹⁵ The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

¹⁵ In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

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1.4 Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

1.5 Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

1.6 Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over

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time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

1.7 The putty/semi-putty specification

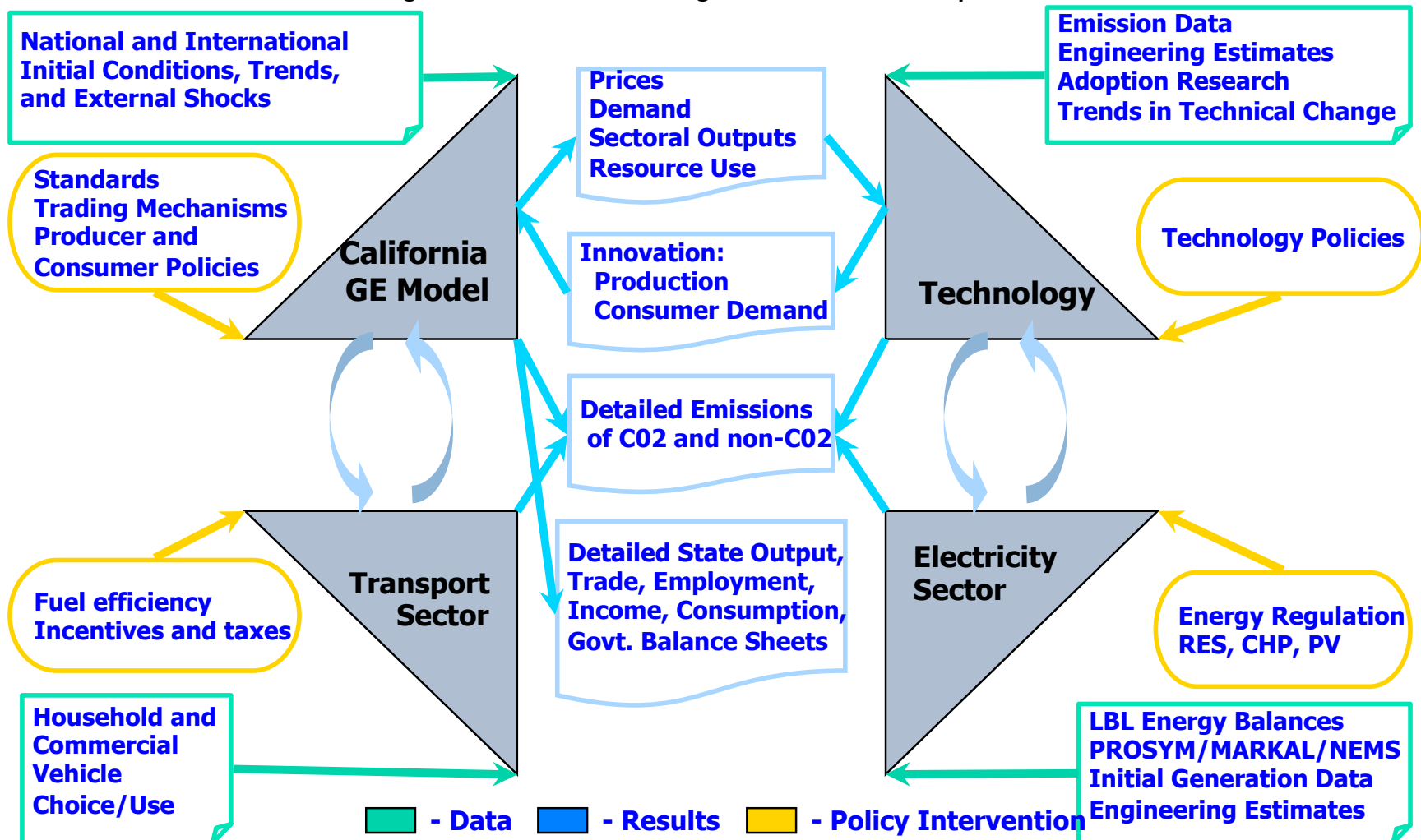
The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

