WSPA

Western States Petroleum Association
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Catherine Reheis-Boyd
President

December 16, 2016

Ms. Rajinder Sahota via e-mail at: rsahota@arb.ca.gov
California Air Resources Board
1001 I Street
Sacramento, CA 95814

Re: WSPA Comments on ARB's discussion draft 2030 Target Scoping Plan Update

Dear Ms. Sahota:

The Western States Petroleum Association (WSPA) is a non-profit trade association representing companies that explore for, produce, refine, transport and market petroleum, petroleum products, natural gas and other energy supplies in California and four other western states. WSPA appreciates this opportunity to provide comments on the Air Resources Board's (ARB) discussion draft 2030 Target Scoping Plan Update.

As a practical matter, two weeks is not sufficient time to allow for meaningful public review and comment on a planning document of this scale, complexity and critical importance to California's economy. This document is also incomplete, substituting placeholders for critical information and analysis for such planning elements as AB 197 (Garcia, 2016) implementation. While we appreciate the opportunity to review a discussion draft ahead of a formal proposal, we believe this piecemeal approach to the update process compromises the value of stakeholder input. These procedural anomalies are driven, at least in part, by the timeline ARB has established for adoption of this Scoping Plan Update. With California still four years away from completing implementation of the AB 32 2030 goal, we fail to understand why the 2030 Target Scoping Plan Update process needs to be compressed into such an artificially short timeframe.

Given these concerns, the following comments should be considered preliminary, and we expect to provide additional comments following ARB's December 16, 2016 comment deadline. We also incorporate by reference our December 12, 2016 comments on 2030 Target Scoping Plan Update information presented during ARB's November 7, 2016 public workshop and the November 17, 2016 Board meeting. Lastly, we request that a sufficient amount of time be provided for meaningful review and stakeholder input once the draft is complete.

Cap and Trade Scenario

The discussion draft represents a reversal of the 2030 Target Scoping Plan Update concepts ARB workshopped in the fall of 2015. In particular, ARB is proposing to substantially reduce the volume of emission reductions that would be obtained through the Cap and Trade program, instead relying on expansion of existing complementary measures and addition of new sector specific control measures. As expert economists have observed, greater reliance on complementary measures relative to Cap and Trade will lead to perverse programmatic outcomes. This approach only shifts emissions among sectors covered by the cap which does not reduce aggregate GHG emissions and therefore does not satisfy the central mandate of AB 32. Direct sector measures also work against the objectives of AB 32 to ensure a cost-effective program because they increase the cost to California consumers of achieving emissions reduction targets.[1] Moreover, ARB has produced no evidence, and in fact has offered its own conclusions to the contrary, that increasing reliance on complementary and sector-specific control measures will lead to greater reductions in localized criteria pollutant emissions relative to reliance on myriad existing federal, state, and local criteria pollutant control measures.[2] ARB staff has also asserted that the Cap and Trade program will result in direct control measures on regulated sectors, which addresses the prioritization goals of AB 197. The available evidence indicates that it is not necessary from a public health standpoint to discount the role of Cap and Trade in an effort to implement AB 197, and is likely to be counter-productive in terms of statewide and localized economic impacts.

WSPA strongly recommends that ARB include a fourth scenario that accounts for existing statutory mandates and relies on Cap and Trade to achieve the balance of the 2030 target emissions reductions. Inclusion of such a fourth scenario is necessary to characterize a reasonable range of policy options available to ARB, including at least one scenario that provides a potentially more cost effective option and minimizes to the extent possible dependence on speculative sector-specific measures. In addition, this scenario would provide a frame of reference for evaluating the economic impacts of the three alternatives described in the discussion draft. The following table describes the elements of this scenario using the same format ARB presented during its November 7, 2016 workshop. Where appropriate, individual elements are footnoted to explain deviations from ARB's reference scenario.

Scenario Element	**Cap and Trade Scenario 4**
Renewable Portfolio Standard	50% by 2030
Energy Efficiency	2 X 2015 IEPR Mid-AAEE[3]
Rooftop PV	18 GW in 2030 (2015 IEPR mid-PV forecast)
Electrification of buildings	No new electrification
Transportation	Current Control Program scenario[4]
Low Carbon Fuel Standard	Current carbon intensity level[5]
Res., com. & industrial pipeline gas	No renewable gas
Industrial & Oil and Gas Extraction	No new measures
Refining	No new measures
Non-energy GHGs	Short-Lived Climate Pollutant strategy (50% reduction in carbon black, 40% reduction in methane and hydrofluorocarbon gases below 2013 levels by 2030)[6]
Carbon pricing	Cap and Trade

[1] Implications of Policy Interactions for California's Climate Policy, Todd Schatzki and Robert N. Stavins, Analysis Group, Inc., Harvard University, August 27, 2012: http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/implications_policy_interactions_california_climate_policy.pdf.

[2] "Assuming all cap-and-trade reductions occur at local facilities has a very small impact on total reductions expected in 2020." Air Resources Board staff presentation, Health Impact Assessment of Cap-and-Trade Program, Progress to Date; May 24, 2010 ; slide 14:

ARB HIA status May 2010 5-23[2]_notate

[3] SB 350 (DeLeon, 2015).

[4] 1.5 million ZEVs by 2025. The current program faces a significant shortfall and is unlikely to meet the target.

[5] The 10% LCFS target in the current regulation is not a statutory mandate, and as noted in the LCFS section of this letter, ARB has not yet demonstrated that the current target is achievable. As such, WSPA continues to maintain that the 10% LCFS is not feasible.

[6] SB 1383 (Lara, 2016).

Refinery Measure

WSPA objects to the inclusion of a new direct control measure on refining and other industries in any of the 2030 target scenarios. WSPA's objection to the refinery measure concept is based on the following issues:

1. Cap and Trade will continue to stimulate on-site GHG emission reductions and will result in more cost effective reductions than sector specific control measures.
2. ARB's own energy efficiency and co-benefits audits for the refining sector have demonstrated that an additional 20% reduction in energy use from this sector is not feasible.
3. Refineries differ from one another, and it is not possible for every refinery to achieve the same efficiency, regardless of the measurement metric.
4. ARB previously concluded that simple-barrel is not an appropriate efficiency metric.
5. The strategies mentioned by ARB are largely if not entirely infeasible.

As we noted in our comments on the November 7 staff presentation, these facilities have already aggressively invested in energy efficiency projects, and the declining cap will continue to stimulate on-site GHG emissions reductions. As we discuss in the following section, this measure is likely to be extremely inefficient from both an environmental and economic standpoint.
The discussion draft proposes to reduce refinery energy use by 20-30% on a sector-wide basis by 2030. To achieve this efficiency target, ARB proposes that each refinery be required to achieve the efficiency of the most efficient existing refinery on a simple-barrel basis through a combination of actions that may include fuel switching, boiler electrification, use of lighter crude slates and deployment of unspecified "newer more energy efficient technologies." (pp. 89)

ARB's Energy Efficiency and Co-Benefits Audit for California refineries determined that most efficiency and emission reduction options available to California facilities have already been implemented or are planned in the near future. ARB has failed to illustrate the feasibility of any large scale additional efficiency improvements.

ARB previously acknowledged in the Initial Statement of Reasons for the 2010 Cap and Trade regulation that the simple barrel output approach may disadvantage more complex refineries relative to their simpler competitors.[7] Moreover, refinery design differs significantly from facility to facility, and it is not possible for every refinery to achieve the same efficiency.

- **Fuel switching.** While there may be some limited opportunities to change out fuel sources to achieve lower CO_2 emissions, in most cases these changes will only provide small incremental improvements, not significant efficiency gains. If such options are even available to California facilities, it is likely they have already been implemented or are planned in the near future, as indicated by ARB's own Energy Efficiency and Co-Benefits Audit for California refineries and several other recent studies undertaken on this topic.

  In theory, electrification of turbines may be feasible and sometimes can be done cost-effectively. However, any actual savings in CO_2 is dependent on the means by which the electricity was generated, as well as the fate of the steam that is no longer used. In some cases, the volume of steam generation may not actually change owing to other factors. In addition, there are times that pumps in a system are intentionally powered by steam as a safety function to mitigate power

[7] https://www.arb.ca.gov/regact/2010/capandtrade10/capv4appj.pdf; page J41-42.

failure risks and minimize flaring. ARB is wrong to assume that such actions are feasible at all times at all facilities.

- **Crude selection (use of lighter crude slates).** Because of the quality of California crudes and California's historic environmental leadership, California refineries have been designed to process heavy crudes in compliance with the world's most stringent environmental regulations. If refineries in the sector were to switch to lighter crudes, heavier California and world crudes would be diverted to other refining regions resulting in emissions leakage and, most likely, higher overall emissions. In addition, each refinery is designed to run a particular crude slate. Within the California refining sector, switching to a lighter crude slate would lead to an inability to fully utilize existing refinery processing plants, either resulting in inefficient operation or requiring extensive and investment-intensive facility re-configuration.[8]

- **Boiler electrification.** This concept is infeasible for boilers of the size operated at refineries. An outlet for byproduct hydrocarbon streams (e.g., light ends) is necessary in any case, and utilizing such streams as boiler fuel will continue to be the optimum approach for California facilities.

- **Process efficiencies.** There are typically incremental options available at individual refineries for additional process efficiencies, such as waste heat recovery opportunities. A market price for carbon will inform the value for these, and will incent the most cost-effective approaches to reduce CO_2 emissions.

Oil and Gas Measure

ARB's "Alternative 1" scenario includes a 25% reduction in GHG emissions from the industrial and oil and gas sectors. While we object to Alternative 1 on the basis that it would eliminate the most cost effective measure for achieving future GHG reductions (the Cap and Trade program), we are also concerned that it may represent a longer term vision of potential additional measures to offset underperformance of the measures identified in ARB's Draft 2030 Target Scoping Plan Scenario.

The concept upon which this measure is predicated – that all production operations can achieve the same level of efficiency as the most efficient operation – is fatally flawed because it ignores major differences among individual operations throughout California. These variables include, but are not limited to, oil field size, volume and type of well production, location, geology, oil types, age and depth of wells and reservoirs, topography, local climate, access to capital and existing or pending rules and regulations. ARB's conceptual measure is also at odds with prior ARB policy decisions, such as the inclusion of separate benchmarks for thermal and non-thermal oil production in the Cap and Trade regulation, which recognize important energy efficiency-related distinctions among California oil production operations.

