California Climate Change Target Setting:

A Workshop Report and Recommendations to the State of California Based on the Third California Climate Policy Modeling Dialogue and Workshop

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A White Paper from the Pacific Southwest Region University Transportation Center

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16. Abstract

California has a range of existing and proposed targets toward a low carbon future. This paper summarizes an analytical review, focused on modeling approaches and what is known about their feasibility and cost. The findings in this paper are based on the Climate Change Policy Modeling (CCPM) forum, which included modelers, policy makers and stakeholders evaluating targets and pathways to low-carbon futures and identifying required policies to achieve goals. The third forum, CCPM-3, was on May 14th, 2018, at the University of California, Davis and provided critical discussion and a gathering of the key experts in this topic area This report builds on the findings of CCPM and integrates with other literature where possible. It includes a review of the CO_2-relevant targets, discussion of studies and modeling efforts to assess meeting such targets, including feasibility and cost. This includes analysis in the transportation and energy sectors, as well as land use and carbon sequestration.

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The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation's University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education, and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Abstract

California has a range of existing and proposed targets toward a low carbon future. This paper summarizes an analytical review, focused on modeling approaches and what is known about their feasibility and cost. The findings in this paper are based on the Climate Change Policy Modeling (CCPM) forum, which included modelers, policy makers and stakeholders evaluating targets and pathways to low-carbon futures and identifying required policies to achieve goals. The third forum, CCPM-3, was on May 14th, 2018, at the University of California, Davis and provided critical discussion and a gathering of the key experts in this topic area This report builds on the findings of CCPM and integrates with other literature where possible. It includes a review of the CO_2-relevant targets, discussion of studies and modeling efforts to assess meeting such targets, including feasibility and cost. This includes analysis in the transportation and energy sectors, as well as land use and carbon sequestration.

California Climate Change Target Setting: A Workshop Report and Recommendations to the State of California Based on the Third California Climate Policy Modeling Dialogue and Workshop

Executive Summary

California will need to reach greater than an 80% reduction in carbon dioxide (CO_2) emissions by 2050 in order to achieve a low carbon scenario that is consistent with the "well-below-2 degrees" global target adopted in the Paris agreement; it is also consistent with California's ambition to provide leadership in this global effort. California's energy sectors (buildings, transportation, industry, electric power) have a range of costs and potentials to reach deep CO_2 reductions, with transportation and industry perhaps having the toughest job ahead.

If energy systems fall short of an 80% reduction goal, there is some potential for non-energy sectors, such as natural and working lands, to make up the difference, including via sequestration of CO_2 that could lead to negative emissions. However, there are many challenges to achieving such a scenario and still a relatively poor understanding of the potential and costs.

Transportation: Within the transportation sector, the possibility of reaching specific targets such as 5 million light-duty zero-emission vehicles (ZEVs, primarily electric and hydrogen) by 2030, as called for by the state governor, appears feasible. However, this could be quite challenging, due to the need for rapid consumer adoption while solutions to awareness and acceptance issues remain uncertain. Even achieving 1.5 million by 2025 will not be on this 5-million path; and 40% or more of sales in 2030 will need to be ZEV to hit such a target.

Electricity: Achieving a 50% - 60% target for renewable energy in the electric sector by 2030 is within reach, though reaching much higher levels of renewables, while possible, is more problematic, especially getting above an 80-90% share. Deploying renewable integration solutions, including a diverse renewable portfolio and a regional grid, as well as advances in "smart grids", energy storage, and "smart" interactions between electric vehicles and the grid, will likely play very important roles in determining when, and how high, renewable generation can go.

Buildings and Industry: Buildings have a clear potential to be mostly decarbonized by 2050, however the long-lifetimes of buildings and building equipment presents a challenge. Decarbonizing buildings would require near-term action. Within the industrial sector, certain industries appear likely to be a major challenge to decarbonize, such as oil refineries and concrete sectors.

New Policy Options: While existing policies on the energy side will play a critical role in achieving the 2030 targets, new (and on-going) policies will certainly be needed. A list and discussion of these policies is provided in the final section of the document.

Introduction

UC Davis, through the Sustainable Transportation Energy Pathways (STEPS) Program and the Policy Institute for Energy, Environment, and the Economy (PIEEE) hosted the third Climate Change Policy Modeling workshop (CCPM-3) on May 14th, 2018. This workshop, attended by energy, transportation and land use modelers, analysts, stakeholders and policy makers, provided important insights to these policymakers and stakeholders as they consider possible new targets and policy initiatives in 2018. This brief reports the findings of this workshop and emphasizes key takeaways. It will specifically inform the planned Governor's Climate Action Summit in September 2018 and provide a critical scientific foundation for targets considered at that summit.

The California targets that were considered included:

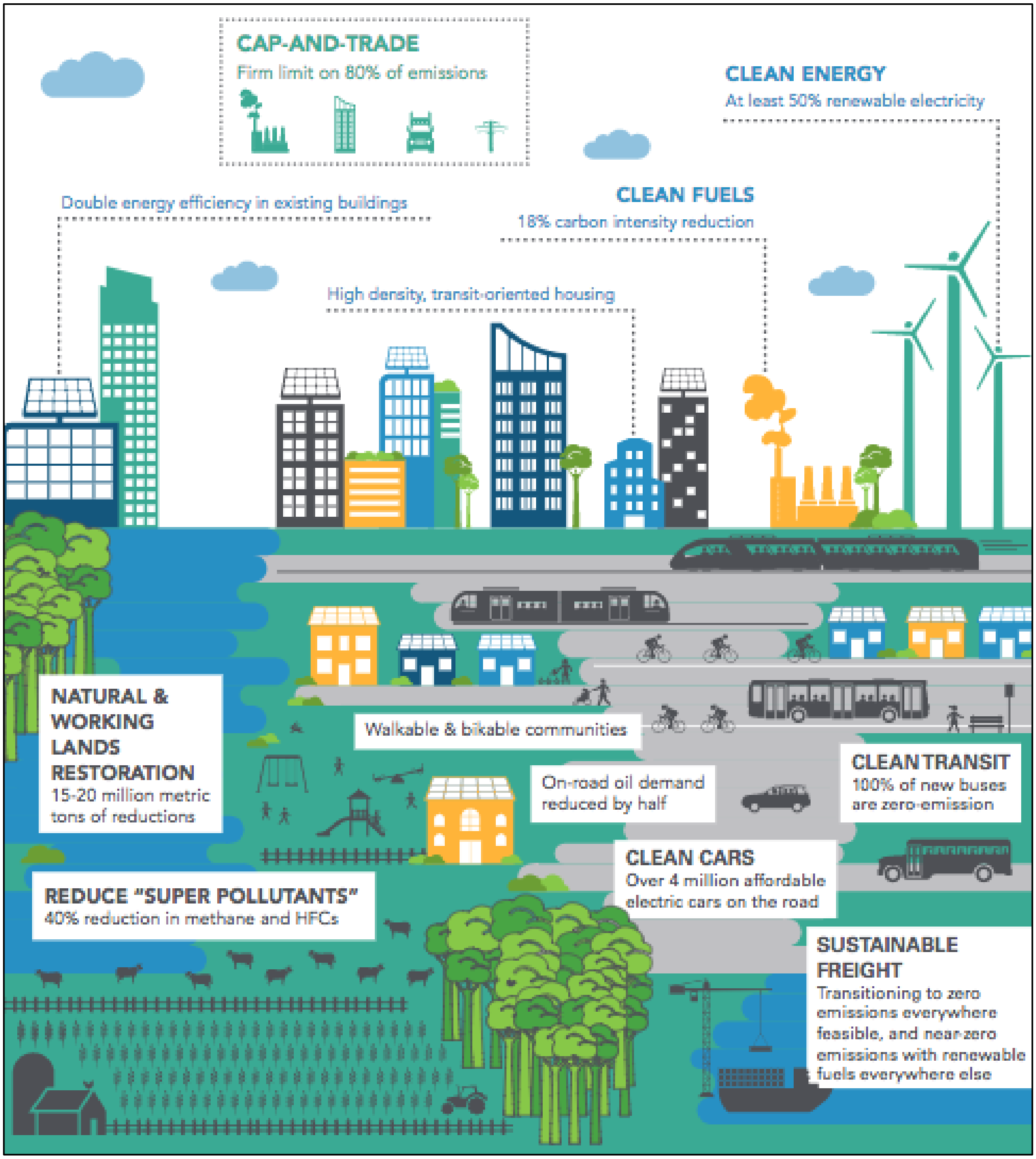
- a very low greenhouse gas (GHG) target, such as near-zero net emissions, by 2050 or earlier;
- a much higher renewables target post 2030;
- a zero-emission vehicle (ZEV) uptake target of 5 million in 2030 and 100% sales target by 2040 or other year;
- truck ZEV targets; and
- potential contributions of agriculture and forestry to a very low GHG future for California.

These targets and other supporting "soft" targets and goals were covered in the first talk of the day, by Aimee Barnes of the Governor's Office, where she indicated both the ambitious range of goals and many of the programs in place to reach them. They are summarized in a "big picture" graphic shown on the following page.

Like previous CCPM efforts, this workshop convened energy system modelers from around the state to compare specific scenarios relevant to potential or actual California targets and estimate optimal pathways and costs of achieving these targets. It broadened the discussion out from energy systems to also include discussions of land use, agriculture and forestry, and carbon sequestration, and how these sectors can contribute to mitigation efforts. This workshop also has a particular focus on the policy implications of the research findings.

Discussions at the day-long event were very interactive between modelers and policymakers. Modeling presentations helped set a research-based foundation and the perspectives of policy makers and other stakeholders helped to contextualize the discussion and capture the most relevant findings. Real world perspectives, including how policy implementation actually happens, will also provide important benefits to modelers going forward.

