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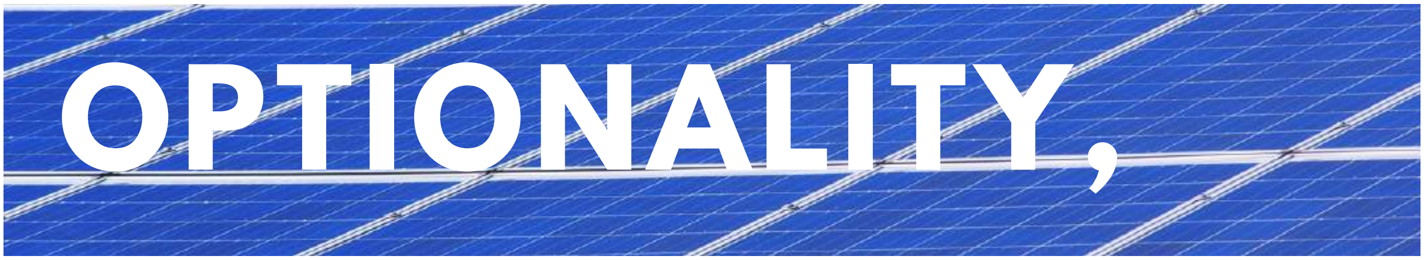

OPTIONALITY, FLEXIBILITY & INNOVATION

PATHWAYS FOR DEEP DECARBONIZATION IN CALIFORNIA

ENERGY FUTURES INITIATIVE

PART 2

MEETING CALIFORNIA'S 2030 EMISSIONS TARGETS

SECTORAL ANALYSES

CHAPTER 2
REDUCING EMISSIONS FROM THE ELECTRICITY SECTOR BY 2030

FINDINGS

The Electricity sector will play a critical role in meeting California's decarbonization targets. Not only can it reduce its own emissions, it can support decarbonization pathways for end-use sectors.

In 2016, emissions from the Electricity sector (including from in-state generation and imported power) comprised 16 percent of statewide greenhouse gas (GHG) emissions. California's policies and decarbonization goals emphasize increasing the deployment of renewable and low-carbon generation, reducing energy and electricity demand, and increasing electrification of the end-use sectors. This will significantly expand electricity's share in California's economywide energy demand.

Meeting the 60 percent Renewables Portfolio Standard (RPS) established in SB 100 will require more renewable generation than is currently planned for through 2030.

According to electric utility resource plans, there are nearly 74 terawatt-hours (TWh) of additional renewable generation expected to come online in California by 2030. This is estimated to increase the state's renewable generation to 47 percent of total generation, assuming electricity demand grows by 1.27 percent, as estimated by the California Energy Commission's midrange forecast. Assuming that growth in other renewables remains flat, meeting the 2030 target will require a growth rate for wind and solar installations similar to their growth rate in the state in 2016. This scenario is discussed in the section on "Reference Frame for SB 100's 2030 Renewables Target."

Reducing emissions from power generation in the near-term will require a broad array of technology and policy options.

Electricity's emissions trajectory of the Electricity sector, including a significant build-out of renewable capacity, is estimated to reduce emissions from 68.6 million metric tons of carbon dioxide-equivalent ($MMTCO_2e$) to 60.6 $MMTCO_2e$ by 2030. Additional mitigation efforts will be necessary, especially as generation from nuclear falls to zero and generation from natural gas declines. Given the magnitude of this challenge, including grid operations impacts, other opportunities to decarbonize the Electricity sector are needed and include: reducing the carbon intensity of imported power; hybridizing the gas generation fleet with energy storage to enable more carbon-efficient operation; deploying a significant amount of renewables paired with energy storage; doping natural gas with hydrogen and/or renewable natural gas; deploying carbon capture, utilization, and storage (CCUS) on gas plants; and demand response.

All pathways for decarbonization of the Electricity sector involve a significant role for intermittent renewables; this will have major impacts on grid operations.

A key challenge associated with increased intermittent generation will be maintaining the reliable operation of the electric grid. Energy storage systems that support renewables, such as lithium-ion batteries, can address certain operational issues (e.g., grid balancing) for short periods of time. There are currently no battery storage options for operational needs with longer duration (i.e., days or weeks). In the near term, grid balancing will continue to be met in large part by natural gas and hydropower, the latter utilizing both reservoir operations and pumped storage.

Energy storage can provide ancillary services, ramping capacity and capability, and short-duration reliability support for systems with high penetration of intermittent renewable resources.