The range of compliance options contemplated for this measure is similar to those contemplated for ARB's conceptual refinery measure. They include fuel switching, boiler electrification, onsite investments in newer, more energy efficient technologies and other undefined "process efficiencies." The discussion draft offers no information about the technical feasibility of these options for different production operations, their cost-effectiveness or their emissions reduction potential. It is possible, if not likely, that for certain marginal operations, imposition of this measure would be cost prohibitive, potentially leading to shut down of production wells. Certainly, achieving emissions reductions in this sector by way of curtailing production would result in emissions and economic leakage, in which case

[8] Chevron Refinery Modernization Project EIR – Appendix 4.3-URM; http://chevronmodernization.com/project-documents/

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this measure would be at odds with the policy objectives ARB identifies in the discussion draft.

WSPA is further concerned that imposition of this measure in the wake of the pending oil and gas methane regulation could require additional investments for the same equipment and systems previously subject to the methane regulation. Such overlapping and potentially counter-productive expenditures are neither justified nor economically sustainable.

Low Carbon Fuel Standard

WSPA asserts that proposals for post-2020 LCFS targets are premature as it is not yet clear that the 2020 target of 10% can be achieved. ARB should wait for the mid-2017 review of the LCFS coupled with a review of the current shortfall in the credit bank and determine at that time what prospects exist to make up the shortfall in the remaining four years of the current program. This process is especially important in light of the steep compliance curve. The credit/deficit balance needs to be closely monitored throughout 2017 to inform compliance targets.

ARB appears to be relying substantially on the recently developed biofuel supply module (BFSM), which is still in beta form, to assess the feasibility of meeting LCFS targets ranging from 18%-25% by 2030. WSPA retained the Boston Consulting Group (BCG) to critique this tool. BCG has suggested enhancements to the model and provided feedback on a process for gaining additional public input. Reliance on a modeling tool that is still in a developmental phase is premature. The BCG critique is included Appendix B and offers the following observations:

- The methodology regarding infrastructure limitations is still incomplete in the BFSM;
- There is no way to link future biofuel capacity investment to economic incentives as stated in the technical documentation;
- There are no options to limit supply based on vehicle availability;
- The gasoline demand curve decline is overly optimistic;
- The default biofuel capacity forecast is overly optimistic.

Despite citing the current 10% target as the LCFS baseline in the November 7 staff presentation, ARB is now citing a “known commitment” of at least 18% by 2030 in the discussion draft because that is the target modeled in ARB’s Mobile Source Strategy for the State Implementation Plan (SIP). However, the fact that ARB modeled an 18% LCFS target in the SIP does not make that target enforceable because it is not an adopted measure. It is not even a measure proposed in the SIP (in contrast to low emission diesel). ARB should temper its reliance on long-term, aspirational LCFS targets until it has sufficient evidence to substantiate the feasibility of existing (pre-2020) targets and to identify a sustainable path to achieve longer term targets. In addition to these issues, we note that the discussion draft acknowledges that secondary emissions from land use decisions are not accounted for in the current GHG models “but are nonetheless important considerations.” One of these issues is increased demand for biofuels leading to greater use of land and water for “purpose-grown crops.” (pp. 53) These secondary impacts deserve greater attention in the 2030 Target Scoping Plan update process. Failure to address them in the scenario modeling will inevitably mischaracterize the technical and economic feasibility of the various post-2020 policy options.

Low Emission Diesel

The discussion draft identifies as a potential new measure “Low-Emission Diesel comprising 50 percent of the on- and off-road diesel sold in-State by 2030.” (pp. 56) WSPA submitted comments on ARB’s

Proposed 2016 State Strategy for the State Implementation Plan, dated July 18, 2016, in which we expressed several concerns with ARB's Low Emission Diesel proposal that should be addressed before moving forward with this program. These issues are reiterated below for ease of reference.

1. **Lack of Clarity in Defining Low-Emissions Diesel.** What is the disposition of conventional gas to liquids (GTL) fuels and other like fuels in this strategy? Why add the carbon intensity component to the LED when the LCFS standard and Cap and Trade program already do this? This fuel could provide significant NO_x and PM reductions similar to renewable diesel. This measure should focus on emissions and allow the market to determine how to get there within the confines of the regulations currently in place.

2. **Questionable Projection Methodology.** Unlike the "top-down" approach used in estimating Renewable Diesel (RD) volumes through 2020 in the Low Carbon Fuel Standard (LCFS) and for Advanced Diesel Fuels (ADF), this analysis is based on "bottom-up projections." Top-down in this context means looking at what RD plants are in operation (or may be in operation in the subject time frame) to arrive at a total renewable diesel available figure to which a "how-much-of-that-is-coming-to-CA" factor is applied. The MSS estimates appear to go all the way to starting with available feedstock that could be converted to RD globally. If this is a correct interpretation of how estimates are calculated, then the estimate could potentially yield an increase in RD into California that is 3 times (or more) higher than the 2020 estimates in ARB's illustrative scenario case (which may be an overestimate to begin with). WSPA requests that ARB explain the assumptions used to determine the available feedstock.

3. **Lack of Demonstration of Measurable Benefit.** By ARB's own estimates, later model year trucks equipped with NO_x traps and PM filters will constitute more than 90% of the fleet by 2023. In addition, there is another measure in the MSS that drives the engine manufacturers to ever lower exhaust emission targets. With those two key elements in mind, it is not clear what the benefits of the resultant potentially highly-expensive fuel would be. WSPA would like ARB provide a forecast of market share for legacy on-road diesel vehicles in 2025 as well as the projected off-road fleet. How did ARB separate the impact of vehicle technology from the impact of the LED fuel? What is the incremental benefit of the LED fuel over the new technology vehicles?

4. **Uncertainly in Demand for Diesel.** The ARB proposal suggests that LED would create a set of circumstances that do not exist today. To fully analyze this issue, WSPA believes that ARB would need to answer several critical questions, including but not limited to the following:

    a. What are the incremental criteria and GHG emissions resulting from the potentially displaced volume of diesel being exported from California? Does ARB assume that the displace diesel will be exported or that refinery capacity will be reduced proportionally?
    b. Where does ARB anticipate the additional renewable diesel will come from? Is it produced in-state? What are the emissions from this production?
    c. If it is imported into California, where does it come from and how does it get here? What are the emissions from the transportation of the renewable diesel?
    d. What would be the AB 32 Cap and Trade Program implications of the increase in renewable diesel imports? Would this cause emissions leakage and/or require border carbon adjustments?

WSPA requests that ARB provide, in consultation with industry, viable options to eliminate or minimize these concerns. The need for emission reductions is regional, not state-wide, while the availability of LED may be extremely limited and the costs potentially, prohibitively high. ARB should consider the logic of directing that limited volume only to those areas with the greatest need. This effort could include analysis of the implications of "leakage", potential bifurcation of the on-road and off-road diesel supply, and other potential distribution optimization opportunities.

ZEV Assumptions

The discussion draft promotes unprecedented penetration of zero emission vehicles (pp. 56) without acknowledging their potential unavailability, nor quantifying the potential environmental and economic impacts of aggressive ZEV policy choices. The following findings are taken from a November, 2016 report by Arthur D. Little comparing battery electric vehicles (BEV) to internal combustion engine vehicles (ICEV).[9] While BEVs currently hold an advantage in GHG emissions relative to ICE vehicles, they also promise significantly greater secondary environmental impacts and a much higher total cost of ownership.

> "Secondary Environmental Impacts – BEVs generate a host of secondary environmental impacts greater than those of ICEVs. A 2015 BEV generates enough toxicity over a vehicle's lifetime to cause an impact to human life equivalent to 20 days of life lost to death or disability, 5 whereas a 2015 ICEV generates enough toxicity to impact the average human life by only 6 days. The differential in secondary environmental impacts will widen for new vehicles in 2025, with BEVs producing even higher levels of human toxicity potential."

> "Total Cost of Ownership (TCO) – For a 2015 Compact Passenger Vehicle, the total cost of ownership over a twenty-year vehicle lifetime is $68,492 for the sample BEV model versus $47,676 for an equivalent ICEV—a 44% cost advantage for the ICEV excluding any government subsidies or incentives. For a 2015 Mid-Size Passenger Vehicle, the total cost to own a BEV is $85,854 versus $53,649 for the ICEV—a 60% cost advantage for the ICEV."

While the cost differential between BEVs and ICEVs is expected to narrow, it is still anticipated that ICEVs will have a cost advantage even in 2025.

As the referenced study suggests, ARB should conduct a life cycle environmental and economic analysis to determine whether ZEVs actually offer a net environmental advantage relative to rapidly advancing internal combustion vehicle technologies, and if so, at what cost.

Social Cost of Carbon

In response to AB 197 (Garcia, 2016), the discussion draft cites USEPA's social cost of carbon "methods and values" as potential metrics to include in economic modeling for the 2030 Scoping Plan Update (pp. 113, 114). It is important to note that while AB 197 requires consideration of "social costs" as defined in Health and Safety Code section 38506, it does not require ARB to use the same approaches employed by USEPA and other federal agencies. ARB should carefully consider the procedural and technical defensibility of the existing federal approach before using it as a basis for its own policy and regulatory decisions.

[9] Battery Electric Vehicles vs. Internal Combustion Engine Vehicles, A United States-Based Comprehensive Assessment, Arthur D Little, November, 2016: http://www.adlittle.us/uploads/tx_extthoughtleadership/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf.

WSPA incorporates by reference comments submitted by various industrial organizations to the U.S. Office of Management and Budget, dated February 26, 2014, which detail a number of problems with a federal interagency process that "generates estimates of the social cost of carbon based on estimates of complex economic impacts hundreds of years in the future, which in turn are based on present day understanding of current and future carbon emissions."[10] The industry comments to OMB summarize the deficiencies in the federal social cost of carbon (SCC) approach as follows:

1. The SCC Estimates fail in terms of process and transparency. The SCC Estimates fail to comply with Office of Management and Budget ("OMB") guidance for developing influential policy-relevant information under the IQA. The SCC Estimates are the product of a "black box" process and any claims to their supposed accuracy (and therefore, usefulness in policymaking) are unsupportable.
2. The models with inputs (hereafter referred to as "the modeling systems") used for the SCC Estimates and the subsequent analyses were not subject to peer review.
3. Even if the process used to develop the SCC Estimates was transparent, rigorous, and peer-reviewed, the modeling conducted in this effort does not offer a reasonably acceptable range of accuracy for use in policymaking.
4. The Interagency Working Group ("IWG") has failed to disclose and quantify key uncertainties to inform decision makers and the public about the effects and uncertainties of alternative regulatory actions as required by OMB.
5. By presenting only global SCC estimates and downplaying domestic SCC estimates in 2010 and 2013, the IWG has severely limited the utility of the SCC for use in cost analysis and policymaking.
6. The IWG must (i) supplement the record to provide all of the data, models, assumptions and analyses relied on to arrive at the SCC Estimates, and (ii) allow the public a reasonable opportunity to review and comment on the supplemented record.

