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<td>Optionality, Flexibility &amp; Innovation - Pathways for Deep Decarbonization in California</td>
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Evolving Energy Realities: Adapting to What's Next

Melanie Kenderdine
Principal, Energy Futures Initiative
California Energy Commission
September 23, 2019

Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California
Under the leadership of Ernest J. Moniz, EFI is committed to objective analysis-based reports on important energy issues to inform policy makers, regulators and others engaged in debates on public policy. Consistent with the prior practice of the principals, EFI seeks multi-source funding, including from relevant industries, for its products. Once a study is initiated, the work and the results are EFI’s; they are in no way vetted or approved by any sponsor, public or private. All EFI analysis is published and publicly available.

Optionality, Flexibility & Innovation: Study Rules and Advisory Group

The Energy Futures Initiative wishes to thank the following individuals for providing comments on this paper. The research and views in this paper are those solely of the Energy Futures Initiative.

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Study Approach: 2030 & 2050 Emissions Reduction Targets by Sector from 2016 Baseline (MMTCO2e)

To meet 80% target, 242.9 MMT CO2e reductions -- 71% of total emissions in 2016 -- are needed from the most difficult to decarbonize sectors.
Timeline of Key California Policies for GHG Reductions

- **AB 32**: Economy-wide GHG emissions equal to 1990 levels.
- **SB 1383**: 75% reduction of organic waste disposed in landfills from 2014 levels.
- **SB 32**: Economy-wide GHG emissions 40% below 1990 levels.
- **SB 1383**: Reduce methane & HFCs 40% and black carbon 50% below 2013 levels.
- **E.O. B-55-18**: Economy-wide carbon neutrality & net negative emissions thereafter.
- **E.O. S-3-05**: Economy-wide GHG emissions 80% below 1990 levels.

- **2020**:
  - **SB 1383**: 50% reduction of organic waste disposed in landfills from 2014 levels.
  - **SB 1275**: One million zero-emission vehicles (ZEVs) or near-ZEVs.

- **2023**:
  - **E.O. B-16-12**: 1.5 million ZEVs.

- **2025**:
  - **E.O. B-48-18**: 5 million ZEVs.
  - **SB 100**: 60% renewables for electricity.

- **2030**:
  - **SB 350**: Double energy efficiency.
  - **Low Carbon Fuel Standard**: Carbon intensity of gasoline reduced 16.8%, diesel 14.9%, and jet fuel 10.1% below 2011 levels*.

- **2045**:
  - **SB 100**: 100% zero-carbon electricity.

- **2050**:
  - **E.O. B-16-12**: Transportation sector GHG emissions 80% below 1990 levels.

*EFI calculated the LCFS reductions percentages using the carbon intensity levels for gasoline, diesel, and jet fuel from 2011-2030 as specified in 17 CCR § 95460-95497.
Sectoral Emissions in California, 2016

- **Industry**: 23%
  - Industry: 100.4
  - Rest of Economy: 329.0

- **Transportation**: 39%
  - Transport: 169.3

- **Electricity**: 16%
  - Electricity: 68.6

- **Buildings**: 9%
  - Buildings: 39.4

- **Agriculture**: 8%
  - Agriculture: 33.8

Source: EFI analysis using data from CARB
Identified Emissions Reduction Potential of Sector-Specific Pathways for Meeting the 2030 Targets

**Electricity**
- NGCC/CCUS: 17.7
- Storage/Up to 10-hr Storage: 8.0
- Decarbonized Imports: 5.0
- RNG Use: 4.0
- Renewables/5-hr Storage: 3.6
- H2 Doping: 3.0
- Demand Response: 2.0
- LDV CAFE: 1.7
- LDV LCFS: 22.0
- LDV Electrification: 16.0
- HDV CAFE: 9.1
- HDV LCFS: 6.3
- Lower LDV VMT: 5.9
- Lower HDV VMT: 5.9
- Other VMT: 1.4
- HDV AEVs: 0.7
- HDV CAFE: 0.4
- Lower Fugitive Emissions: 12.8
- Fuel-switch to H2: 7.2
- Best Management Practices: 6.7
- Injection/Additive Manufacturing: 5.5
- Fuel-switch to Natural Gas: 4.3
- Biogas Capture: 4.3
- RNG Use: 3.6
- Lower Fugitive Emissions: 3.1
- CHP: 1.0
- Electric CHP: 5.1
- NGCC CHP: 3.9
- Electric NGCC CHP: 3.9
- Biogas Capture: 4.5
- Optimize Fertilizer: 0.2
- Reduce Fuel: 0.2