As costs continue to fall, storage options can play a major role in Electricity decarbonization, including a variety of lithium-ion batteries, electrochemical (e.g., flow batteries), mechanical (e.g., compressed air energy storage), and thermal storage options (e.g., ice energy), all of which have been deployed at low levels today. For battery storage, lithium-ion chemistries are the predominant technology at grid-scale but remain costly. Other battery chemistries may be commercial by 2030 but deployment at scale and market diffusion is unlikely.

Natural gas generators play an important role in providing the electric grid with operational flexibility, enabling growth in the use of intermittent generation resources.

Natural gas-fired generation helps the electric grid address operational issues of both short and long duration, including the management of seasonal shifts in demand. As natural gas plants in California increasingly respond to daily load-following and grid-balancing needs, these plants are being operated at higher heat rates for shorter intervals. Such inefficient operation can increase plant emissions by as much as 46 percent, even as the plants generate fewer total megawatt-hours. Sustainable solutions are needed to efficiently decarbonize the electricity system, avoiding the construction of large amounts of redundant power generation or operating assets in inefficient modes.

There are supply-chain risks associated with renewable generation and storage technologies that must be considered when pursuing clean energy pathways.

Raw materials for sustainable energy technologies require serious supply-chain planning that considers demand growth and production rates; reliance on supply controlled by "too few" countries; and other supply and price risks. In addition to supply-chain planning, investments should be made in developing clean energy technologies that use earth-abundant materials.

Current market structures may not provide adequate compensation for the services that energy storage systems can provide.

In California's current electricity market, wind and solar generation are generally dispatched first, as they have low to zero direct marginal costs. This keeps marginal electricity prices low but diminishes investment incentives for baseload or intermediate generation, as well as for grid-scale storage of longer duration and higher capacity. In addition, demand response and storage inherently reduce the magnitude and duration of energy price spikes; this further reduces the revenue, above marginal production costs, that is available to recover the capital costs for generation and grid infrastructure.

Developing CCUS technologies at existing natural gas generation facilities adds significant flexibility for meeting emissions targets while supporting grid operations.

CCUS technology is not necessary for reaching aggressive levels of decarbonization in electricity generation; this analysis assumes a limited deployment of CCUS at select facilities by 2030 due to its currently limited market diffusion. However, some CCUS can significantly improve the optionality and flexibility of both moderate and deep decarbonization, as it will both help preserve the important operational support that gas generation provides to the grid while reducing emissions. California has large sequestration capacity for carbon dioxide, providing opportunities for significant CCUS at natural gas plants. The profile of the state's NGCC fleet, as well as the availability of section 45Q tax credits for CCUS, also enhance the viability of this pathway.

While California has made significant progress in introducing lower- and zero-carbon technologies for the generation of electricity, achieving the goals set for 2030 and the deep decarbonization set for 2050 will be very challenging.

CEC estimates suggest that there could be an overall increase in electricity demand of 33 percent between 2015 and 2050. Peak electrical load in the state could almost double from 67 gigawatts (GW) in 2015 to 132 GW in 2050, because of the implementation of progressive electrification as a decarbonization pathway in the Transportation and Buildings sectors. Meeting this demand with zero-carbon generation by midcentury will be difficult and innovative technologies will be necessary.

Adding offshore wind generation capacity is an attractive option for increasing renewable energy deployment and taking advantage of the unique characteristics of offshore resources.

These resources are attractive because offshore wind generation is more consistent, can provide generation at night when solar generation decreases, has higher capacity factors than solar or onshore wind (as high as 60 percent in prime locations), and can sometimes be sited closer to load centers than onshore resources. The vast majority (95 percent) of California's offshore wind resources are located at water depths (exceeding 60 meters); this would require floating platform infrastructure. Technology commercialization of such platforms is advancing quickly, including full-size systems now deployed in Europe. While there may be some offshore wind deployed in California by 2030, it is considered a breakthrough technology by midcentury.

CHAPTER 3
REDUCING EMISSIONS FROM THE TRANSPORTATION SECTOR BY 2030

FINDINGS

California's Transportation sector is its single largest emitting sector and will require transformational change to achieve a 40 percent reduction in emissions by 2030.

The Transportation sector is the largest energy-consuming and greenhouse gas-emitting sector in California's economy. It accounts for 39 percent of the state's greenhouse gas (GHG) emissions, and 41 percent if emissions of substitutes for ozone-depleting substances are included. Light-duty vehicles (LDVs) produce 70 percent of the sector's total emissions.

California's plans for addressing emissions from this sector rely on four basic mitigation strategies.