WSPA submits that ARB should work with stakeholders through a transparent and inclusive process to develop a methodology for evaluating "social costs" that does not suffer from the aforementioned deficiencies, and those detailed in the referenced comments.

Economic Modeling

ARB is relying on the Energy + Environmental Economics (E3) PATHWAYS model as the foundation for evaluating the feasibility of the Scoping Plan scenarios. E3 has publicly acknowledged that the PATHWAYS model cannot optimize for a least-cost set of policy options. Therefore WSPA remains concerned about ARB's heavy reliance on this model as the primary means of evaluating the economic feasibility of its alternative Scoping Plan Scenarios.

WSPA contracted with ICF to conduct an independent analysis of PATHWAYS modeling of GHG reductions in the transportation and energy sectors, and the integration of PATHWAYS results into REMI. A copy of the ICF report is included in Appendix C. The Report demonstrates that the current

[10] Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order No. 12866; Docket ID OMB-OMB-2013-0007, dated February 26, 2014

Scc1.pdf

Scoping Plan Scenarios and assumptions produce unrealistic estimates of technology penetration and the costs to achieve the target 2030 emissions reductions. The conclusions from this work include the following:

- Costs in the PATHWAYS model tend to be under-estimated or excluded for important transportation and energy sector variables (e.g., vehicle pricing, alternative fueling infrastructure, dispatch of renewable energy).
- The PATHWAYS model ignores significant barriers to consumer acceptance of proposed emission reduction strategies.
- The PATHWAYS model cannot determine the feasibility of any proposed scenario – it can only evaluate costs for assumptions and inputs defined by the user.
- The PATHWAYS model, even in combination with REMI, cannot help ARB determine a least cost mix of policies for the 2030 Scoping Plan Update.

International Solutions

The discussion draft in Section IV(C) discusses the State's work internationally in establishing partnerships and agreements to share experiences and technology. Section I(B) speaks strongly to preserving and maintaining healthy forests and natural lands in California and internationally. Curtailing tropical deforestation has been and should remain a top priority. The Scoping Plan and regulations should more clearly address this priority. To that end, ARB should increase the current offset use limit (8%) and accelerate rulemaking to allow international sector-based offsets including offsets obtained through programs designed to reduce emissions from deforestation and forest degradation (REDD). Any retraction of the offset use limitation would be viewed by many as a step in the wrong direction. ARB's good work with Acre, Brazil should be broadly recognized. While the Scoping Plan's primary purpose is a California pathway to 2030, it should also include a plan to encourage and incent the protection of international forests.

WSPA appreciates ARB's consideration of our comments, and we look forward to your responses. If you have any questions, please contact me at this office, or Tiffany Roberts of my staff at troberts@wspa.org.

Sincerely,

enclosures

cc: Richard Corey - ARB
Edie Chang - ARB
Mary Jane Coombs - ARB
Tiffany Roberts - WSPA

Enclosure A

Technical Support Documents for Refinery Efficiency and Benchmarking

1. ***ARB Discussion Draft Appendix B, July, 2011:*** Documented Refinery simple bbl benchmark of approximately 46 tonnes/1000 bbls. Showed range of performance from about 28 to about 88 tonnes/1000 bbls (range > 3:1)

   https://www.arb.ca.gov/cc/capandtrade/meetings/072011/product-benchmarks.pdf

2. ***Ecofys Draft Report for ARB, August 20, 2012:*** Discusses CWT (Complexity Weighted Tonne) approach relative to EU experience and the CA refining sector. Concludes that differences in emissions intensity (emissions/CWT) are smaller than other benchmark approaches.

   https://www.arb.ca.gov/cc/capandtrade/meetings/08282012/refinerydraft.pdf

3. ***Solomon Report, May 17, 2013:*** Prepared for WSPA and provided to ARB for use in CA. Develops and documents CWB approach for use in CA.

   https://www.arb.ca.gov/cc/capandtrade/meetings/081313/cwt-cwb_backgrounddocument.pdf

4. ***ARB Benchmark Guidance February 26, 2014:*** Presents ARB's preliminary development of CWB and Hydrogen Benchmarks. The April 2014 regulatory package presented the current benchmark of 3.89 vs the typical and atypical refinery benchmarks discussed in the 2/26/14 document. Emissions intensity range about 3.4 to 6.7 (range < 2:1).

   https://www.arb.ca.gov/cc/capandtrade/refinery-benchmarking-approach-guidance.pdf

5. ***Solomon Report, 2015:*** Prepared for WSPA and shared with ARB. Illustrates emissions intensity (emissions/CWB) in relation to crude throughput.

   Emission Intensity vs
   Crude Throughput (2

6. ***Netherlands Reports on the Multiyear Agreement on Energy Efficiency (MEE):***

   a. ***KBC Report Netherlands Refining Industry, May, 2008:*** **Illustrates that not all refineries can achieve the same efficiency.** Concludes that Netherlands refineries might be able to save 12 to 14% energy plus 7% savings related to cogeneration.

   http://www.vnpi.nl/Files/file/KBC%20Report%20Rev%204%20-%20FINAL%20version.pdf

b. ***CE Delft Report, 2011.*** Estimates that 19% energy savings with 5 yr payout may be possible, in line with an MEE agreement to achieve 20% savings. The measures would include on-site efficiency, cogeneration, supply of CO2 and heat to existing off-site environment and horticulture, and use of bio-mass. Report emphasizes every single project would be need to be implemented and perform per forecasts to achieve the objective.

   http://www.cedelft.eu/?go=home.downloadPub&id=1177&file=4348_Summary.pdf;
   http://www.cedelft.eu/publicatie/improving_the_energy_efficiency_of_the_petroleum_industry_in_the_netherlands/1177

c. ***Wood Mackenzie Report January 2015.*** The report does not specifically address GHG or energy, but notes that the **MEE covenant is voluntary and consistent with a 5 yr payback period. No supplementary national policy governing CO2 reduction or energy conservation will be imposed on these companies and no specific national energy tax will be levied on these companies.**

   http://www.vnpi.nl/Files/file/VNPI-EN.pdf

7. ***ARB Energy Efficiency report for refining June 6, 2013:*** Illustrates that only very limited emissions and energy efficiency improvements, other than those already implemented, have been identified for the CA refining sector.

   https://www.arb.ca.gov/cc/energyaudits/eeareports/refinery.pdf

Enclosure B

Boston Consulting Group Critique of ARB Biofuel Supply Module

ARB Biofuel Supply Module

Model suitability assessment

November 2016

The Boston Consulting Group

Executive summary

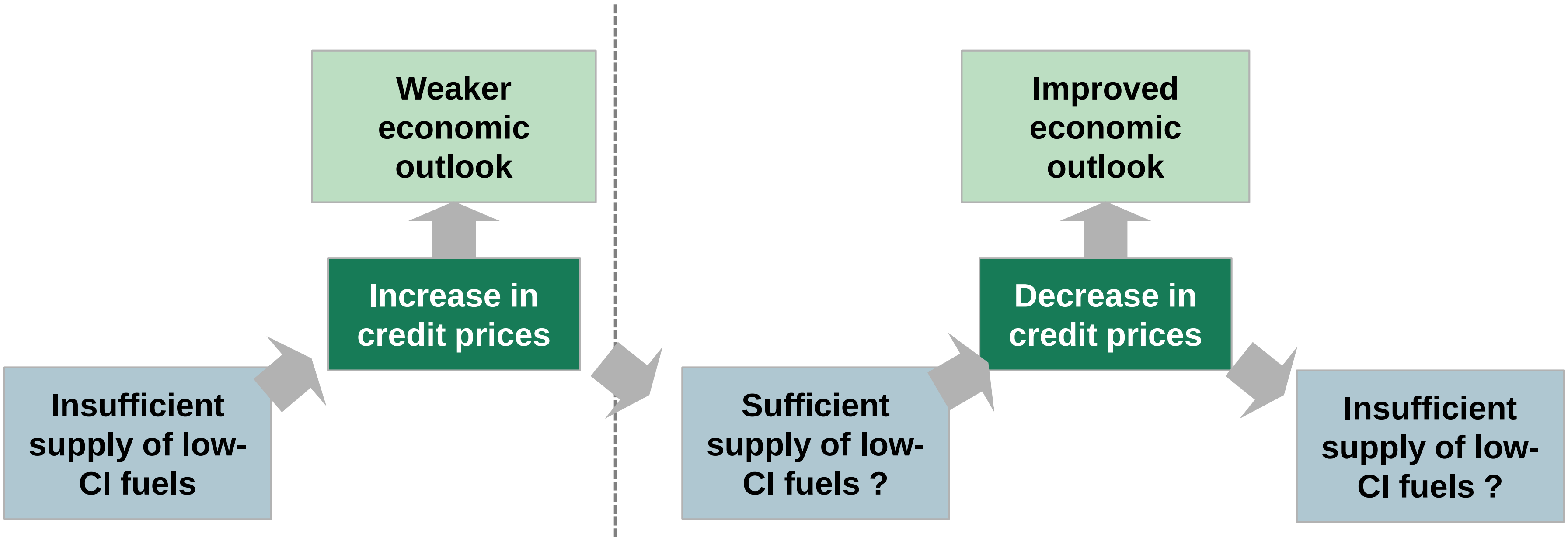
- The California Air Resources Board (ARB) has released their Biofuel Supply Module[1] version 0.83 Beta. The model is expected to be used to estimate the biofuel supply that may be available for use in California's vehicles. It's likely that this analysis will be part of ARB's 2017 Scoping Plan Update.
- As ARB has invited feedback on the model, the goal of this review is to provide feedback on the methodology, assumptions and data inputs to improve future iterations of the model.
- The complex model can serve as a starting framework for having interested parties discuss and understand potential scenarios for biofuel supply in California. It would be a significant benefit to have a single model in common accessible and usable by all interested parties.
- This type of model is an improvement over static compliance curves and models often used for this analysis. Open questions regarding methodology, assumptions, and design that should be considered before it is used in the 2017 Scoping Plan Update.

1. While documentation refers to the Biofuel Supply Module, the model itself includes the title "Biofuel Scenario Model"
Note: An audit of formulas, detailed logic and model structure (i.e. formatting, layout, and efficiency) was not considered in this review.