Figure 1. California's 2030 vision; as presented by Aimee Barnes, Office of the Governor of California.



Review of the Sessions

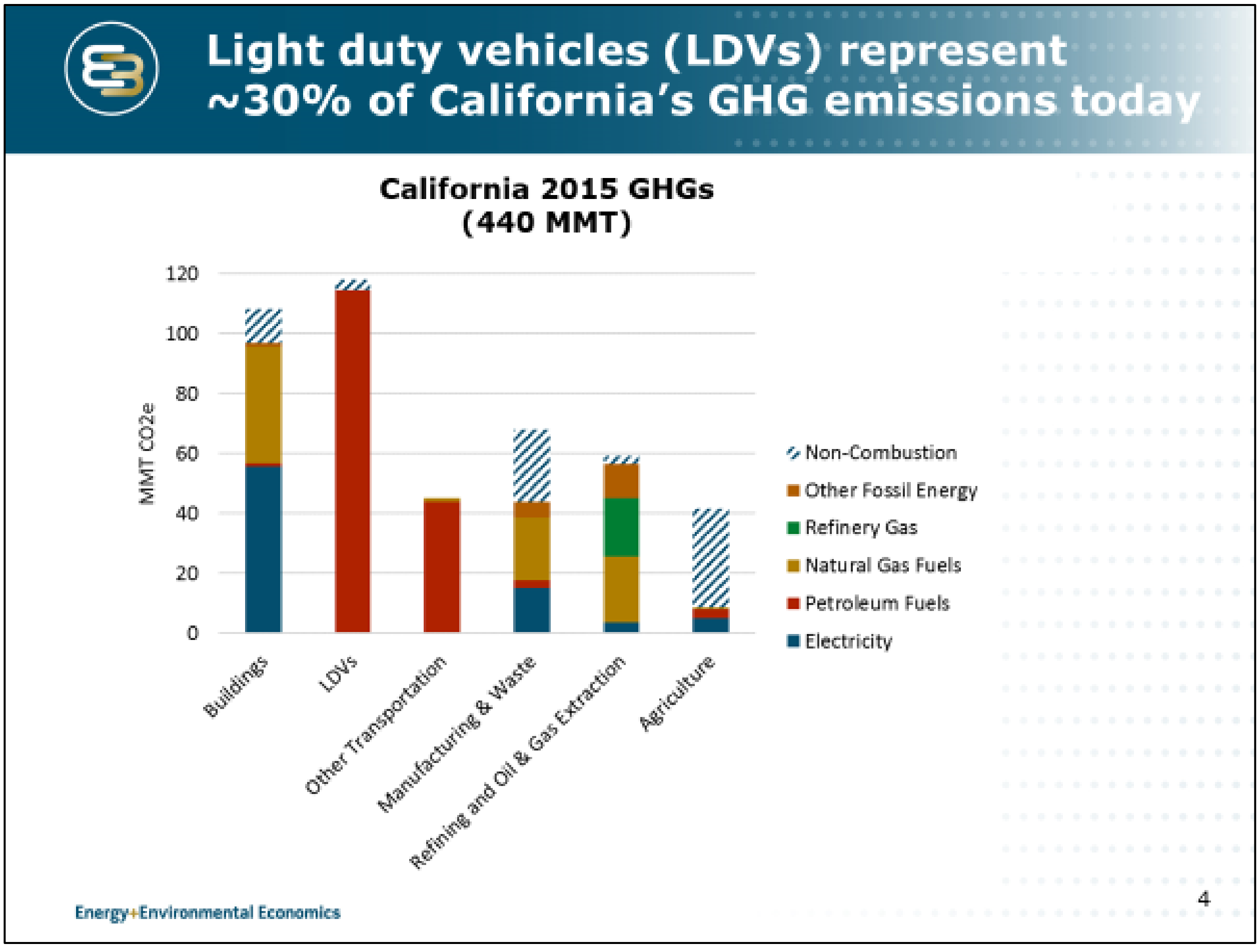
The CCPM-3 had five topical sessions, reviewed and summarized below, in some cases broken into sub-sessions. One additional integrated section covered the economic and social cost and benefit impacts of reducing CO_2 emissions.

1 Achieving California Targets: The big picture
2 Electric power
3 Transportation: Light-duty Vehicles
4 Zero Emission Trucking
5 Role of agriculture and forestry in achieving very low CO_2 futures
6 Reducing CO_2 emissions: other factors and impacts of concern

Achieving California Targets: The Big Picture

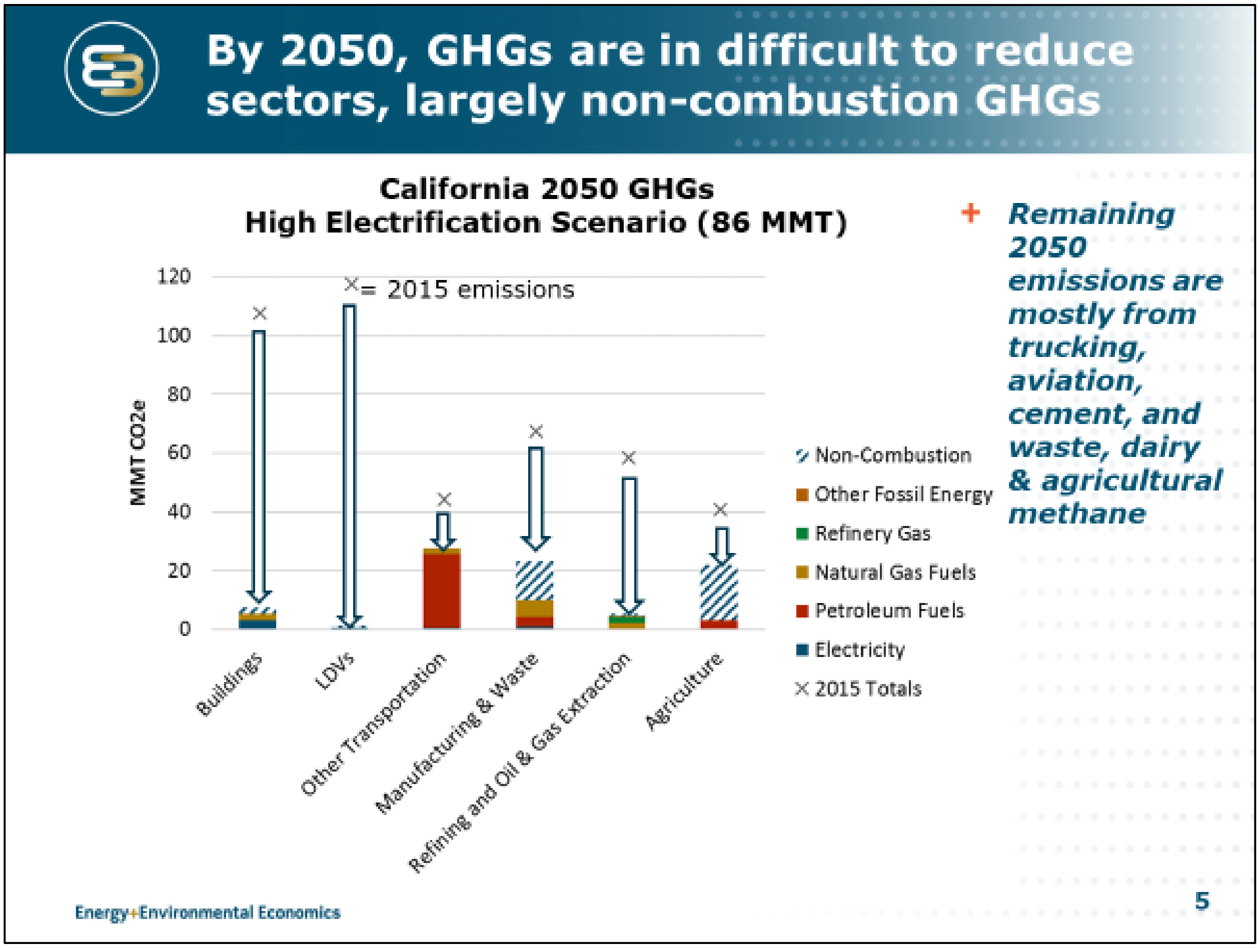
In order to achieve an 80% or greater reduction in CO_2 and other GHG emissions in California by 2050, and 40% by 2040, all sectors will need to contribute in a significant way. This becomes apparent when one considers the situation in 2015: 5 different sectors each contribute 10% or more of total GHG emissions; and only transportation accounts for more than 25%. (Light duty vehicles or LDVs account for 30%, other transportation modes add another 10%, for a total of 40% from all transportation.) Thus, even complete decarbonization of one or two of these sectors by 2050 would by itself be insufficient. Several researchers pointed out that deeper links between sectors (for example, electrification of vehicles and energy services) could enable progress between sectors to be mutually supportive.

Figure 2. California 2015 GHG emissions by sector as modeled in PATHWAYS; as presented by Amber Mahone, E3.



In one future "High Electrification" scenario, developed by E3 as a plausible pathway to achieving the state's 2050 GHG reduction goals, most sectors are nearly completely decarbonized by 2050, with only "other transportation" remaining as a significant source of combustion-related emissions, and industry and agriculture remaining as a source of non-combustion emissions such as methane and nitrous oxide (N_2O).