These strategies are deploying alternative fuel vehicles, including electric vehicles; increasing vehicle fuel efficiency; reducing vehicle-miles traveled; and decreasing the carbon intensity of fuels. Deploying electric and other alternative fuel vehicles can only make up part of the solution; fuel efficiency standards and the Low Carbon Fuel Standard have the highest mitigation potential.

Current pathways will be insufficient for reducing Transportation emissions by 40 percent.

Closing the gap will likely involve more aggressive policies along the same pathways, as the introduction of any new, viable strategies deployed at-scale by 2030 is unlikely. Additional reductions will likely be achieved in the LDV subsector, due to its size and the difficulties with decarbonizing other subsectors. This lack of optionality for meeting the 2030 target presents a potential risk if barriers to deployment of low-carbon technologies, such as infrastructure and costs are not addressed.

Technology pathways for achieving 2030 goals are likely to differ from the pathways for deeper emissions reductions by 2050, requiring a simultaneous and dual-track approach.

As in other sectors, maintaining optionality and flexibility is key. For some Transportation subsectors, such as heavy-duty vehicles, the solutions that are viable in the near term do not have the same decarbonization benefits as technologies that require additional development for market readiness. The sector should avoid locking in technologies that will be suboptimal for deep decarbonization.

There are constraints on biofuels production that may limit its supply in California by 2030.

The four main biofuel resources used in California are ethanol, biodiesel, renewable diesel, and renewable natural gas. The state's current biofuels usage requires both imported feedstocks as well as in-state biofuels. In addition to constraints on supply, the transportation sector must compete with other sectors for available biomass.

Achieving deep decarbonization in the Transportation sector will require going beyond energy/fuel-based technologies and will depend on an ecosystem of solutions that include new infrastructure systems, platform technologies, behavioral incentives, urban design, and advancements in materials science.

There are a number of effective options for reducing GHG emissions in the Transportation sector but quantifying and predicting their emissions reduction potential varies significantly. These options are particularly important to the fuel-efficiency and demand-reduction pathways. Downsizing, light-weighting, improving aerodynamics, improving tires, and increasing thermal efficiency of engines all contribute to efficiency, as do behavioral practices like avoiding idling and rapid acceleration. Demand reduction is entirely dependent on non-fuel options such as urban design (e.g., for reduced traffic congestion), infrastructure (e.g., public transit), behavior (e.g., telecommuting), and platform technologies (e.g., digital technologies that enable autonomous vehicles).

Because individual consumers are the owners and operators of emissions-generating vehicles, consumer behavior plays an important role in mitigation efforts in Transportation.

Transportation is unlike other sectors, such as Electricity or Industry, where emissions sources are more centralized and individual consumers have limited service options. Decarbonization solutions for transportation of light duty vehicles must be attractive to consumers on both a cost and general appeal levels. Success of clean pathways depends on the vehicle stock turning over. Last year, there were 2 million new vehicles sold, while the average age of on-road vehicle in California is 11.3 years.

The aviation, marine, rail, and off-road subsectors are among the most difficult to decarbonize.

The most viable near-term strategy for reducing the emissions from these subsectors is energy demand reduction. Other options include electrifying rail and water-borne transportation and using heavy-duty vehicle technology for off-road transportation.

CHAPTER 4
REDUCING EMISSIONS FROM THE INDUSTRY SECTOR BY 2030

FINDINGS

Industry is the second-largest contributor of GHG emissions in California and one of the most difficult sectors to decarbonize.

Since 2000, annual Industry sector emissions in California have accounted for approximately one-fifth of the state's economywide greenhouse gas (GHG) emissions, second only to the Transportation sector. There are very limited options for reducing emissions from several industrial processes, due in part to their requirements for high-temperature process heat. These include coking, metal smelting and melting, calcining, and non-metal melting for such things as glass and ceramics.

There is a large technical potential for GHG emissions reductions from a range of mitigation options that can help decarbonize the Industry sector. Given the complexity and heterogeneous nature of many industrial processes, however, an effective decarbonization strategy will require tailored solutions that take into account the unique challenges and opportunities in each subsector.

The portfolio of decarbonization strategies needed for the Industry sector includes a range of options whose selection depends on factors such as the source of emissions (e.g., fuel combustion versus non-combustion) and the unique characteristics that define each subsector (e.g., process heat requirements; electrification potential). Emissions reduction pathways encompass a range of mitigation opportunities across the Industry sector as a whole and within specific subsectors including: Cement; Chemicals and Allied Products; Food Products; Industrial Combined Heat and Power (CHP); Landfills; Oil & Gas Production and Processing; Petroleum Refining and Hydrogen Production; and Transmission and Distribution (of natural gas).