Methodology regarding infrastructure limitations still incomplete in the BFSM

- An important part of the BFSM is the multi-step process of understanding which fuels will be available to California.
- There are a number of allowances within the model to limit supply. For example, they can set blending limits, limit California vs. US supply, and manually adjust production capacity growth rates. However, there are two components that should be added for the model to be more complete.
- First, there is no way to explicitly link future biofuel capacity investment to economic incentives as stated in the technical documentation
  - Forecasted capacity is based on a manually entered growth rate
- Second, there are no options to limit supply based on vehicle availability
  - This issue could also be addressed on the demand side with the demand input for natural gas or electricity for vehicles

How would the model handle the potential cycle of credit prices driving investment in low-CI fuels?



BCG forecasts indicate that the supply of low-CI fuels will not be sufficient , making it likely that credit prices will increase

Will the LCFS appropriately encourage investment? RFS2 has consistently been adjusted downward as investment has lagged expectations

As "traditional" pathways like corn ethanol reflect lower-CI values, the gap required to fill with very low-CI fuels lessens, making investment even riskier.

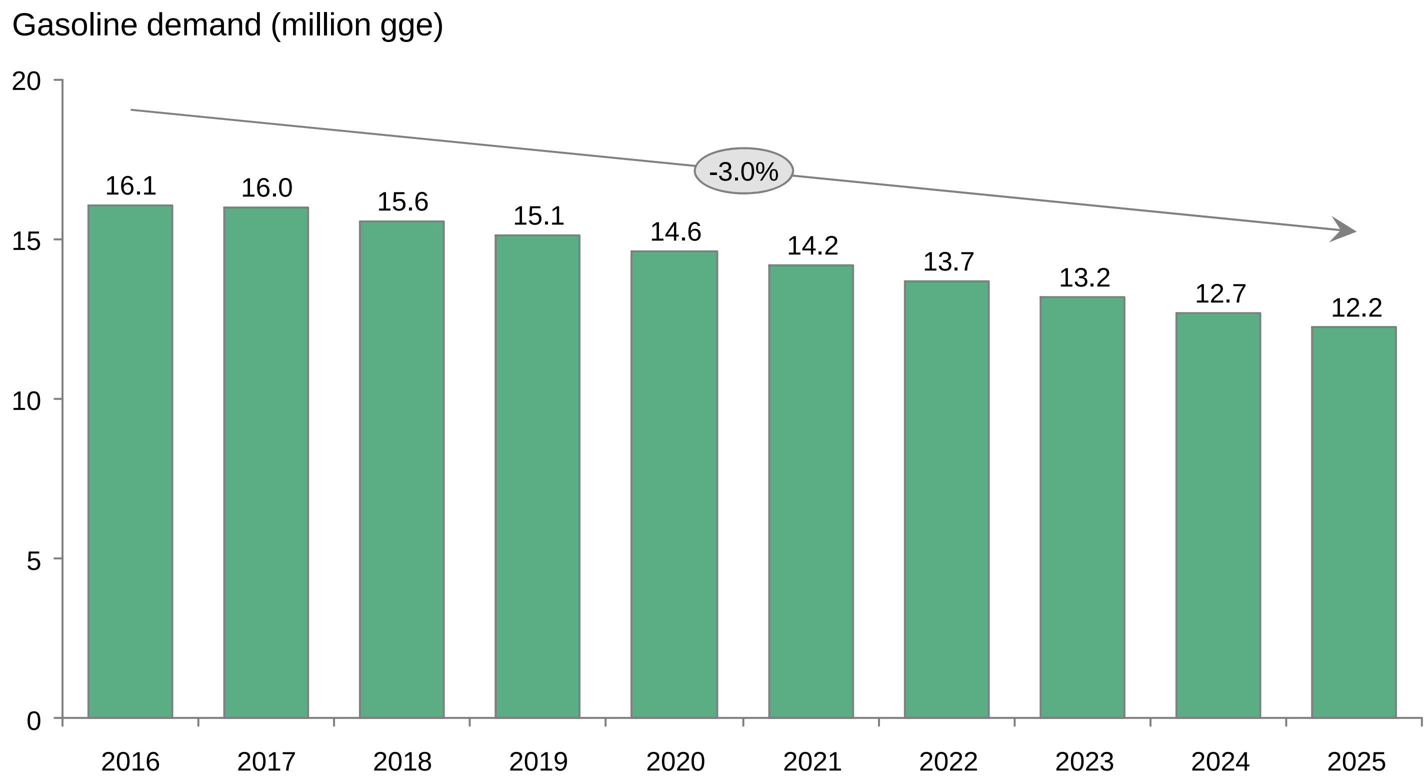
With lower credit prices, will producers continue to invest enough? Will existing investments still be making a suitable return?

Will the market respond?

Source: BCG analysis

Model assumes an average decline of 3% in gasoline demand through 2025

The forecasted volumes of gasoline demand decrease more rapidly than many other sources (including past compliance curves). While the numbers are stated as from E3 PATHWAYS, it would be useful to understand the sensitivity of this assumption.



Note: Includes ethanol, renewable gasoline, electricity, CARBOB, an hydrogen demand
Source: ARB BFSM

Default biofuel capacity forecast very optimistic

- To determine the forecasted capacity for renewable diesel and cellulosic ethanol, the BFSM assumes a growth rate equal to that for the first 15 years for biodiesel and conventional ethanol.

- These growth rates should be reconsidered for the following reasons:

  – Biodiesel and ethanol's initial growth were driven by unique forces (RFS2 for biodiesel and a combination of MTBE replacement and subsidies for ethanol) that provide greater economic incentive than second generation fuels

  – The growth of these fuels came in times of generally increasing demand for fuels in the US

  – There is discrepancy between EIA (numbers used) and RFA for ethanol production 1981-82 which would result in a significantly different growth rate

- It is unreasonable to assume a 41% growth rate per year in capacity growth. Are there enough planned facilities in 2018-2020 when these growth rates start to be used to indicate the potential for 40%+ growth?

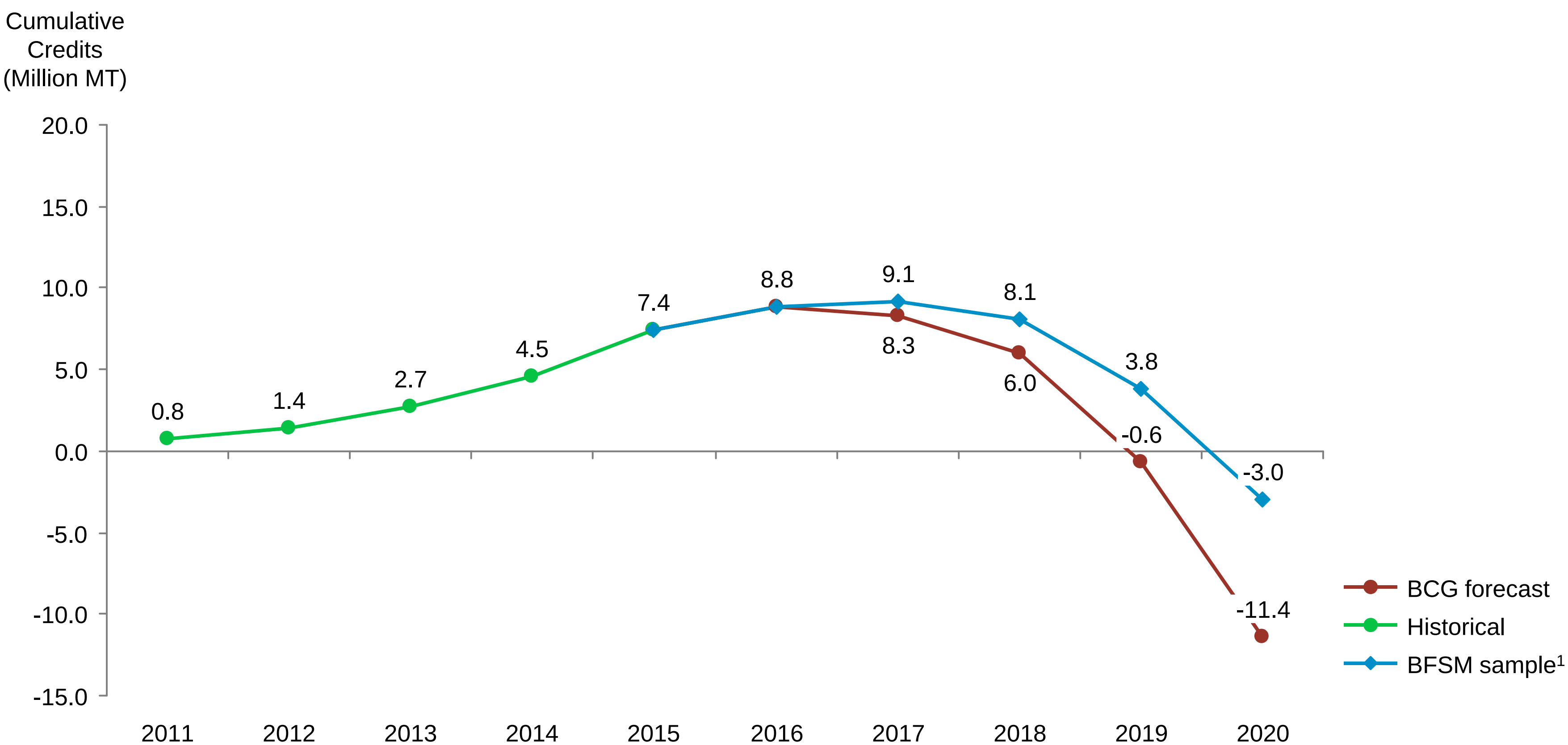
Additional assumptions worth understanding

- Some of these are explicitly mentioned in the BFSM technical documentation, but should be part of the discussion regarding reasonableness for iterations beyond the beta version:
  - Current assumption in the model is that 100% of US biomass can be used (if economic) to produce fuels for California
  - Demand for fuels from other regions doesn't impact available supply, nor does it influence the economic incentive to increase supply
  - Within the model it is noted that sugarcane is the maximum Brazilian production – are other feedstocks US based?
  - Innovative crude credits and low complexity credits are hard coded in a hidden sheet
  - Why were AEO 2015 wholesale price used instead of more up-to-date 2016 wholesale prices in Fuel Prices tab?