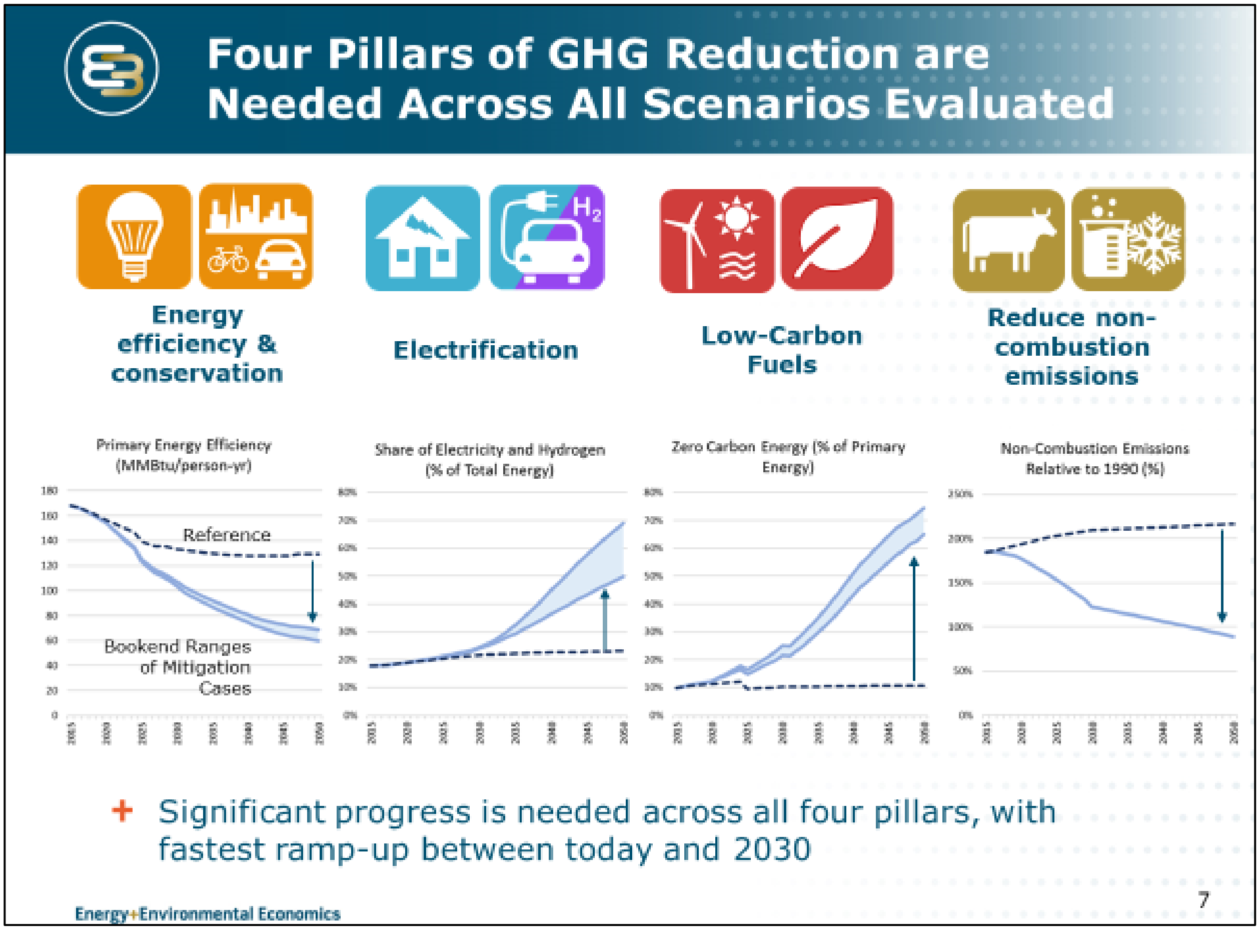
Figure 3. Emission Reduction Achievable by 2050, by sector; as presented by Amber Mahone, E3.



How are such reductions achieved? There are many possible approaches, and most will be difficult, though many are not expected to be expensive. For example, E3 cites efficiency improvement across sectors as a way to cut energy use by 50% at low or negative cost. Electrification can also provide modest-cost reductions, basically shifting vehicles and other end use equipment to electricity along with reducing the carbon intensity of that electricity. Finally, close to a 50% reduction in non-combustion emissions is achieved through a range of measures, but some of these actions will be costly and challenging[1].)

[1] E3, Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model, Final Report, June 2018, https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf

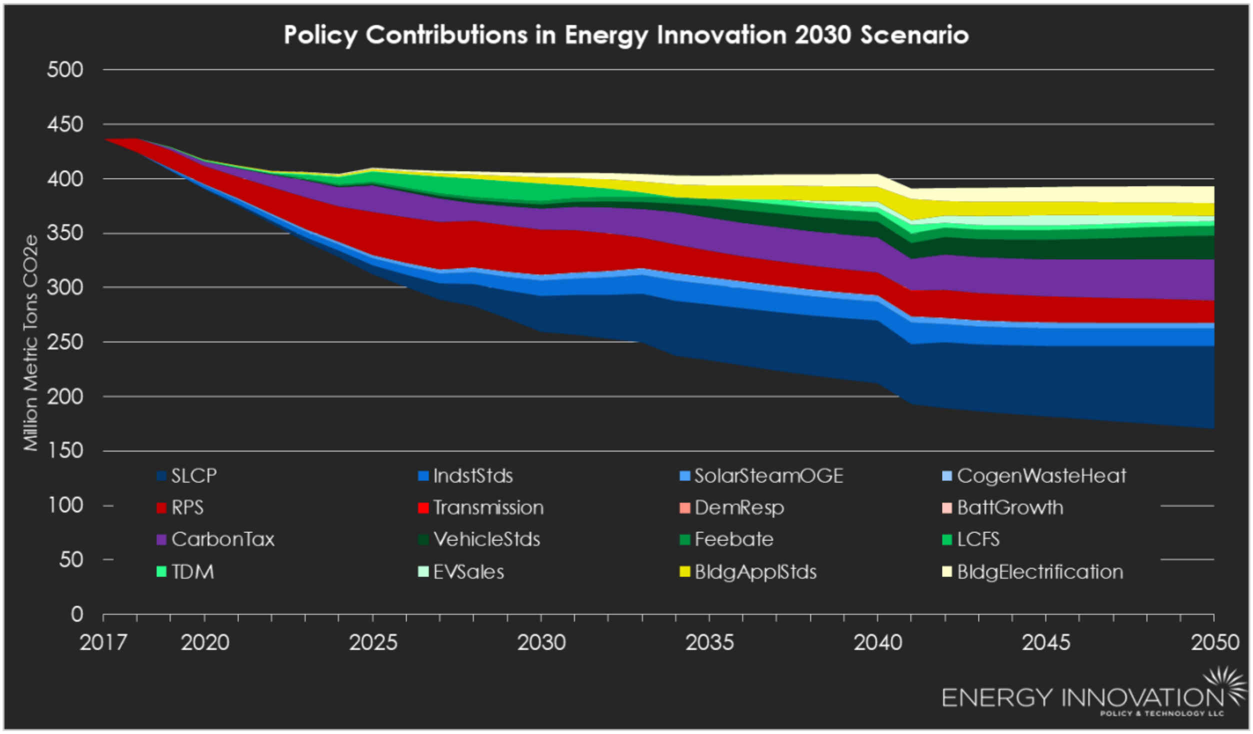
Figure 4. Four pillars of GHG reductions; as presented by Amber Mahone, E3.



Much of the foundational change must occur by 2030, even if the actual GHG emission reductions by 2030 are less than half of those targeted by 2050. This is because of the long lifetimes of equipment that use energy and emit GHGs. Relatively long timeframes are thus necessary to achieve stock turnover, which limits the potential effectiveness of policies absent more draconian interventions to force early replacement.

Energy Innovation's California Energy Policy Simulator develops a package of policies in order to meet the 2030 target at lowest cost and achieving other pillar goals, such as ZEV targets. It suggests that the state's policy portfolio includes most if not all of the necessary elements, but that intensification will be required across the board. The 2030 target is achieved through a carbon price that reaches about $85 per ton in that year; electricity policies including a renewable portfolio standard of nearly 60% backed by measures to increase flexibility; policies to increase efficiency and electrification in transportation and buildings, and; successful achievement of all the emission reductions in short-lived climate pollutants proposed in the 2030 Scoping Plan. Figure 5 presents the emission reduction wedges for the 2030 policies.

Figure 5. Policies to achieve the 2030 target; as presented by Chris Busch, Energy Innovation.



Energy Innovation's recommended 2030 policy package also includes ZEV sales requirement policies to support achievement of the governor's 5 million ZEV goal. These do not show up in the above policy emission reduction wedges for two reasons. First, under California's carbon accounting rules, biomass is considered a zero-carbon fuel whereas grid-connected battery-electric vehicles include the upstream emissions from power generation. Second, we establish policy effects by measuring the effect of disabling the policy in question while the rest of the policies remain in force. One could also measure policy effectiveness by testing their impact with none of the other policies enabled, but this would obscure interactive effects. The disable approach to measuring policy impact means that when ZEV sales mandates are eliminated from the package of policies, the Low Carbon Fuel Standard drives more biofuels. Biofuels the gap left by lower use of electricity as a transportation fuel, resulting in lower emissions because biofuels are deemed zero carbon. These results in no way cast doubt on the value of ZEV policies, because of the limitations in sustainable biofuels, the value of electric vehicles as a source of shiftable load or storage, and the imperative for ZEVs for reaching deeper decarbonization goals.