1.8 Profits, Adjustment Costs, and Expectations

Firms output and investment decisions are modeled in accordance with the innovative approach of Goulder and co-authors (see e.g. Goulder et al: 2009 for technical details). In particular, we allow for the possibility that firms reap windfall profits from events such as free permit distribution. Absent more detailed information on ownership patterns, we assume that these profits accrue to US and foreign residents in proportion to equity shares of publically traded US corporations (16% in 2009, Swartz and Tillman:2010). Between California and other US residents, the shares are assumed to be proportional to GSP in GDP (11% in 2009).

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Figure A1.2: Schematic Linkage between Model Components



1.9 Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.¹⁶ When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

1.10 Modelling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO₂ and the other primary greenhouse gases, which are converted to CO₂ equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.¹⁷ In this framework, mission levels have an underlying monotone relationship with production levels,

¹⁶This involves computing in each period a measure of Harrod-neutral technical progress in the capital-labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

¹⁷ See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

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but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels. In some of the policy simulations we evaluate sectoral emission reduction scenarios, using specific cost and emission reduction factors, based on our earlier analysis (Hanemann and Farrell: 2006).

The BEAR model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table A1.1 below. Our focus in the current study is the emission of CO₂ and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

An essential characteristic of the BEAR approach to emissions modeling is endogeneity. Contrary to assertions made elsewhere (Stavins et al:2007), the BEAR model permits emission rates by sector and input to be exogenous or endogenous, and in either case the level of emissions from the sector in question is endogenous unless a cap is imposed. This feature is essential to capture structural adjustments arising from market based climate policies, as well as the effects of technological change.

Table A1.1: Emission Categories

Air Pollutants

1.	Suspended particulates	PART
2.	Sulfur dioxide (SO ₂)	SO2
3.	Nitrogen dioxide (NO ₂)	NO2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR

Water Pollutants

8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT

Land Pollutants

12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

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Table A1.2 California SAM for 2012 – Structural Characteristics

1. 124 production activities
2. 124 commodities (includes trade and transport margins)
3. 3 factors of production
4. 2 labor categories
5. Capital
6. Land
7. 10 Household types, defined by income tax bracket
8. Enterprises
9. Federal Government (7 fiscal accounts)
10. State Government (27 fiscal accounts)
11. Local Government (11 fiscal accounts)
12. Consolidated capital account
13. External Trade Account

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Table A1.3: Aggregate Accounts for the Prototype California CGE

The 50 Production Sectors and Commodity Groups represent the aggregation of the 2012 used for this assessment.

Sectoring Scheme for the BEAR Model

The following sectors are aggregated from a new, 199 sector California SAM

Label	Description
1 A01Agric	Agriculture
2 A02Cattle	Cattle and Feedlots
3 A03Dairy	Dairy Cattle and Milk Production
4 A04Forest	Forestry, Fishery, Mining, Quarrying
5 A05OilGas	Oil and Gas Extraction
6 A06OthPrim	Other Primary Products
7 A07DistElec	Generation and Distribution of Electricity
8 A08DistGas	Natural Gas Distribution
9 A09DistOth	Water, Sewage, Steam
10 A10ConRes	Residential Construction
11 A11ConNRes	Non-Residential Construction
12 A12Constr	Construction
13 A13FoodPrc	Food Processing
14 A14TxtAprl	Textiles and Apparel
15 A15WoodPlp	Wood, Pulp, and Paper
16 A16PapPrnt	Printing and Publishing
17 A17OilRef	Oil Refining
18 A18Chemicl	Chemicals
19 A19Pharma	Pharmaceutical Manufacturing
20 A20Cement	Cement
21 A21Metal	Metal Manufacture and Fabrication
22 A22Aluminm	Aliminium
23 A23Machnry	General Machinery
24 A24AirCon	Air Conditioning and Refridgeration
25 A25SemiCon	Semi-conductor and Other Computer Manufacturing
26 A26ElecApp	Electrical Appliances
27 A27Autos	Automobiles and Light Trucks
28 A28OthVeh	Vehicle Manufacturing
29 A29AeroMfg	Aeroplane and Aerospace Manufacturing
30 A30OthInd	Other Industry
31 A31WhlTrad	Wholesale Trade
32 A32RetVeh	Retail Vehicle Sales and Service
33 A33AirTrns	Air Transport Services
34 A34GndTrns	Ground Transport Services
35 A35WatTrns	Water Transport Services
36 A36TrkTrns	Truck Transport Services
37 A37PubTrns	Public Transport Services
38 A38RetAppl	Retail Electronics
39 A39RetGen	Retail General Merchandise
40 A40InfCom	Information and Communication Services
41 A41FinServ	Financial Services
42 A42OthProf	Other Professional Services
43 A43BusServ	Business Services
44 A44WstServ	Waste Services
45 A45LandFill	Landfill Services
46 A46Educatn	Educational Services
47 A47Medicin	Medical Services
48 A48Recreatn	Recreation Services
49 A49HotRest	Hotel and Restaurant Services
50 A50OthPrSv	Other Private Services