Complex tools can be easily misunderstood

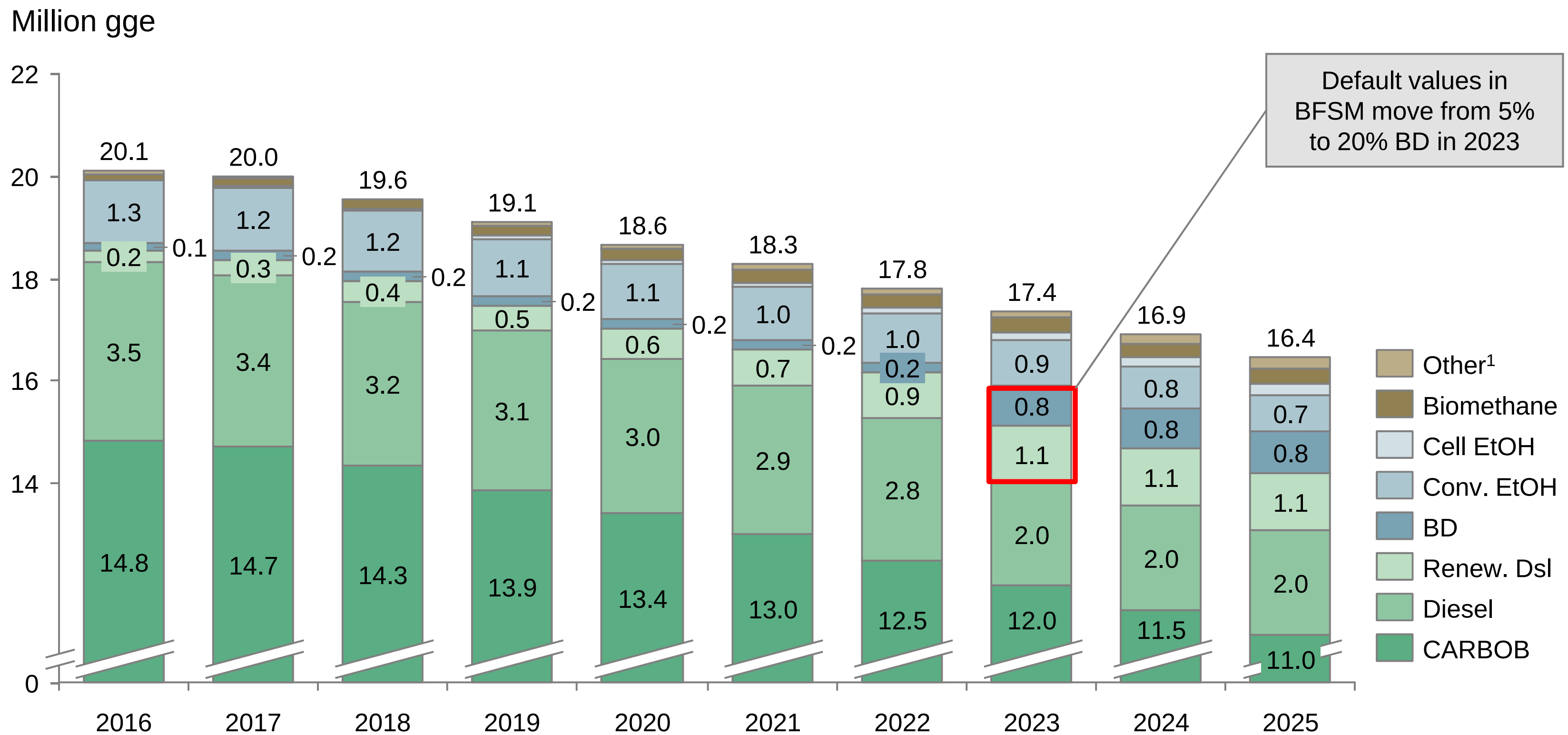
- The BFSM is generally well structured given the complexity of its scope. However, with a complex tool, the risk of misunderstanding the key drivers of results increases sharply. To mitigate these risks the model should do the following (these items are done in varying degrees already):
  - Mark all user inputs clearly:
    - Include a description of how the inputs are used in calculations
    - Inputs should be either in a common area (input sheet) or a listing should direct the user to available inputs
    - Inputs should not be in hidden sheets (unless functionality inactive)
    - Units of measure should be clearly specified
  - Include the ability to do sensitivity analysis or document the variables that have high or low impact on the results
  - Include some elements of the documentation in the model itself including FAQ

Slightly adjusted BFSM indicates probable deficits in the medium term



1. Used BFSM v83B base model, changing the credit price from $0 to $150 and the growth rate of biofuel capacity from 41% to 25%. Not intended to be a fully researched "base case" estimate.
Source: ARB (historical), ARB BFSM, BCG analysis

Initial run of BFSM beta version indicates that blended fuels will continue to dominate through 2025



1. Includes electricity, hydrogen, conv. natural gas
Note: BFSM adjusted for $150 credit price, 25% biofuel capacity growth
Source: ARB BFSM, adjusted for $150 credit price, 25% capacity growth

Path forward

- ARB should consider feedback from interested parties to improve the beta version of its model. This includes fixing any errors found and implementing any reasonable enhancements that would encourage usage of the model.
- Once the model is out of the beta stage and the documentation is updated, it might benefit interested parties to have a workshop on the model to discuss changes made and other issues that were brought up during the feedback process.
- Before official recommendations are made using the model, the sensitivity of key drivers and estimated ranges for these inputs should be published to inform the discussion. Base case scenarios are valuable tools, but are much more effective and approachable when more context (documentation of the base case and other alternative scenarios) is presented.

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Enclosure C

ICF Critique of PATHWAYS Model

Final

Review of E3 PATHWAYS Modeling

December 2016

Submitted to:
Western States Petroleum Association

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Executive Summary

California state agencies, including the California Air Resources Board (CARB), California Energy Commission (CEC), California Public Utilities Commission (CEC), and the California Independent System Operator (California ISO), engaged Energy + Environmental Economic (E3) to evaluate the feasibility and cost of meeting potential interim 2030 targets as part of the state's broader objective of reducing greenhouse gas (GHG) emissions to 80 percent below 1990 levels by 2050. E3 employed the California PATHWAYS model, which "encompasses the entire California economy with detailed representations of the buildings, industry, transportation, and electricity sectors." The modeling effort was informed by developing many scenarios designed to capture potential paths to reduce GHG emissions in California. As part of the Scoping Plan Update process, CARB has indicated that they intend to use the results of the PATHWAYS modeling as inputs into a macroeconomic modeling exercise using the REMI model.

ICF was retained by the Western States Petroleum Association (WSPA) to review the PATHWAYS model, with a focus on the following elements:

- PATHWAYS model mechanisms. This focuses on the decision-making protocols and architecture of the model, and how the design of the model impacts the results.
- Sectoral inputs. The PATHWAYS model is built with modules covering economic sectors and the corresponding activity that leads to GHG emissions. ICF reviewed the inputs associated with key sectors–including transportation and renewable energy. Where appropriate, we reviewed how some key parameters or variables impact the modeling results. This should not be confused with the design aspects, which is linked to the modeling mechanisms.
- Implications of linking PATHWAYS to REMI. Given the stated intent of CARB to link PATHWAYS modeling to REMI, ICF reviewed the potential challenges associated with doing this. Further, ICF sought to identify and review examples of CARB staff using the REMI model and identify points for clarification in a potential exercise whereby PATHWAYS is linked to REMI.

ICF's review is limited exclusively to the PATHWAYS modeling; this report is not intended to review the full extent of the Scoping Plan Update. Furthermore, ICF has purposefully avoided any commentary regarding the feasibility of existing policies or the types of policies that might be implemented or extended to achieve the GHG reductions included in the PATHWAYS modeling. This approach mirrors the PATHWAYS modeling project, in that it is not prescriptive with regard to the policies or interventions required to achieve the corresponding GHG reductions.

ICF notes two key findings prior to a summary of the findings based on the more structured review of the model:

- Firstly, ICF finds that costs included in the PATHWAYS model tend to be under-estimated. This observation is linked to several aspects of the modeling, including: some of the raw cost data employed (e.g., vehicle pricing); specific assumptions employed (e.g., renewable energy that is efficiently dispatched, thereby reducing the amount of higher cost renewable generation that might actually be required); or aspects that were excluded from the modeling (e.g., fueling infrastructure costs required to support alternative fuel consumption, such as hydrogen, electricity, and natural gas). On an individual basis, the costs and assumptions that affect the total costs of a deployment scenario are not egregiously under-estimated. The complexity of the PATHWAYS model and the multiple scenarios considered preclude an accurate quantification of what ICF characterizes as many critical areas where costs are likely under-estimated. In aggregate, however, these issues raise some concern about the utility of the modeling as it relates to total costs and associated economic impacts.

- Secondly, the modeling seems to overlook nuanced areas of technology and/or energy supply-demand (including vehicle miles traveled) that are linked to consumer choice. Given that the objective of the modeling is to outline scenarios that achieve defined GHG reduction targets, the model is inherently biased towards new and emerging strategies that reduce GHG emissions. The scenarios enable the user to work backwards from a target and estimate the extent to which various reduction strategies need to be deployed. However, there is no explicit link to or consideration of consumer acceptance as it relates to some of these new and emerging strategies. As a result, the modeling likely over-estimates the extent to which certain technologies or strategies can be deployed, and glosses over some of the more challenging consumer acceptance barriers that many energy markets face.

Modeling Mechanisms

The scenario analysis approach exposes the PATHWAYS modeling to conventional critiques, which generally focus on significant deviations from historical relationships between variables modeled. ICF appreciates the effort to outline a visionary approach towards achieving emission reductions and has no inherent objections to a scenario-based approach. However, the PATHWAYS reporting documentation states that the purpose of the project is "to evaluate the *feasibility* and cost of a range of greenhouse gas reduction scenarios in California" (emphasis added). ICF finds no mechanism in place throughout the model review to indicate that there is a determination of the feasibility of any scenario outlined. Rather, the modelers are very forthcoming in that "adoption rates of technologies are defined by user". ICF has a hard time reconciling the stated purpose, which includes feasibility, and the modeling structure, which in most aspects is only modestly constrained by more than the user's imagination.

More specifically, ICF's review of the modeling documentation finds that there is an inconsistent application of supply constraints, that the lack of any optimization limits the utility of the model to inform policy, and that the exclusion of strategies, most notably in the transportation fuels sector, that reduce emissions on a lifecycle basis sends a mixed policy signal. Together, these three potential shortcomings of the PATHWAYS modeling yield scenarios that relay a false sense of precision and accuracy in the results:

- **Inconsistent application of supply constraints**. The PATHWAYS model explicitly describes what the scenarios include, however, ICF frequently could not understand or identify boundary conditions applied to each scenario or particular supply constraints. While E3 states that they took an approach that limits the user's ability to deploy "emerging technologies", it is unclear how that happens in line with similarly stated "technological conservatism". For instance, in the case of battery electric vehicles, the user can simply increase the deployment rate without constraints such as consumer choice, projected vehicle availability, or consumer willingness to pay. Furthermore, it is unclear how consumer choice is incorporated into the model's supply constraints. In other words, what are the lifestyle changes required to adopt the new and emergent technologies included in PATHWAYS?

