Achieving a near-zero CO$_2$ transportation system in CA: strategies and costs

Dr. Lewis M. Fulton
Director, Energy Futures Program, ITS-Davis

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Road Vehicles Represent 36% of California CO2 Emissions

Recent California actions toward Achieving very low road transportation CO2

The state has set a carbon neutrality goal for 2045.

Transportation has specific targets:
• 5 million zero-emission vehicle (ZEV) light-duty vehicles (LDVs) on the road by 2030
• Advanced Clean Truck (ACT) ZEV truck targets, up to 75% of sales by 2035
• Low-carbon fuel standard (LCFS), 20% reduction in average fuel carbon intensity by 2030 (vs 2010)

And the newest one…
• Executive Order: 100% LDV ZEV sales by 2035, trucks by 2045
Modeling Transportation Low-carbon Scenarios

We use our Transportation Transitions Model to examine scenarios of BEV, PHEV, FCV market penetration and advanced fuels in California on-road vehicle fleet.

Currently developing very low carbon scenarios, building on our previous “80-in-50” study; here we focus on “Executive Order” for LDVs and “ACT scenario” for trucks.

• Transparent spreadsheet stock turnover model
• Includes on-road LDVs, trucks, buses
• Inputs: fleet stocks, vehicle sales, VMT, fuel economy, vehicle and fuel costs
• Calibrated to historical ARB EMFAC data
• Outputs: vehicle stock by technology, fuel usage, GHG emissions, fleet vehicle and fuel costs
• Includes a wide range of technology and cost data and projections
Two scenarios

• BAU – incorporates all current and planned policies, except one (I will explain)

• A fast ZEV uptake, very low-carbon scenario
  ▪ Near 0 CO2 emissions in 2045
  ▪ Fast ZEV LDV and HDV penetration (2035 LDV and varying ACT ZEV sales targets)
  ▪ Some reduction in passenger travel vs BAU
BAU Scenario

LDVs: 1.5 million ZEVs in 2025, 3.0 million ZEVs in 2030
Fuel cells stall at 1/10th of ZEV sales
Trucks: 2% ZEV Market Penetration in 2030 for most truck types
Trucks follow Advanced Clean Truck (ACT) regulation through 2035

In 2040 ZEV Sales share = 98%
2030 sales shares by technology for this low carbon scenario

Note: HD = heavy duty, MD = medium duty
2045 sales shares by technology for the low carbon Scenario

Note: LH = Long haul truck, SH=short haul truck
Resulting Fuel Use by Scenario

Fuel Consumption in BAU

Fuel Consumption in low-carbon scenario
Resulting Greenhouse Gas Emissions

LC Scenario includes: 100% renewable electricity and hydrogen by 2045
100% biofuels share of gasoline (ethanol) and diesel by 2045
Thinking about costs – H2 as an example
Recent estimates of produced and delivered electrolytic H2

Delivered pump price, $/kg

<table>
<thead>
<tr>
<th>Study</th>
<th>2020</th>
<th>2025</th>
<th>2030+</th>
<th>Notes</th>
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<tbody>
<tr>
<td>US DOE targets [21]</td>
<td></td>
<td></td>
<td></td>
<td>Targets, but considered achievable in time frame</td>
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<tr>
<td>- Low volume (higher cost)</td>
<td>16</td>
<td>10</td>
<td></td>
<td>For long term target, only a high volume one ($4)</td>
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<tr>
<td>- High volume (lower cost)</td>
<td>13</td>
<td>5</td>
<td>4</td>
<td>Mid sized truck stop, low electricity cost, does not include H2 transportation, if needed</td>
</tr>
<tr>
<td>Sinha (UC Davis 2020 draft-[22])</td>
<td>12.9</td>
<td>6.6</td>
<td>3.4</td>
<td>Mid-range electrolysis cost with trucking (pipeline very similar)</td>
</tr>
<tr>
<td>H2 Council/McKensey 2020 [21]</td>
<td>10.4</td>
<td>4.4</td>
<td></td>
<td>Mid case, based on mid electricity price, electrolyser cost, capacity factor</td>
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<tr>
<td>IEA (2019) [23]</td>
<td>12</td>
<td>7</td>
<td></td>
<td>Not clear that the station cost includes all components of getting hydrogen from production to vehicle.</td>
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</table>
Our resulting cost projections ($/kg) for electrolytic hydrogen for FC trucks, reflecting technology and volume-related cost reductions...

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
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<td>Base (average)</td>
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<td>Lower cost</td>
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### Key Assumptions and Input Ranges

<table>
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<tr>
<th>Year</th>
<th>Diesel ($/gal)</th>
<th>Low</th>
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<th>High</th>
<th>Electricity ($/kWh)</th>
<th>Low</th>
<th>Base</th>
<th>High</th>
<th>Hydrogen ($/kg)</th>
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<th>Base</th>
<th>High</th>
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<tbody>
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<td></td>
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<td>12.00</td>
<td>17.00</td>
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<tr>
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<td></td>
<td>4.00</td>
<td>5.00</td>
<td>6.00</td>
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</table>

**NOTE:** Electricity includes $0.02/kWh amortized charging station, No LCFS credits

<table>
<thead>
<tr>
<th>Year</th>
<th>Battery ($/kWh)</th>
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<th>High</th>
<th>Fuel Cell</th>
<th>Low</th>
<th>Base</th>
<th>High</th>
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<td>145</td>
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<td>100</td>
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<td>75</td>
<td>65</td>
<td>78</td>
<td>90</td>
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</table>
Relative total cost of ownership, by technology/year

BEVs generally compare well to diesel; FCEVs catch up, but is it too late?

These do not take into account the value of non-market cost factors, like range/refueling time – these can be critical

Cost of hydrogen and electricity are particularly uncertain
Scenario Cost Comparison

Comparing our low carbon to BAU scenarios, annual expenditure difference including vehicle purchase costs and fuel costs

Cumulative cost difference between LC and BAU ($ billions)

<table>
<thead>
<tr>
<th></th>
<th>2020-2030</th>
<th>2031-2045</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDVs</td>
<td>13</td>
<td>-181</td>
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<tr>
<td>Trucks</td>
<td>9</td>
<td>-26</td>
</tr>
</tbody>
</table>
What happens to ICEs and liquid fuels as we transition to ZEVs?

- Even with a very rapid transition to ZEVs (e.g. all new LDVs are ZEV by 2035), a lot of ICE vehicles will remain through 2045-2050.

- The strong ramp-down in liquid fuels may need to be accompanied by a strong ramp up in replacement of fossil liquids with very low-carbon liquids.
We may need a lot of bio or synthetic liquids

- In this scenario, we need to replace both gasoline and corn ethanol between 2030 and 2040.
- Cellulosic ethanol hits a blend wall at 15% by volume
- We end up needing nearly 3 billion gallons of “bio-gasoline” by 2040, eventually going back down.
Some takeaways

• Achieving California’s transportation ZEV and low-carbon targets will require rapid transitions and will be challenging in the given time frames
• Costs may be substantial, but eventually the benefits appear likely to be much greater
• The costs associated with achieving very low carbon liquid fuels may be a significant part of the overall costs
• We need to better understand what it will take to get consumers (households and fleets) to adopt large numbers of ZEVs
  • The values of non-cost attributes
  • The types of incentives that will be needed
Thank you!