California's Industry sector has both combustion and non-combustion emissions. The sector can achieve a 40 percent reduction in GHG emissions from 2016 levels by 2030 by focusing only on the mitigation of fuel combustion-related emissions, which represent two-thirds of the sector's emissions.

While the Industry sector in California could meet its 2030 goal by only reducing emissions from fuel combustion, the state could maximize industrial emissions reductions by focusing on the mitigation of both fuel combustion and non-combustion emissions. This can be addressed through a combination of technologies and practices including carbon capture, utilization, and storage (CCUS); fuel-switching; facility best management practices; new technology adoption; biogas collection; reducing fugitive emissions; renewable natural gas (RNG); industrial CHP; and energy efficiency. Fuel-switching (to hydrogen or electricity) and CCUS have a large technical potential to help meet the sector's 2030 goal.

The dominance of natural gas use in the Industry sector represents an opportunity for emissions reductions using RNG, but there would be significant associated costs, including for infrastructure.

The majority of California's industrial energy consumption in 2016 was supplied by natural gas (54 percent), which constituted 33 percent (661 Bcf) of the total in-state gas usage.

Electrification of industrial processes that require lower-temperature process heat could reduce the sector's emissions.

The subsectors with the greatest potential for industrial electrification include those that have lower energy costs; exhibit less process complexity and a lower level of systems integration; require lower-temperature process heat; are able to use induction-heating technology, and have end uses that do not currently employ CHP. Possible challenges and risks to industrial electrification include large capital costs for equipment turnover; higher costs of electricity as a fuel, relative to other energy resources; low natural gas prices (particularly for California industrial consumers relative to other sectors in the state); technical hurdles to providing high-temperature process heat; aversion to process disruption; and a current lack of industry momentum for electrification.

CCUS, RNG, and hydrogen offer options for decarbonization of industrial processes with requirements for higher-temperature process heat.

At present, CCUS is likely the only option available for decarbonizing several industrial processes, including cement production, oil refining, and natural gas processing. CCUS also provides further opportunities across California's large industrial base to meet the sector's 2030 goal. CCUS could take advantage of California's estimated geologic storage potential of 34 to 424 billion metric tons of CO_2, making it a viable option for industrial decarbonization. The use of RNG for decarbonizing pipeline gas is particularly well-suited to helping reduce GHG emissions from the Industry sector, since natural gas plays a prominent role in numerous industrial applications--as a resource for process heat, as a fuel for CHP systems, and as a feedstock for commercial products such as chemicals. A further opportunity to achieve a comparatively smaller reduction in emissions could include fuel-switching to natural gas from coal and petroleum.

Deployment of CHP technology can provide emissions reductions from a number of Industry subsectors by reducing energy consumption.

According to the Department of Energy (DOE), California has the second-highest total potential for new CHP projects in the United States, behind only Texas. In total, the Industry subsectors with the highest technical CHP potential in California were Petroleum Refining (1,427 MW); Chemicals (1,111 MW); Food (776 MW); Stone, Clay, and Glass (204 MW); and Transportation Equipment (147 MW).

Opportunities for reducing emissions in the Industry sector include energy efficiency measures and the adoption of facility best management practices. There are, however, a range of institutional and personnel challenges to pursuing energy efficiency in the Industry sector.

These challenges include lack of awareness of energy efficiency opportunities; challenges accessing technical assistance and qualified personnel; business strategies that are focused on profit margins and not energy management; risk aversion to new technology adoption and process disruption; and limited organizational resources (e.g., time, capital) to devote toward energy efficiency assessments and projects.

As with other sectors, smart systems offer opportunities for decarbonization of the Industry sector.

Smart systems for process automation in the Manufacturing subsector could achieve a reduction in energy intensity of 20 percent. For example, smart sensors could engender behavioral changes, use less energy for the same output (energy efficiency), and reduce overall energy use (conservation).

CHAPTER 5
REDUCING EMISSIONS FROM THE BUILDINGS SECTOR BY 2030

FINDINGS

The Buildings sector, which includes both commercial and residential buildings, is responsible for 9.2 percent of the state's GHG emissions. Energy efficiency and fuel switching are major pathways for both subsectors.