- **Optimization**. The lack of a relationship between technologies deployed and their corresponding cost-abatement curve relative to other technologies yields a situation whereby an outcome cannot be optimized. In other words, the model does not solve for a lowest-cost, lowest-emitting solution based on the linkages between sectors. Rather, the user characterizes the inputs, and the model does a good job of accounting for the emissions and dollars on an annual basis.
- **Tailpipe vs lifecycle**. Strategic decisions and investments are being made today in the transportation fuels sector that include GHG accounting on a lifecycle basis. Given that the policy context is currently driven by lifecycle GHG accounting, PATHWAYS focus on so-called tailpipe emissions is a shortcoming of the scenario analysis. As a result of this, the model is blind to potentially more cost-effective pathways (e.g., feedstock switching in biofuels) towards GHG emission reductions in the fuels sector.

Transportation

The transportation sector modeling in the PATHWAYS model has multiple shortcomings, summarized here:

- With regard to inputs, the model is built upon EMFAC2011; moving forward, this should be updated to EMFAC2014 for consistency with other modeling efforts. There are a variety of improvements that are included in the updated version of EMFAC, and changes that impact the modeling. For instance: VMT is generally lower post-2015 in EMFAC2014 compared to EMFAC2011 and EMFAC2011 does not account for the effects of the Great Recession. The former difference allows users to get higher than expected GHG emissions reductions through VMT reduction measures, which are introduced at no cost in the model. The impact of the latter is that potentially too many vehicles are deployed.
- Although the PATHWAYS model is based on EMFAC2011, the number of light-duty vehicles reported in the output files is 15-30% higher than it should be based on ICF's estimates of EMFAC2014 and other resources that CARB employs to forecast emissions and vehicle populations. ICF believes that this is a function of the stock rollover function that E3 employs in the PATHWAYS model. In essence, they are deploying too many vehicles and keeping vehicles on the road too long, thereby inflating the GHG emission reductions of alternative fueled vehicles compared to conventionally fueled vehicles.
- The modeling inputs are not granular enough to assess the feasibility of the electric vehicle deployments included in the scenarios. More specifically, the split between light-duty cars and trucks is an important determinant in EMFAC modeling as it relates to electric vehicle and fuel cell vehicle deployment. However, it is unclear what ratio of vehicles cars to trucks was employed by E3 in the PATHWAYS modeling.
- The PATHWAYS model appears to include two to three generic feedstocks that were not included in the referenced Billion Ton Study from the Department of Energy. These generic feedstocks do not have a specific designation as other feedstock types (e.g., agricultural residue or forest residue) and are simply added to the resource supply. Furthermore, it appears that these feedstocks are made available at a lower cost than other feedstocks. ICF believes this erroneously decreases the costs associated with biogas production and consumption in PATHWAYS modeling; however, it is difficult

to ascertain the extent of the impact given that there is not an explicit output modeling file available that includes how much of each feedstock was consumed (rather, the output files provide the amount of biogas consumed, in units of exojoules).

- The PATHWAYS model assumes that the energy used to refine petroleum and extract oil and gas decreases proportionally with demand for liquid fossil fuels. This approach is incongruent with real world operations and effectively leaves refiners in California exposed to drastic reductions in utilization. Further, it is unclear how the costs associated with reduced runs at refineries impacts overall costs in the modeling.
- The technical documentation and output files from the PATHWAYS modeling makes it near-impossible to determine how vehicle miles traveled (VMT) reductions were accounted for in the analysis. Without further clarification, the language in the technical documentation can lead to VMT reductions by 2050 ranging from 13—39% on an absolute basis. Given how broad that range is, it is impossible for ICF to assess the feasibility of this as a viable strategy in the PATHWAYS modeling. Furthermore, it is important to note that VMT reductions are introduced at no cost in the modeling, thereby delivering inconceivable free GHG emissions reductions.

Renewable Energy

ICF's review of the renewable energy components of the modeling yield the following conclusions:

- Near-term renewable projections. The PATHWAYS analysis does not specify renewable resource capacity or generation in the near-term, but instead simulates renewable resource procurement to meet California's RPS. This leads to a mismatch in actual versus modeled renewable generation. A review of existing renewable energy generation and capacity indicates that California's actual 2015 renewable energy generation does not align with the 2015 renewable generation projected in the PATHWAYS analysis. In fact, the difference is greater than 20 percent. This discrepancy delivers greater GHG reductions and decreases the overall costs in the modeling.
- Systems operations. ICF's review of the systems operations processing in PATHWAYS yields an artificially high amount of renewable energy capacity and generation in the PATHWAYS analysis. The reasons for this include large amounts of grid electrolysis or energy storage, a lack of representation of operational realities in building the supply curve, and no representation of congestion. These issues are discussed in detail below.
  - Large amounts of grid electrolysis capacity consume large amounts of renewable energy generation when generation peaks and exceeds base load in many of the scenarios modeled using PATHWAYS. Grid electrolysis is a process that uses an electrolyzer to form hydrogen gas. In the PATHWAYS analysis, this hydrogen gas is used in fuel cell vehicles (e.g., 27% of new vehicle sales in the Straight Line Scenario are fuel cell vehicles). Since the renewable energy used for the electrolysis does not result in any GHG emissions, the fuel cell vehicles do not produce any emissions. ICF notes however, that although this technology has been deployed today, it is unproven at grid scale. The scale of current operations implies many orders of magnitude increases in deployment.

   - Congestion. A lack of representation of congestion in the PATHWAYS analysis may be causing the model to overestimate the operational flexibility of the California system. The California Independent System Operator (CAISO), which operates 80% of California's power grid, is a nodal market, where generators in the day-ahead forward market receive locational marginal pricing (LMP). According to CAISO, "LMP is a mechanism for using market-based prices for managing transmission congestion".[1] When prices differ from one node to another, there is congestion preventing lower cost generation from meeting load.

- Curtailment, the process by which some electrical generation is reduced as a result of some market-driven process, averages just 0.72% of available energy from 2020 to 2030 in the Straight Line Scenario. This very low curtailment rate implies extremely efficient use of renewable generation – effectively an underlying assumption that renewable energy is easily dispatched and cheap. However, there are a number of aspects that ease supply-demand balance in the PATHWAYS analysis that may be leading to an underestimation of curtailment over this time frame. These include lack of detailed analysis around certain operational characteristics, such as congestion, thermal must-run generation, and minimum generation requirements for some thermal units, as well as large amounts of grid electrolysis or energy storage to balance supply and demand. In reality, using renewable generation that efficiently may be much more challenging.

- As previously mentioned, the PATHWAYS analysis overestimates how much renewable capacity and generation is currently online. As a result, even more renewable capacity will have to come online to meet California's clean energy goals than what is already projected in the PATHWAYS modeling. Developing additional renewable capacity will mean a number of challenges, including higher costs and siting more renewable capacity in a WECC region with highly ambitious renewable energy goals. Additionally, if curtailment is indeed higher than the PATHWAYS analysis' projections, then renewable capacity will also have to be overbuilt to meet California's RPS goals.

REMI Modeling

Several aspects of the PATHWAYS model results create problems when trying to model PATHWAYS outputs in REMI. The PATHWAYS model may show what technologies are needed to decarbonize the economy but the model does not indicate how this can be done. In addition, inputting PATHWAYS into REMI will not necessarily result in an economy indicative of the transformational changes that occur in PATHWAYS. It is strongly up to the modeler to develop a realistic representation of the PATHWAYS world in REMI to justify that world through careful modeling decisions and deep understanding of both the PATHWAYS model and its outputs.

- Translating PATHWAYS outputs to REMI inputs can be a difficult process due to the physical nature of changes to consumption. The outputs are very specific in regards to the amount of each type of fuel consumed and at the same time have prices for these fuels. Given the scale of the modeling exercise, it is unclear if it is possible to turn expenditures from PATHWAYS into a single price input to REMI. If it was possible, it is not clear that the price would result in the kind of transformational changes that exist in PATHWAYS outputs.

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[1] http://www.caiso.com/docs/2004/02/13/200402131607358643.pdf

- Modeling technological change in REMI is challenging because of the different sectoral impacts of deploying new and emerging technologies.
- Using PATHWAYS results as an input to REMI modeling requires a choice between the use of prices or modeling investments directly. The outputs of PATHWAYS describe the change in amount of money invested in technology. Since it is not an optimization exercise, the PATHWAYS scenario analysis incorporates the increase in cost, to deploy more expensive technologies, into energy prices. Therefore a modeler must choose between accurately modeling the differences in making investments to deploy technology or inputting changes to energy prices. Modeling both is not possible because it would result in double-counting. The choice of modeling only energy prices may not result in an economy reflecting the transformational changes that occur in PATHWAYS. It is also unclear how accurate the energy prices would be, if used, given that they are not determined by an optimization framework.
  - There are knock-on effects associated with modeling choices made. For instance, in a scenario using prices, one could assume that consumer and industrial preferences change to be willing to pay higher prices for lower emitting technologies. By modeling the investment changes directly, there is no mechanism to bring about the technological changes required to be consistent with the future envisioned by PATHWAYS scenarios. Similarly, modeling the raw data of technological investments will always result in a net economic benefit because the investments are in more expensive technologies than those that would have been built in a reference case. The increased investments required to achieve the reductions outlined in the PATHWAYS scenarios requires the investment money come from somewhere; to model it otherwise is to assume free money.

1. Introduction

The California Air Resources Board (CARB) retained Energy and Environmental Economics (E3) to develop pathways for greenhouse gas (GHG) emission reductions between 2020 and 2030. E3 utilizes what they refer to as the PATHWAYS modeling framework. With CARB seeking to pair the results of the PATHWAYS modeling with an a macroeconomic model (e.g., the REMI model) to evaluate the potential economic impacts associated with alternative policies to achieve GHG reduction targets and sector specific targets, now is a critical time for stakeholders to provide feedback and peer review to CARB on some of the underlying assumptions used in the PATHWAYS modeling. To that end, the Western States Petroleum Association retained ICF to review the PATHWAYS model, with a focus on critical inputs and assumptions, and review the potential for pairing PATHWAYS with a REMI model.