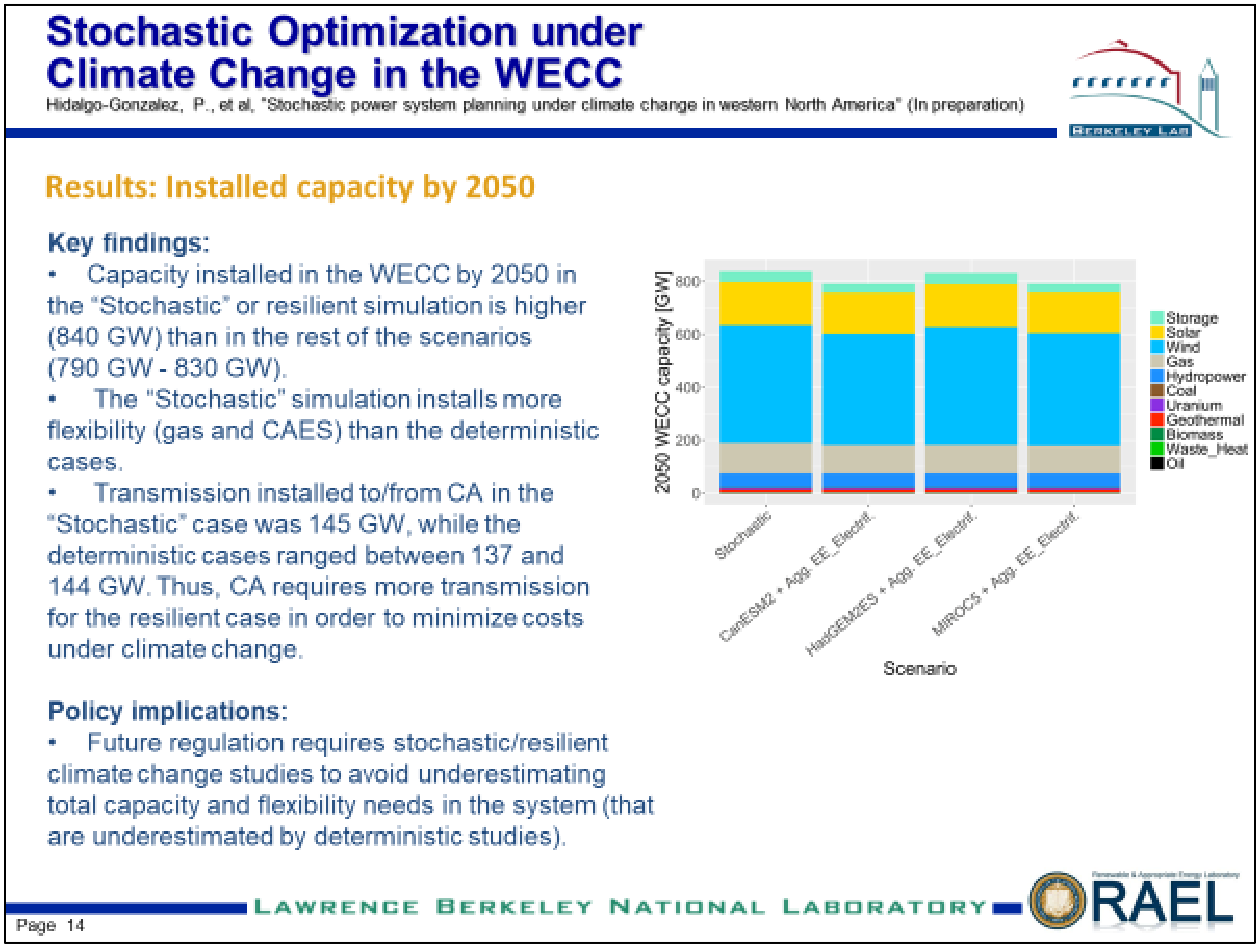
Electric Power

In the electric power generation sector, several modelers agree that deep decarbonization is possible and necessary, and that high renewables shares are possible by 2050, though no presented scenario quite reaches 100%.

A typical set of model run results for the Western Electricity Coordinating Council (WECC) area is shown in Figure 6 (LBNL SWITCH model). In each scenario, renewables reach nearly 90% of generation with some residual natural gas generation. The achievement of this high renewables scenario is based on a range of assumptions and requirements:

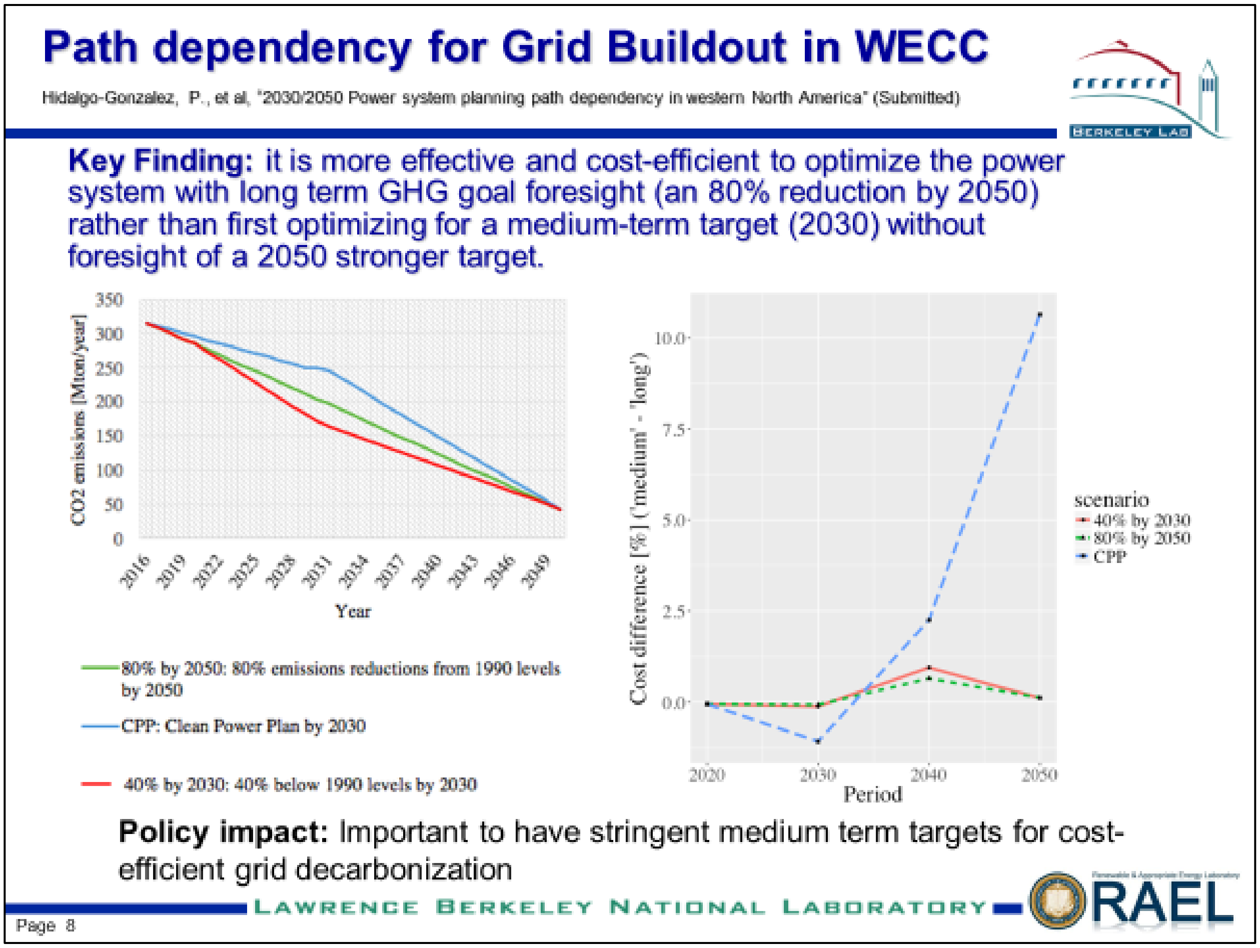
- Diverse renewable generation portfolio, and new transmission to support renewable development
- Strong electrification in all end-use sectors
- Coordinated plug-in electric vehicle grid-to-vehicle/vehicle-to-grid (G2V/V2G) storage
- Renewable hydrogen (H2) scale up
- Energy storage
- Other demand shifting policies to align peak demand and supply periods

Figure 6. WECC Area Simulations; as presented by Max Wei, Lawrence Berkeley National Laboratory.



The same analysis indicates that optimizing the path to 2050 produces lower overall costs and deeper CO_2 reductions than first optimizing to 2030 and thereafter to 2050. The "Clean Power Plan" (CPP), with its less demanding 2030 target, leads to a higher cost pathway in 2050 than would a more demanding 2030 target (Figure 7). The medium-term optimization for "CPP" emits CO_2 at its maximum allowed in 2030 due to its lack of foresight of the more stringent carbon cap in 2050. This weaker policy in the first step of the optimization for 2030 results in more stranded deployment of carbon-intensive technologies. The second step of the optimization has to transition more abruptly to cleaner technologies to achieve the 2050 target. This capacity expansion investments are suboptimal compared to the alternative capacity expansion shown by the long-term optimization case.