**Transportation**
- LDV CAFE: 17.7
- LDV LCFS: 8.0
- HDV CAFE: 5.0
- HDV LCFS: 4.0
- Lower LDV VMT: 3.6
- Lower HDV VMT: 3.0
- Other VMT: 2.0
- HDV AEVs: 1.7
- HDV CAFE: 22.0
- HDV LCFS: 16.0
- LDV Electrification: 9.1
- LDV LCFS: 6.3
- Lower LDV VMT: 5.9
- Lower HDV VMT: 5.9
- Other VMT: 1.4
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- Biogas Capture: 4.5
- Optimize Fertilizer: 0.2
- Reduce Fuel: 0.2

**Industry**
- LDV CAFE: 17.7
- LDV LCFS: 8.0
- HDV CAFE: 5.0
- HDV LCFS: 4.0
- Lower LDV VMT: 3.6
- Lower HDV VMT: 3.0
- Other VMT: 2.0
- HDV AEVs: 1.7
- HDV CAFE: 22.0
- HDV LCFS: 16.0
- LDV Electrification: 9.1
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- Biogas Capture: 4.5
- Optimize Fertilizer: 0.2
- Reduce Fuel: 0.2

**Buildings**
- LDV CAFE: 17.7
- LDV LCFS: 8.0
- HDV CAFE: 5.0
- HDV LCFS: 4.0
- Lower LDV VMT: 3.6
- Lower HDV VMT: 3.0
- Other VMT: 2.0
- HDV AEVs: 1.7
- HDV CAFE: 22.0
- HDV LCFS: 16.0
- LDV Electrification: 9.1
- LDV LCFS: 6.3
- Lower LDV VMT: 5.9
- Lower HDV VMT: 5.9
- Other VMT: 1.4
- HDV AEVs: 0.7
- HDV CAFE: 0.4
- Lower Fugitive Emissions: 12.8
- Fuel-switch to H2: 7.2
- Best Management Practices: 6.7
- Injection/Additive Manufacturing: 5.5
- Fuel-switch to Natural Gas: 4.3
- Biogas Capture: 4.3
- RNG Use: 3.6
- Lower Fugitive Emissions: 3.1
- CHP: 1.0
- Electric CHP: 5.1
- NGCC CHP: 3.9
- Electric NGCC CHP: 3.9
- Biogas Capture: 4.5
- Optimize Fertilizer: 0.2
- Reduce Fuel: 0.2

**Agriculture**
- LDV CAFE: 17.7
- LDV LCFS: 8.0
- HDV CAFE: 5.0
- HDV LCFS: 4.0
- Lower LDV VMT: 3.6
- Lower HDV VMT: 3.0
- Other VMT: 2.0
- HDV AEVs: 1.7
- HDV CAFE: 22.0
- HDV LCFS: 16.0
- LDV Electrification: 9.1
- LDV LCFS: 6.3
- Lower LDV VMT: 5.9
- Lower HDV VMT: 5.9
- Other VMT: 1.4
- HDV AEVs: 0.7
- HDV CAFE: 0.4
- Lower Fugitive Emissions: 12.8
- Fuel-switch to H2: 7.2
- Best Management Practices: 6.7
- Injection/Additive Manufacturing: 5.5
- Fuel-switch to Natural Gas: 4.3
- Biogas Capture: 4.3
- RNG Use: 3.6
- Lower Fugitive Emissions: 3.1
- CHP: 1.0
- Electric CHP: 5.1
- NGCC CHP: 3.9
- Electric NGCC CHP: 3.9
- Biogas Capture: 4.5
- Optimize Fertilizer: 0.2
- Reduce Fuel: 0.2

Source: EFI analysis
Sectoral GHG Emissions Reductions Achieved by 2030 From Top Two Technology Pathways*