The Residential Buildings subsector contributes approximately two-thirds (63 percent) of the Buildings sector's greenhouse gas (GHG) emissions, while the Commercial Buildings subsector contributes the remaining one-third (37 percent). Energy efficiency has contributed to declining emissions in buildings, even as the overall stock in California has grown. The majority of emissions from buildings come from natural gas use in space and water heating, and for cooking.

Clean energy pathways for the Buildings sector require overcoming barriers such as the sector's highly distributed nature, consumer choice dynamics, existing policies, cost, and the historic rate of stock turnover of end-use systems.

Four emissions reduction pathways were identified that promote optionality and flexibility: energy efficiency of building end-use technologies, increased use of renewable natural gas (RNG), expanded deployment of combined heat and power (CHP) units in large commercial facilities, and increased electrification of certain end uses.

Energy efficiency for commercial and residential buildings, and the appliances used in buildings, represent significant emissions reductions potential.

Energy efficiency has contributed to a decrease in the sector's emissions since 2000, despite the sector's growth since then. According to the California Energy Commission (CEC), mandatory codes and standards, plus programs that incentivize emissions reductions through behavioral and financial mechanisms, can save 152 Bcf of natural gas by 2029, which equates to a reduction of 8.4 $MMTCO_2e$.

Combined heat and power offers a flexible, cost-effective option to reduce emissions in commercial buildings.

California has the second highest CHP potential in the United States. CHP is a mature technology that generates electrical and thermal energy from a single fuel source to reduce energy consumption, lowering fuel costs and associated GHG emissions. California policy promotes CHP deployment by allowing CHP owners to sell excess generation to the grid, providing both a revenue stream and a pathway for emissions reduction.

California's Zero Net Energy (ZNE) Buildings initiative aligns with increased building electrification, especially for new buildings.

California's Residential subsector is expected to grow by 1.5 million new homes by 2030. All new residential construction is slated to be ZNE starting in 2020. While on-site renewables will play a significant role, increased end use electrification can contribute to measurably lowering residential emissions by 2030.

CHAPTER 6
REDUCING EMISSIONS FROM THE AGRICULTURE SECTOR BY 2030

FINDINGS

Agriculture is one of the most difficult sectors in California to decarbonize. More than 80 percent of the sector's emissions are from widespread, non-combustion sources, principally livestock and fertilizer use.

California's Agriculture sector's unique emissions profile is largely from the livestock subsector, which contributed 68 percent of the sector's emissions in 2016. Livestock emissions in 2016 were nearly 15 percent higher than 2000 levels, even though the cattle population increased only 1 percent. Fertilizers, which includes manure-based and synthetic fertilizers, contribute another 16 percent of the sector's total.

One-third of the sector's emissions are due to enteric fermentation from ruminant livestock for which no substantial abatement pathways exist.

Enteric fermentation is a natural process among ruminant animals (mainly cattle), in which microbes in the digestive tract decompose and ferment food, producing methane. Reducing emissions from livestock is particularly challenging due to California's large cattle population, which was 5.15 million in 2016.

Due to the sector's unique emissions profile, a combination of biogas capture, fertilizer application optimization, and electrification, could be pathways to reduce emissions.

The Agriculture sector emits 8 percent of California's total greenhouse gas (GHG) emissions. Three decarbonization pathways were identified in the 2030 timeframe: capturing methane (biogas) from livestock manure for renewable natural gas (RNG) production, optimizing fertilizer application rates to reduce non-combustion emissions, and reducing fuel-use emissions by gradually electrifying the light-duty tractor fleet.

The Agriculture sector's greatest contribution to statewide emissions reductions is its biogas production potential for use as RNG.

Utilizing agricultural residues and manure as biogas feedstocks for RNG could provide up to 46.6 Bcf per year of carbon-neutral gas by 2030, providing emissions benefits to end-use sectors. Biogas capture also could provide emissions reductions and economic benefits to the Agriculture sector since methane that is released into the atmosphere has a global warming potential (GWP) that is 8.5 times higher than methane combusted to CO_2. Diverting methane into a useable product in the form of RNG could have a significant net impact on GHG levels—potentially reducing the Agriculture sector's emissions 13 percent by 2030.

Policies and strategies for the Agriculture sector must consider the unique nature of local factors, such as soil composition and weather patterns, making standardized approaches difficult.

Decarbonization pathways, if improperly planned or implemented, could adversely impact farmers, local communities, consumers, and the sector as a whole. This underscores the importance of localized farm management strategies, as the agronomic and environmental factors that impact emissions are different on each farm. Additionally, agricultural areas may have limited access to infrastructure and the internet, which must be considered when assessing various technological solutions.