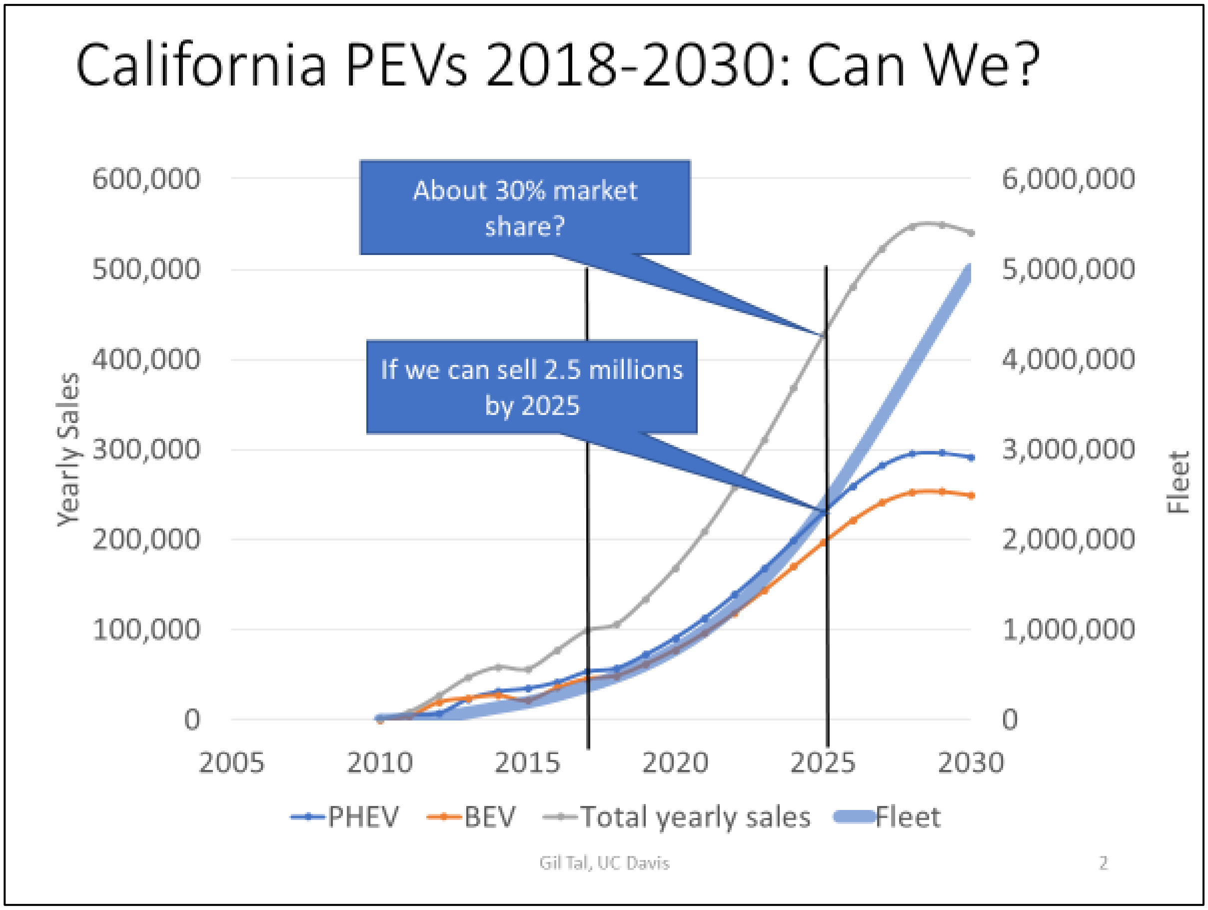
Figure 7. Path Dependency for Grid Buildout in WECC; as presented by Max Wei, Lawrence Berkeley National Laboratory.



Transportation: Light-Duty Vehicles

The State of California has a formal target of 1.5 million ZEVs and plug-in hybrid electric vehicles (PHEVs) on the road by 2025 (though this will be adjusted via various credit systems). The governor has also called for a 2030 target of 5 million. This could prove the more challenging target, in part because on a smooth ramp-up trajectory it would require over 2 million in 2025, as shown in the figure below. In a scenario where "only" 1.5 million ZEVs are on the road by 2025, there would need to then be a sharp upturn in sales rates to hit the 2030 target.

Figure 8. California plug-in electric vehicles (PEVs); as presented by Gil Tal, UC Davis.



Either way, can such a rapid sales growth be achieved? It will depend on many factors, but perhaps most important will be the vehicles themselves. Improvements needed are likely to include:

- **Driving Range Extensions** – from 80 to 300+ miles
- **Affordable Vehicle Price: price parity with ICEVs (internal combustion engine vehicles) for all segments** – lower battery prices, down to $100/kWh cell $125 pack
- **Quick Charging** – 80% state of charge (SOC) in 20 minutes, even 80% in 5 minutes
- **Lower cost PHEVs** – new drivetrain designs

More generally there will also need to be:

- Availability of a wide range of vehicle makes and models that can meet consumer needs across a range of market segments.
- Prices for these vehicle models that are competitive, either with or without price incentives. This will depend on lower battery and fuel cell system costs, but also on the

policy support system. The current market share of around 3% must rise to 40% or more by 2030, and this suggests a much more competitive position for PEVs, which seems inconsistent with a removal of the current subsidy system unless the most optimistic predictions regarding ZEV purchase prices falling to equivalency with internal combustion engines by the mid-2020s turn out to be correct. ZEV mandates force automakers to lower prices in order to sell ZEVs, and thus can provide some of the same effect as purchase incentives. However, they generate more opposition from automakers because of the reduction in profitability.

- Adequate recharging infrastructure, at home, work and commercial locations, in whatever numbers and combinations are needed to rapidly build markets and widespread PEV use. This is still highly uncertain.
- Much increased awareness and experience across the population regarding PEVs, to move beyond the small segment of the population that currently accounts for the majority of PEV purchases. Increased awareness and interest will also be needed from buyers of secondhand vehicles as PEVs are turned over into this large market.