Industry: 23%
Need 40 MMT reduction by 2030
Top 2 pathways get halfway there

Transportation: 39%
Need 68 MMT reduction by 2030
Top 2 pathways get 44% of way there

Electricity: 16%
Need 27 MMT reduction by 2030
Top 2 pathways get 100% of target

Buildings: 9%
Need 15 MMT reduction by 2030
Top 2 pathways get 93% of way there

Agriculture: 8%
Need 13 MMT reduction by 2030
Top 2 pathway gets 35% of the target

*From 2016 emissions baseline, growth not assumed
In-state Generation by Fuel Type, 2001/2016 (GWh)

- **Coal**: 0.1%
- **Other**: 0.2%
- **Biomass**: 3%
- **Geothermal**: 5.8%
- **Nuclear**: 9.5%
- **Natural Gas**: 49.8%
- **Large Hydro**: 12.3%
- **Small Hydro**: 2.3%
- **Solar**: 10%
- **Wind**: 6.8%

**In-state generation from sources that are covered by the state RPS:**
- **28%**

**Generation from Large Hydro, Nuclear, Natural Gas:**
- **72%**

**Generation from Natural Gas:**
- **50%**

**Figures denote % change in generation by type, 2001-2016**

Source: EFI using data from CEC Almanac

*Note: The table and chart provide a visual representation of the in-state generation by fuel type for 2001 and 2016, along with the percentage change for each category.*
Over the course of a year large-scale dependence on both wind and solar will result in significant periods requiring very large-scale back-up options.

Hourly trends in solar and wind capacity factors in CA for 2017 aligned to normalized variation in hourly load relative to peak daily load.

Source: CAISO data, EFI analysis
Seasonal Variation in Solar & Wind

Metered Solar Generation

- 1.5 TWh in January
- 3.2 TWh in June
- Delta: 1.7 TWh

Wind Generation

- 0.6 TWh in January
- 2.0 TWh in June
- Delta: 1.4 TWh

Wind/Solar Seasonal Delta Between January and June, 2016

- 3.1 TWh

Source: EFI, compiled using data from CAISO
...between 2007-2009, a period of significant drought, hydro generation fell to about 13 percent of California’s total generation, down from a peak of 18 percent, with monthly hydro production falling from 5,000 MWh/month to less than 1,000. In the most recent and more severe drought, hydro generation was under seven percent of total generation.

Source: Pacific Institute, 2017
Efficiency improvements have the highest mitigation potential in the Transportation sector, resulting in 28.3 MMTCO$_2$e in reductions. CAFE could, in fact, have one of the largest emissions impacts of any single policy in any sector.
Industry: Multiple Subsectors, Combustion and Non-Combustion Emissions Require a Range of Pathways

Industry Sector Energy Consumption by Fuel Type

Potential Sequestration Sites for Industrial Facilities

- Cement Plants
- Gas Processing Plants
- Oil Refineries
- Oil & Gas Reservoirs
- Saline Formations
Industry is the sector that is most difficult to decarbonize. Innovation is needed in hydrogen, carbon capture, storage and utilization, and biogas.

Expanded 45Q Tax Credit for Carbon Capture, Utilization and Storage (CCUS), AOTA
Utilizing agricultural residues and manure as biogas feedstocks for RNG could provide up to 46.6 Bcf/year of carbon-neutral gas by 2030...Biogas capture also could provide emissions reductions and economic benefits to the Agriculture sector ....Diverting methane into a useable product in the form of RNG can have a significant net impact on CO₂e levels—potentially reducing the Agriculture sector’s emissions 13 percent by 2030.
Meeting the Clean Energy Ministerial's target of 30 million electric vehicle sales by 2030 would require 314 kt/yr. of cobalt, almost three times the 2017 level for all uses. At those rates, reserves would last 23 years.

Tesla’s global supply manager for battery metals, told a closed-door Washington conference of miners, regulators and lawmakers that the automaker sees a shortage of key EV minerals coming in the near future...Tesla will continue to focus more on nickel, part of a plan by Chief Executive Elon Musk to use less cobalt in battery cathodes.

Electrek, May, 2019

Source: USGS, 2019