ICF's review focused on the mechanisms employed in the PATHWAYS modeling and a review of modeling inputs and outputs for the transportation sector and renewable energy sector. Within each sector, ICF considered inputs to the model (including a review of source data) and how those inputs impact the modeling results. Finally, ICF reviewed some of the challenges associated with integrating PATHWAYS with a macro-economic modeling framework such as REMI.

The remainder of this document is structured as follows:

- Section 2 presents an overview of the PATHWAYS model and the modeling performed for CARB.
- Section 3 includes ICF's review of the modeling mechanisms employed in PATHWAYS.
- ICF reviews the findings of reviewing the transportation sector of the model (Section 4) and the renewable energy sector of the model (Section 5).
- Finally, ICF reviews the process and potential pitfalls associated with linking PATHWAYS results to a macroeconomic model like REMI (Section 6).

2. Overview of PATHWAYS Model

California state agencies, including the California Air Resources Board (CARB), California Energy Commission (CEC), California Public Utilities Commission (CEC), and the California Independent System Operator (California ISO), engaged Energy + Environmental Economic (E3) to evaluate the feasibility and cost of meeting potential interim 2030 targets as part of the state's broader objective of reducing greenhouse gas (GHG) emissions to 80 percent below 1990 levels by 2050. E3 employed the California PATHWAYS model, which "encompasses the entire California economy with detailed representations of the buildings, industry, transportation, and electricity sectors." The modeling effort was informed by developing many scenarios designed to capture potential paths to reduce GHG emissions in California.

As E3 documents clearly in its technical documentation, the model is constructed around a basic 4-step process:

1. Energy demand. This includes projections for energy demand for 10 final energy types. The projections are built upon an activity-based approach with sector-specific stock rollover accounting.
2. Energy supply. The energy supply is informed by the energy demand projections (see 1 above); and can be supplied by fossil fuel or decarbonized sources and processes. The energy supply module includes costs and GHG emissions of all energy types.
3. Non-energy, non-CO2 GHG emissions. This module accounts for methane and N2O emissions from agriculture, waste, refrigerant F-gases, and emissions from cement production.
4. Total GHG emissions and Energy system costs. Finally, the model includes total GHG emissions and energy-system costs based on the inputs that make up a scenario.

The focus of this review is on the modeling mechanisms, as well as transportation as a demand sector and electricity generation from renewable sources as a final energy type.

3. Modeling Mechanisms

Inconsistent Application of Supply Constraints

The PATHWAYS model is driven almost exclusively by user-inputs. ICF finds that there is an inconsistent application of supply constraints for various technological measures to reduce GHG emissions. The supply of some technological options e.g., the deployment of electric vehicles, can be modified by the user, but is not necessarily bound by some function linked to consumer acceptance or consumer willingness to pay. Conversely, biomass availability is more explicitly constrained according to a supply-cost relationship developed based on estimates from the Department of Energy.

Ultimately, these inconsistent supply constraints enable the user to develop scenarios that may or may not reflect real-world constraints. In principle, a scenario analysis should capture what the user thinks is possible, rather than a future that the user would like to see. Without more rigorous supply constraints, the results of the scenarios modeled give a false sense of precision and accuracy.

The unconstrained deployment of battery electric vehicles, for instance, can lead to a scenario such as the High BEV Scenario, which assumes that by 2025, 35 percent of the market for light-duty vehicles is captured by plug-in electric vehicles; more than two times higher than what is currently forecasted in California. Furthermore, if we assume, as CARB has in the development of the EMFAC model, that electric vehicles will be limited to passenger cars (and not deployed in light trucks), then this effectively assumes that more than 50 percent of all passenger cars sold in California are either battery electric vehicles or plug-in hybrid electric vehicles, representing a near 20-fold increase from today, and a 10-fold increase compared to the deployment of hybrid electric vehicles today.

ICF understands that there is no hard supply constraint for electricity used in electric vehicles, however, there most certainly is a constraint on the number of electric vehicles that can be deployed given consumer behavior. ICF recognizes this type of consumer behavior is more complicated to introduce than a supply constraint based on a technical resource assessment. However, absent some effort to include a constraining factor, the user can effectively choose the future which s/he would like to see, and then present the results of the modeling as a feasible solution. As stated previously, the description of the PATHWAYS project includes a mention of identifying feasible solutions. However, ICF found no discussion of the challenges or feasibility associated with deploying this level of electric vehicles – or the feasibility of deploying other emerging technologies (e.g., electrolysis, grid energy storage, etc.). The implicit assumption, then is that the PATHWAYS model somehow has these feasibility constraints built into it, which does not seem to be the case upon ICF's review. As a result, the results are given a false sense of precision and accuracy, as if the user could not introduce a technology at an infeasible rate.

Supply constraints can be introduced in a simple fashion across the model. As it stands, the PATHWAYS model effectively "accepts" any user-inputs that might be technologically achievable and for the most part, enables the user to increase the penetration of that technology with only modest constraint.

Lack of Optimization

While the PATHWAYS model has robust linkages between sectors, the results are inextricably linked to user-driven inputs. Those inputs will ultimately determine the scenario GHG emissions and costs. There is no cost-abatement curve or comparable relationship against which an outcome can be optimized. In other words, the model does not solve for a lowest-cost, lowest-emitting solution based on the linkages between sectors. Rather, the user characterizes the inputs, and the model does a good job of accounting for the emissions and dollars on an annual basis.

While the PATHWAYS model and project results are explicit in that they are neither policy-based nor policy-prescriptive, the lack of optimization makes it difficult to assess the feasibility of the strategies deployed. The user-driven nature of the model is powerful, and the associated accounting and linking across economic sectors is robust. However, that is effectively a complicated accounting tool rather than a model that enables stakeholders to make informed decisions about the deployment of abatement strategies.

The lack of optimization, when considered in light of the lack of supply constraints discussed previously, reinforces this notion of false sense of precision and accuracy that is included in the results. This makes it difficult to understand how the results will inform the policies that might be implemented to achieve the corresponding GHG emissions reductions.

The scenario-based modeling approach that PATHWAYS employs is an alternative to optimization modeling. As such, it is unclear to ICF how optimization could be incorporated into the modeling framework. The supply constraints (discussed in the subsection above) could be paired with abatement costs, and the subsequent relationships could be used to constrain the modeling. This would not necessarily yield an "optimized" solution; however, it would introduce a clearer indication of the tradeoffs between costs and abatement.

Tailpipe vs Lifecycle Perspective

One aspect of the transportation fuels market that is absent relates to the regulatory environment in which regulated parties, most notably refiners, operate. We recognize that the PATHWAYS modeling is conducted absent consideration of policies or market-based mechanisms. However, the fact is that strategic decisions and investments are being made today in the transportation fuels sector that include GHG accounting on a lifecycle basis. These are being driven by the federal Renewable Fuel Standard and by California's Low Carbon Fuel Standard (LCFS). The intent of this review is not to advocate for nor challenge either of these policies; however, given that the policy context is currently driven by lifecycle GHG accounting, we think that the PATHWAYS focus on so-called tailpipe emissions is a shortcoming of the scenario analysis. As a result of this, the model is blind to potentially more cost-effective pathways towards GHG emission reductions in the fuels sector. For instance, the model effectively discounts the potential for feedstock switching amongst conventional biofuels like ethanol and biodiesel. More specifically, the user is left seeking reductions via potentially more costly next generation biofuels, electric vehicles, or hydrogen fuel cell vehicles, all of which have their own challenges associated with increased adoption. This type of modeling architecture generates more of a technical leap in the modeling, which is generally unsubstantiated in historical observations in the vehicles and fuels markets.

ICF notes that one of the underpinnings of scenario analyses is that the modeling is freed from the bounds of past observations. Given the focus of our review–in the 2030 timeframe–it is unlikely that these types of technical leaps will occur because of the nature of the transportation market.

The underlying strength of PATHWAYS is its robust accounting mechanisms for costs and GHG emissions across sectors; it should be trivial to introduce an accounting mechanism for GHG emissions on a lifecycle basis, particularly in the transportation fuels sector. It is unclear if lifecycle GHG accounting is necessary in other sectors.

If the PATHWAYS model were improved to include enhanced supply-cost constraints (as discussed previously), then the introduction of lifecycle GHG emissions could make this exercise more difficult. For instance, if lifecycle GHG accounting were only introduced in the transportation sector, then the supply-cost curves employed to constrain the modeling may be introduced on an inconsistent or conflicting basis.

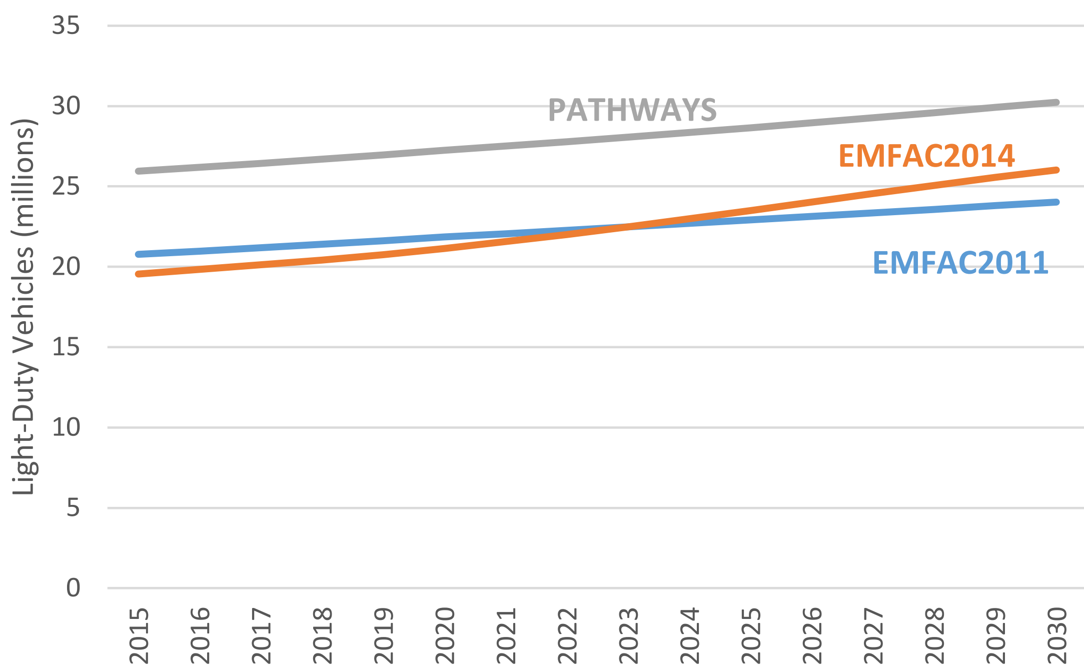
4. Transportation

Review of PATHWAYS Inputs–Transportation

Vehicle Stock

The PATHWAYS model is built using EMFAC2011; this version of EMFAC is outdated and should be updated to EMFAC2014. There are substantive differences between these two models, which will have a material impact on the results. For instance, EMFAC2011 has a very shallow treatment of some of the impacts of the Great Recession on vehicle registration. EMFAC2014 also has a better treatment of VMT and vehicle ownership. However, based on ICF's review of the PATHWAYS model documentation, it appears that E3 has implemented its own stock rollover component. As a result of this, it appears that the PATHWAYS model deploys too many light duty vehicles (see Figure 1 below), with a deployment about 15-30% higher by 2030 compared to EMFAC2011 and EMFAC2014.