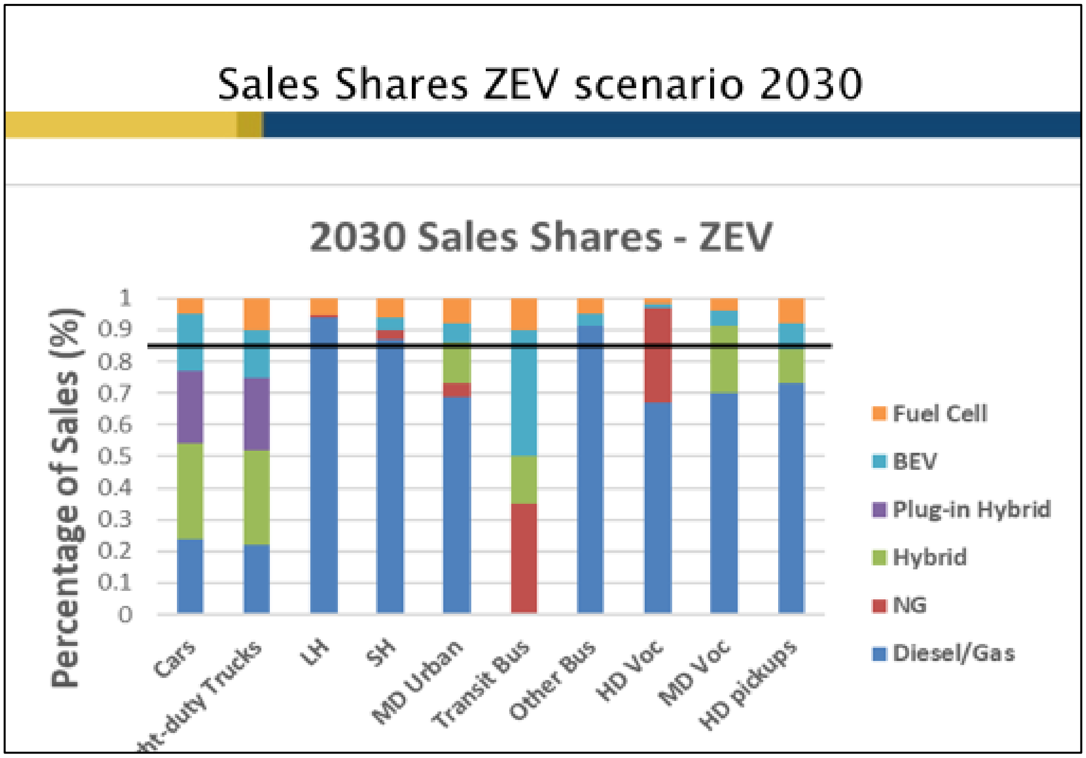
Zero Emission Trucking

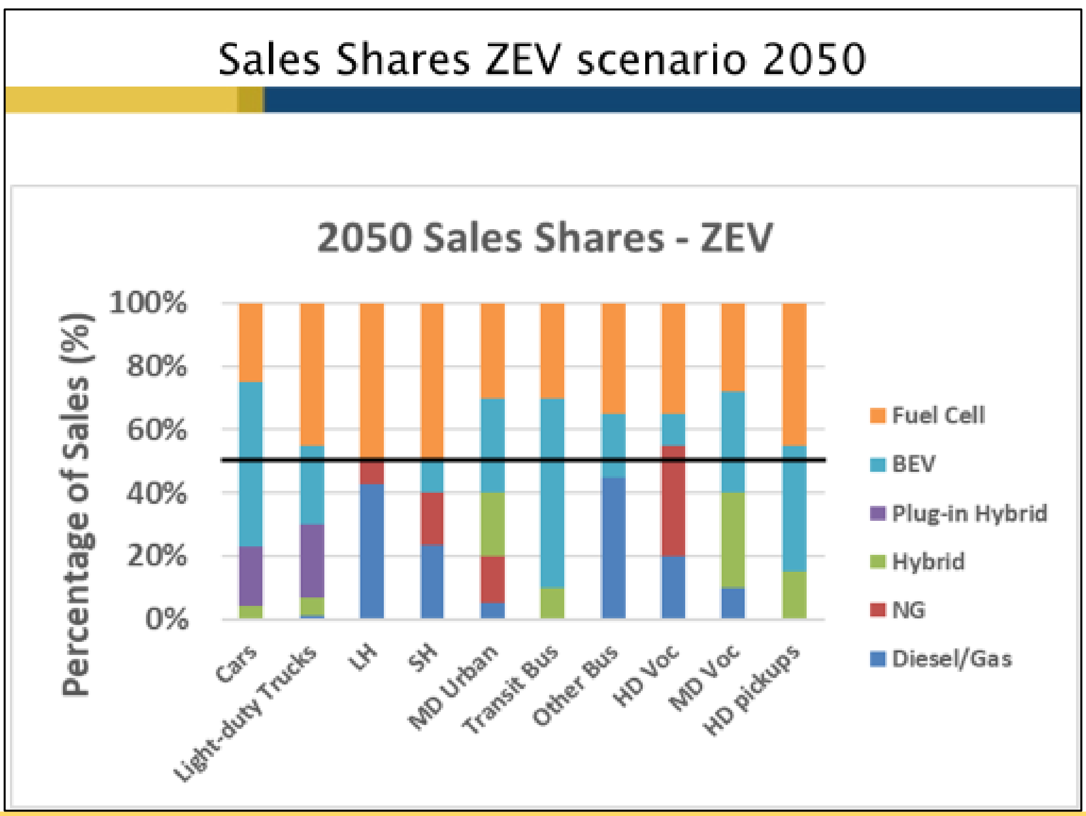
Beyond LDV targets, there is discussion in California of ZEV targets for a range of truck applications and classes. The California Air Resources Board (CARB) has floated the possibility of 15% sales targets by 2030 across classes 2B to 7, with Class 8 not covered but able to earn credits. This type of target would require a near revolution in the manner in which trucks are powered, as there are very few of any type on the road today that are powered by electric motors. Manufacturers tend to argue that diesel engines are so entrenched, and provide such superior performance, that it will be very difficult to change this status quo, or that it will take a long time.

UC Davis has developed transition scenarios for trucks to 2030 and out to 2050, that pass through a 15% target in 2030 and reach at least a 50% market share by 2050. Based on analysis of the potential rates of adoption of ZEV (electric and fuel cell truck) adoption in each of 8 major truck applications, the ZEV scenario does achieve the targets but at a relatively high cost, and assuming strong policy interventions to make the trucks competitive in the market as early as 2023. The 2030 and 2050 sales shares are shown in the figures below.

Most truck classes achieve a small share of battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) by 2030, but by 2050 FCEVs represent a far larger share of the market for most classes. A notable exception is transit buses, which appear to be a strong application for battery electrics. In any case a related analysis of “truck choice” indicates that in order to convince truck fleets to purchase these technologies will require both significant improvements (such as in driving range) and possibly strong price incentives.

Figure 9. Truck sale shares; as presented by Marshall Miller, UC Davis.

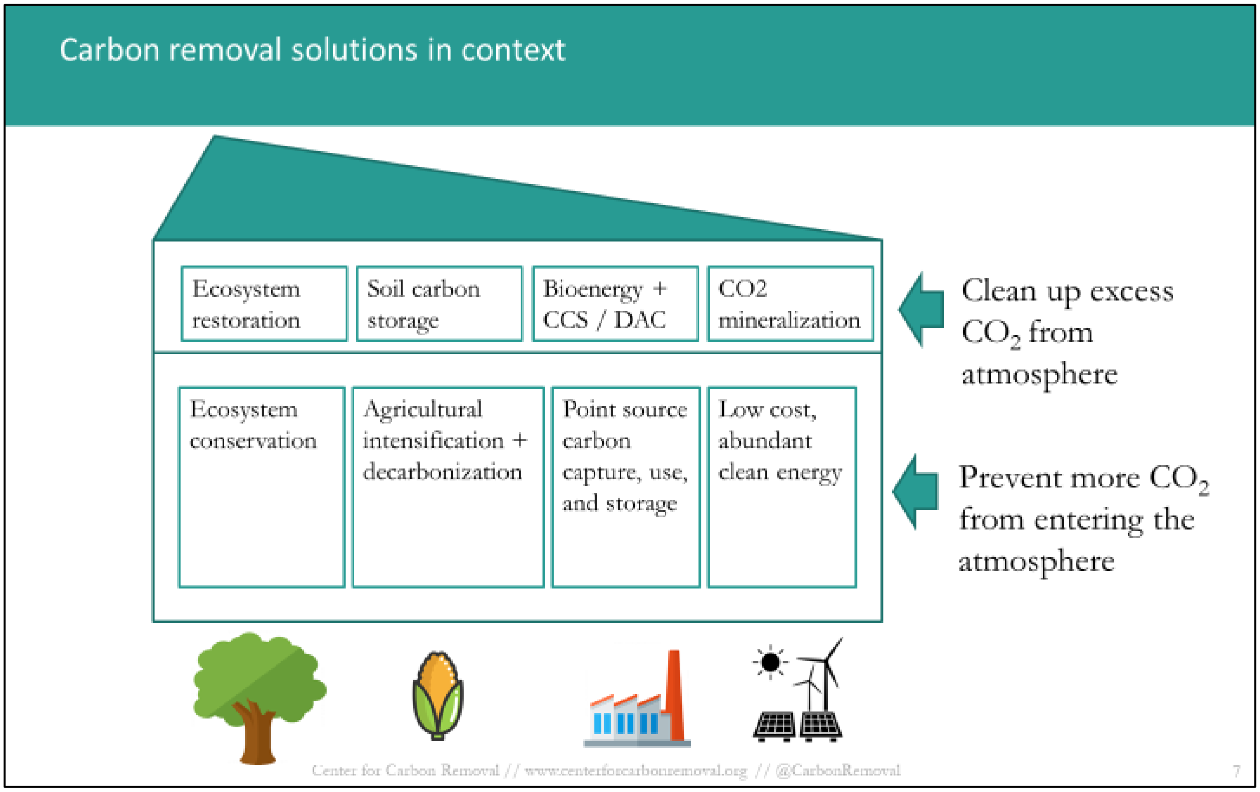




Role of Agriculture and Forestry in Achieving Very Low CO_2 Futures

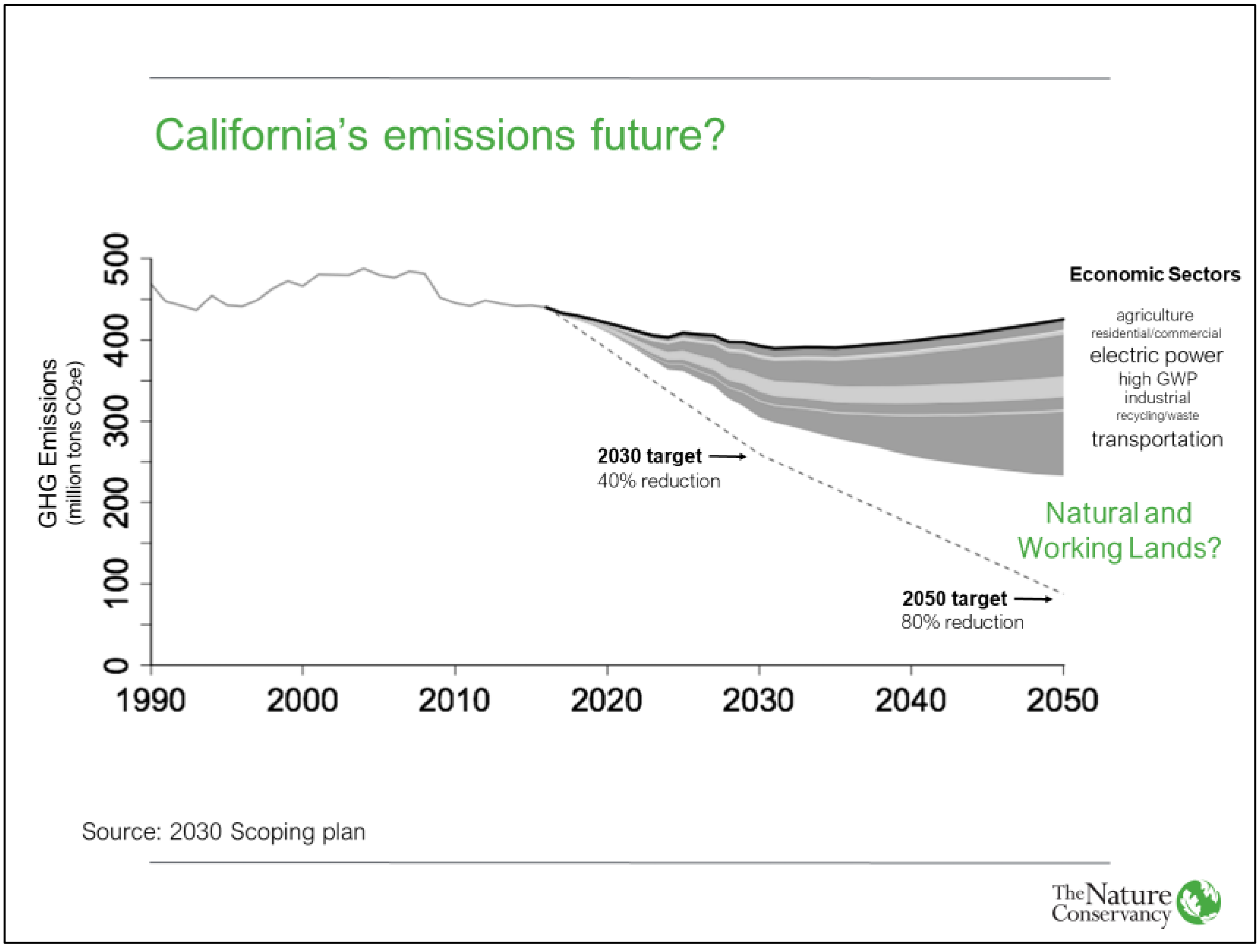
In addition to dramatically cutting energy-related CO_2 emissions, changes in land use must ensure that CO_2 emissions from agriculture and forestry are minimized and CO_2 sequestration is maximized. An estimated 5 gigaton per year in global emissions from these two sectors now occurs (in the context of around 50 GT from all sectors), which could go to net zero by 2050 through a range of measures. As shown in the figure below, these measures include ecosystem, soil/agriculture, bioenergy and CO_2 capture/removal related actions.