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- 1) Labor Categories
 - a) Skilled
 - b) Unskilled
- 2) Capital
- 3) Land
- 4) Natural Resources
- 5) 8 Household Groups (by income)
 - a) HOUS0 (<\$0k)
 - b) HOUS1 (\$0-12k)
 - c) HOUS2 (\$12-28k)
 - d) HOUS4 (\$28-40k)
 - e) HOUS6 (\$40-60k)
 - f) HOUS8 (\$60-80k)
 - g) HOUS9 (\$80-200k)
 - h) HOUSH (\$200+k)
- 6) Enterprises
- 7) External Trading Partners
 - a) ROUS Rest of United States
 - b) ROW Rest of the World

These data enable us to trace the effects of responses to climate change and other policies at unprecedented levels of detail, tracing linkages across the economy and clearly indicating the indirect benefits and tradeoffs that might result from comprehensive policies pollution taxes or trading systems. As we shall see in the results section, the effects of climate policy can be quite complex. In particular, cumulative indirect effects often outweigh direct consequences, and affected groups are often far from the policy target group. For these reasons, it is essential for policy makers to anticipate linkage effects like those revealed in a general equilibrium model and dataset like the ones used here.

It should be noted that the SAM used with BEAR departs in a few substantive respects from the original 2012 California SAM. The two main differences have to do with the structure of production, as reflected in the input-output accounts, and with consumption good aggregation. To specify production technology in the BEAR model, we rely on both activity and commodity accounting, while the

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original SAM has consolidated activity accounts. We chose to maintain separate activity and commodity accounts to maintain transparency in the technology of emissions and patterns of tax incidence. The difference is non-trivial and considerable additional effort was needed to reconcile use and make tables separately. This also facilitated the second SAM extension, however, where we maintained final demand at the full 119 commodity level of aggregation, rather than adopting six aggregate commodities like the original SAM.

Emissions Data

Emissions data were obtained from California's own detailed emissions inventory. In most of the primary pollution databases like this, measured emissions are directly associated with the volume of output. This has several consequences. First, from a behavioral perspective, the only way to reduce emissions, with a given technology, is to reduce output. This obviously biases results by exaggerating the abatement-growth tradeoff and sends a misleading and unwelcome message to policy makers.

More intrinsically, output based pollution modeling imperfectly to capture the observed pattern of abatement behavior. Generally, firms respond to abatement incentives and penalties in much more complex and sophisticated ways by varying internal conditions of production. These responses include varying the sources, quality, and composition of inputs, choice of technology, etc. The third shortcoming of the output approach is that it give us no guidance about other important pollution sources outside the production process, especially pollution in use of final goods. The most important example of this category is household consumption. BEAR estimates emissions from both intermediate and (in-state) final demand.