Figure 10. Carbon removal solutions in context; as presented by Noah Deich, Center for Carbon Removal.



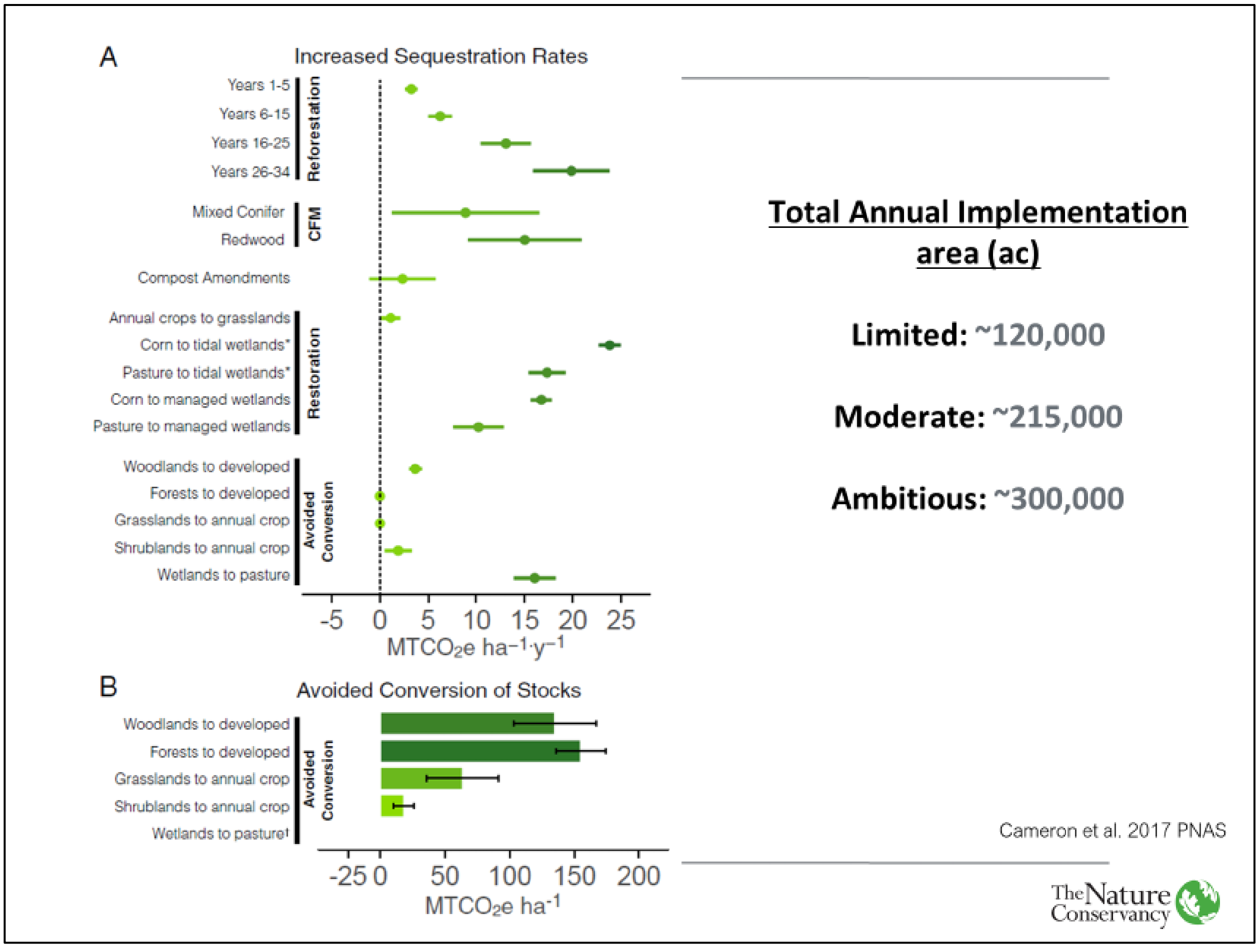
One view of the potential role of "natural and working lands" in CO_2 emissions reductions in California is provided by the Nature Conservancy (Figure 11). By 2050 the energy sector provides about a 50% reduction in total CO_2, leaving about a 30% additional reduction to come from lands.

Figure 11. Potential role of "natural and working lands" in CO_2 emissions reductions in California; as presented by Dick Cameron, The Nature Conservancy.



A breakdown of potential CO_2 reductions from changes in land use is shown below. These can come from reforesting or otherwise restoring lands from developed (e.g., agricultural) back to natural uses, or limiting CO_2 emissions by avoiding conversion of natural lands for a range of development purposes, such as avoiding converting wetlands to pasture.

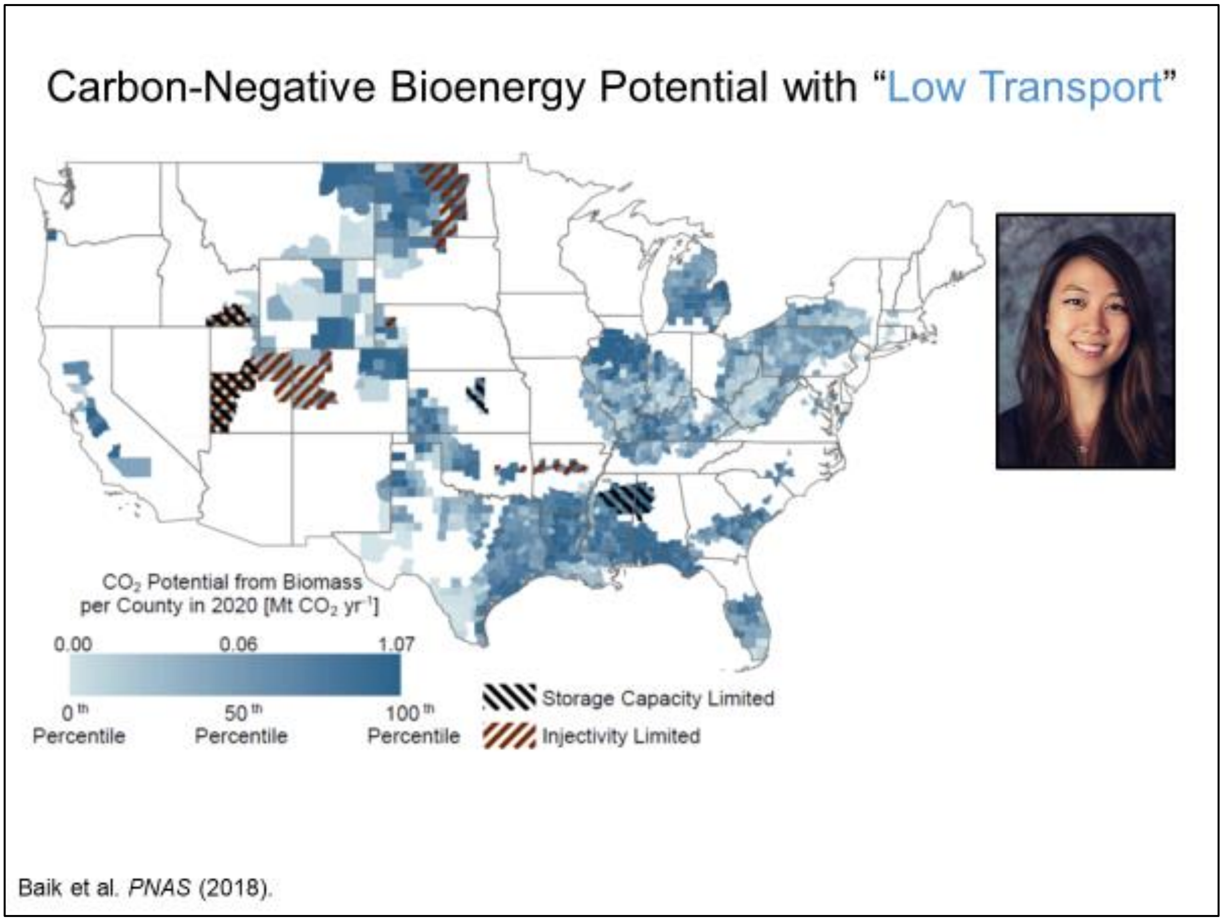
Figure 12. Potential CO_2 reductions from changes in land; as presented by Dick Cameron, The Nature Conservancy.



One potentially important strategy is "BECCS" (bio-energy with carbon capture and storage). The opportunities for locating bioenergy facilities with short-distance in-ground capture and storage are numerous, including a few locations within California (Figure 13).

Another opportunity within the forestry sector is carbon offsets via management and tracking systems. Some of these are already being exploited but many more opportunities have been identified.

Figure 13. Carbon-Negative Bioenergy Potential with "Low CO_2 Transport"; as presented by Katharine Mach, Stanford University. Note: Ejeong Baik, Stanford Center for Carbon Storage pictured.



This figure shows the spatial co-location of biomass and CO_2 storage potential. These areas represent near-term potential for bioenergy with carbon capture and storage with low transport of CO_2 and of biomass.

Reducing CO_2 Emissions: Other Factors and Impacts of Concern

In the process of reducing CO_2 emissions, a range of costs and benefits can occur. The direct costs of reduction may include investments in new technologies and systems, higher fuel or maintenance costs, etc. But other costs include impacts on air emissions, safety, noise and a range of secondary economic impacts (e.g., jobs), macroeconomic feedback effects, land use effects, etc. Another area of concern is distributional allocation of the range of costs—i.e., equity and social justice impacts of concern. For example, an analysis by UC Berkeley's Mark Delucchi indicates that the cost of BEVs is lower than ICEs when taking into account many of these impacts, beyond the basic cost of owning and operating the vehicles (Figure 14).

Figure 14. Social lifetime costs of compacts cars using different technologies; as presented by Marc Delucchi, UC Berkeley.

Quantitative comparison: social lifetime cost, 2020

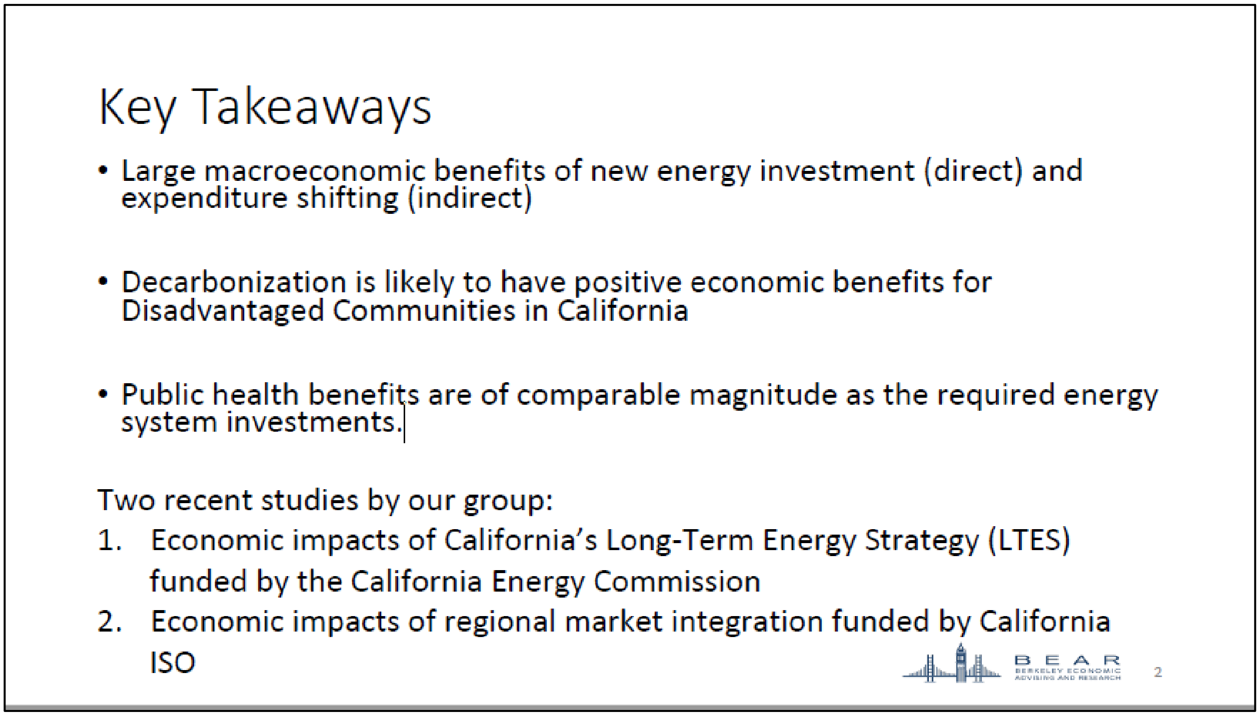
Compact car, Li-ion battery, FUDS cycle (present value of costs)

Gasoline	Ethanol	BPEV-120	HEV-35	H2-300	COST ITEM
0	0	0	0	0	Blank -- not used
0	0	2,094	2	0	Purchased electricity (accounts for regenerative braking from fuel cell, power to heat battery, mai
0	0	951	0	0	Space heating fuel for EVs
0	0	18,369	19,373	613	Battery and tray and auxiliaries (Li-ion)
0	0	192	0	0	Off board battery-charging wiring and equipment
0	0	0	0	4,159	Fuel-cell stack and auxiliaries
0	0	0	0	0	On-board fuel reformer
20,854	20,704	17,576	19,023	16,890	Vehicle, excluding battery, fuel cell, and hydrogen storage
13,103	13,314	0	10,658	14,318	Motor fuel, excluding excise taxes and electricity*
see "vehicle"	62	0	0	2,660	Fuel-storage system
11,204	10,952	13,222	12,199	12,552	Insurance (calculated as a function of VMT and vehicle value)
14,527	14,527	10,755	15,232	11,929	Maintenance and repair, excluding oil, inspection, cleaning, towing, but including time costs
259	259	0	178	0	Engine oil
669	668	615	629	422	Replacement tires (calculated as a function of VMT and vehicle weight)
2,862	2,862	2,862	2,862	2,862	Parking, tolls, and fines (assumed to be the same for all vehicles)
1,248	1,241	0	1,470	1,149	Registration fee (calculated as a function of vehicle weight)
1,717	1,717	605	1,816	605	Vehicle safety and emissions inspection fee
2,867	2,867	2,867	2,867	2,867	Federal, state, and local fuel (energy) excise taxes
971	971	971	971	971	Accessories (assumed to be the same for all vehicles)
70,282	70,144	71,079	87,281	71,996	Total private (consumer) lifetime cost
1,806	1,498	0	603	0	Dollar value of air pollution external costs (lifecycle of fuels and vehicles) (best estimates)
0	0	0	0	0	Blank
619	619	464	489	441	Dollar value of noise external costs (best estimates)
19	1	0	15	0	Dollar value of oil use external costs (best estimates)
19,389	11,827	0	3,411	0	Dollar value of climate change external costs (lifecycle of fuels and vehicles) (best estimates)
-2,867	-2,867	-2,867	-2,867	-2,867	Taxes and fees that are transfers, not resource costs
-4,914	-679	-548	-3,997	-730	Producer surplus on fuel (wealth transfer in excess of resource cost)
-928	-919	-1,435	-1,481	-1,069	Producer surplus (qua "true corporate profit) on vehicle price
83,405	79,624	66,692	83,454	67,772	Total social lifetime cost
n.a.	2.86	3.03	5.96	3.20	Breakeven gasoline price, private-cost basis ($/gal)^
n.a.	2.20	-0.13	2.90	0.06	Breakeven gasoline price, social-cost basis ($/gal)^

Source: Current beta version of AVCEM; see Delucchi et al. (2000) for documentation of prior version.

Research by David Roland-Holst, Sam Evans and colleagues at UC Berkeley have led to their following general conclusions regarding the economic impacts of decarbonization (Figure 15).

Figure 15. Key Takeaways; as presented by Sam Evans, UC Berkeley.



Policy Implications

Leading policy thinkers at the workshop interpreted the findings of the modeling work in terms of potentially helping inform future policy decisions. Some specific policy-relevant findings that were presented or discussed included:

- Energy and climate policy should include all sectors, and take into account links between sectors. Achieving climate targets will require major progress in all sectors. Technologies and policies that allow better links between sectors (for example, electrification) can make reaching goals more achievable than attempting to do so in each sector in isolation.
- Enormous progress is possible with known technology and incremental improvements. Modeling research presented was based on technoeconomic representation of well-understood technologies that are at least at the demonstration scale today.
- Policymakers should avoid dead ends by focusing on technologies that have a clear role in a net neutral energy, transportation, and land system. Some technologies are available today that reduce emissions but cannot provide 80% or more net reductions. If these have a role in a future climate-neutral system, it will necessarily be a niche one.
- Create and support long-term goals and a predictable framework of implementation. Industry can only innovate against a predictable policy background. A dependable set of long-term goals provides the market signals necessary to inform investment by businesses in new technology.
- Commit to continual improvement in policy specifics. While a predictable long-term framework is key, the specifics of policies will need to evolve as the technologies do. Specific policies governing technology deployment should develop in a science and stakeholder-based process.
- Where appropriate for the specific sector, complementary measures in support of overall policy goals can create a virtuous cycle of technology development. For example, an overall cap on emissions can drive deployment of incremental technology and the addition of early-market research, development, and deployment policy can spur invention of transformation technology.
- Foster collaborative learning and local leadership between leading jurisdictions.
- Overall, we have the tools in the toolbox—but it will take all of them to get to the sort of increased ambition necessary to avoid the worst impacts of climate change.

Next Steps, Future Research

There is a saying in the modeling community generally attributed to the statistician George Box, "all models are wrong, some are useful." The purpose of CCPM-3 and the broader effort to model our energy and climate future is not to provide a perfect forecast. Instead, it is to continually improve our representation and understanding of systems and to inform policy actions taken now. Researchers and policymakers discussed key new and expanded research needs.

One major next step identified at the workshop is to model and explicitly evaluate GHG reduction scenarios and targets that are more aggressive than 80% reductions by 2050, and get closer to 80% reductions by 2040, or net zero carbon by 2040. Little modeling work has been done on such "well-below 2 degree" type scenarios.

Other specific areas for future research include:

- More attention to land use and carbon sequestration.
- Improve integrated modeling between energy sectors and energy/land use interactions.
- On-going work to cost out specific reduction strategies and how these strategies should be timed.
- The extent to which new and/or stronger versions of existing policies will be needed to hit 2030 and (especially) post-2030 targets, and the needed timing and intensity of such policies.
- The net costs and benefits of CO^2 reduction strategies, taking into account a full range of private and social costs, such as environmental externalities and hedonic costs.

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