Figure 1. Light-duty vehicle population in different models, 2015—2030



Light-duty Vehicles: Trucks vs Cars

It is unclear how the PATHWAYS model distinguishes between light-duty trucks and passenger cars. The share of these two light-duty vehicle types is critical when assessing the feasibility of transitions, particularly as it relates to zero emission vehicles (ZEVs). Most of CARB's rulemakings and models (e.g., EMFAC) assume that ZEV deployment is nearly exclusively in the passenger car segment. Public documentation from CARB (and others) generally cite a statistic akin to "by 2025, 15% of new sales will be ZEV"; when digging deeper into EMFAC, however, one finds that CARB actually pushes nearly 24% of new sales as ZEVs in the passenger car segment by 2025 for compliance as shown in Table 1 below, broken down by plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and fuel cell vehicles (FCVs).

Table 1. ZEV Program Requirements for New Car Sales included in EMFAC2014

Model Yr	% Passenger Car Sales			
	%PHEV	%BEV	%FCV	Total
2012	1.80%	0.20%	0.10%	2.00%
2013	1.80%	0.20%	0.10%	2.10%
2014	1.80%	0.20%	0.10%	2.10%
2015	2.50%	0.60%	0.30%	3.50%
2016	2.70%	0.70%	0.30%	3.60%
2017	2.70%	0.70%	0.30%	3.70%
2018	5.70%	1.40%	0.30%	7.30%
2019	6.80%	2.60%	0.60%	10.10%
2020	8.00%	3.60%	1.00%	12.70%
2021	9.20%	4.50%	1.50%	15.30%
2022	10.30%	5.10%	2.10%	17.60%
2023	11.50%	5.70%	2.70%	19.90%
2024	12.60%	6.10%	3.30%	22.00%
2025+	13.70%	6.10%	4.10%	23.90%

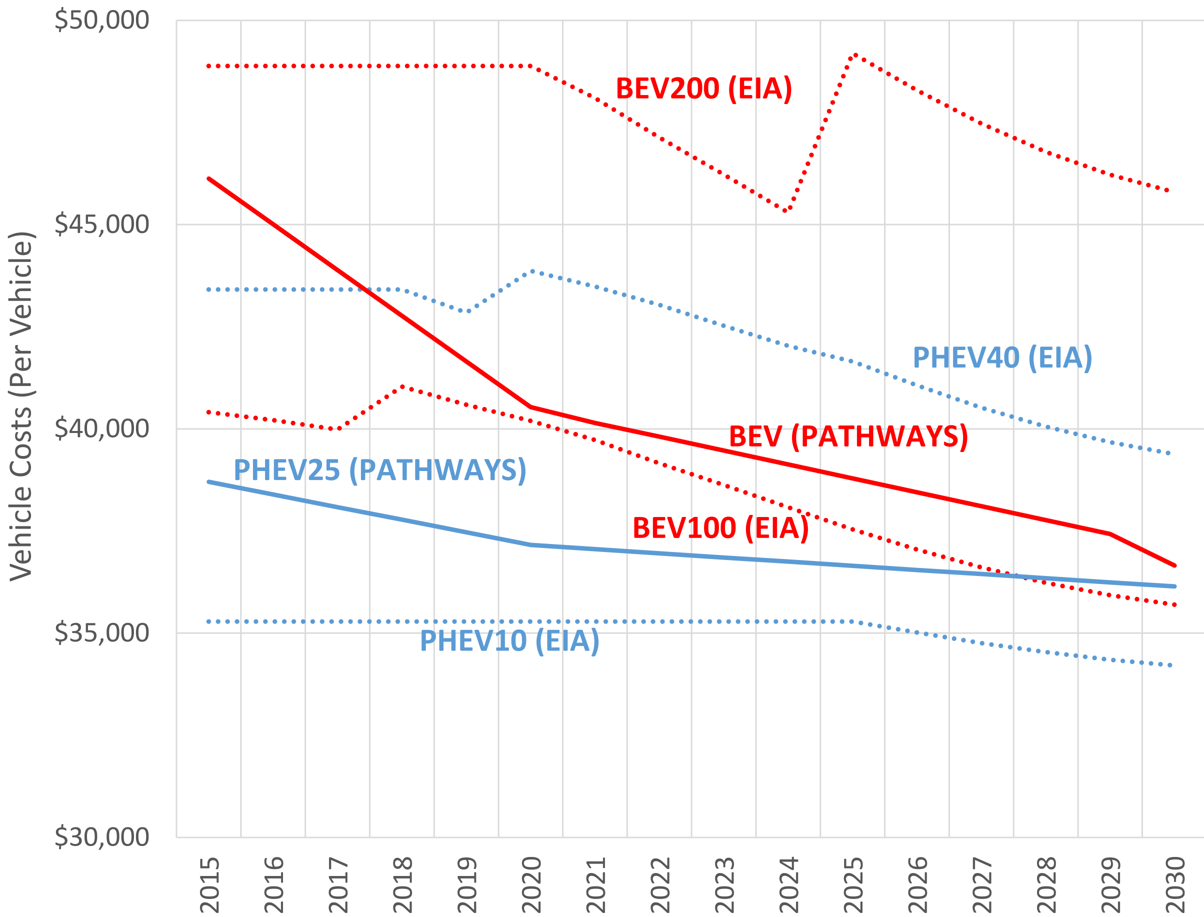
By comparison, the High BEV scenario assumes 15% PHEVs and 20% BEVs by 2025, for all light-duty vehicles. If we use the same assumptions from CARB (i.e., that ZEVs will be deployed exclusively in the passenger car segment and that the passenger car segment represents about 65% of new light-duty vehicle sales), then this amounts to 23% of new passenger car sales (compared to 13.7% in the reference scenario, as shown in the table above) and 31% of new passenger car sales (compared to 6.1% in the reference scenario shown in the table above) for 2025. In other words, in the next 10 years, 54% of new passenger car sales, up from the 5.2% of new passenger car sales from 2015. By comparison, hybrid electric vehicles currently make up about 6% of new light-duty vehicle sales, with a peak of nearly 7% in 2013.

If the split between passenger cars and light trucks does not shift to the former at the same rate(s) CARB is predicting, then the ZEV populations included in the PATHWAYS modeling become all the more implausible. Although ICF cautions against using near-term phenomenon to forecast far into the future, the recent decrease in gasoline prices has had a material impact on the market for passenger cars. In California, the share fell from 61.4% in 2014 to 58.5% in 2015, with similar expectations for 2016. These percentages are considerably lower than CARB's assumption, held constant over time, in EMFAC2014 that passenger cars will comprise about 65% of new light-duty vehicle sales.

Vehicle Pricing

Based on ICF's analysis of vehicle pricing in PATHWAYS, the model tends to under-estimate the cost of deploying plug-in electric vehicles (see Figure 2 below) when compared to EIA data. The data shown in include ICF's estimate of the average cost of battery electric vehicles and plug-in hybrid electric vehicles, weighted by the share of light truck and passenger car sales in the EMFAC model and using purchased vehicle data from the California New Car Dealers Association.

Figure 2. Electric vehicle pricing in PATHWAYS



Source: ICF analysis of EIA data and E3 data

The solid red line (for BEVs) and blue line (for PHEVs) indicate ICF estimates of the per vehicle costs in PATHWAYS. Because the PATHWAYS model output files do not clearly indicate the share of trucks and passenger cars, these values are estimates.

If ICF's estimates are correct, then we believe that the PATHWAYS scenarios under-estimate the cost of deploying electric vehicles. In the High BEV scenario for instance, the cumulative impact (2015 to 2030) of this under-estimated price is about $19 billion; and by 2030, it amounts to a net incremental price differential of $3.2 billion. This is substantial considering that the "incremental cost relative to reference" for the Straight Line and Early Deployment scenarios are about $2 and $12 billion, respectively.

Biomass Resource Availability

Note that biomass is used in multiple sectors in the PATHWAYS model; we have included it as a subsection in our consideration of transportation inputs, but this is merely for convenience.

- ICF notes that PATHWAYS documentation links to the Billion Ton Study (BTS). The way that the source material is employed is transparent and consistent for about 90-95% of the more than 25 feedstocks. However, E3 added 2-3 generic feedstocks and put the entire resource availability for these 2-3 feedstocks in a cost bin of $40/ton. As a result of this methodological decision, the weighted average cost of biomass is reduced from about $65/ton (as estimated using BTS data) to a cost of about $50/ton. This lower cost propagates through the entire cost build-up in the PATHWAYS model. Given the current barriers in biomass processing, reducing the cost of the primary feedstock has a dramatic impact on costs down the line. The PATHWAYS model documentation, notably the model outputs, do not provide the type of feedstock that was utilized in each scenario; as a result, we cannot determine the cost impacts of this deviation from the BTS data.
- ICF's reading of the biomass module suggests that the modeling assumes that all primary energy inputs into biomass conversion (or processing) are from biomass. In other words, the biomass effectively powers the production facility. This decision erodes part of the model's cross-sectoral strength, in that it is much more likely that this primary energy for biomass processing is a mix of on-site power and imported power.

Refinery Operations

The PATHWAYS model assumes that the energy used to refine petroleum and extract oil and gas decreases proportionally with demand for liquid fossil fuels. ICF reads this assumption to mean that the model assumes that petroleum refiners will simply reduce runs, rather than maximize facility operation and seek other markets (e.g., exports) for refined products. This assumption in PATHWAYS runs counter to our current understanding of the export market for refined products in the U.S., which has increased every year since 2004, and was about 2,800 thousand barrels per day (TBD) in 2015, up from about 870 TBD in 2002 according to the Energy Information Administration (EIA). Furthermore, there are significant incentives (e.g., via the Low Carbon Fuel Standard program) for petroleum refiners and oil extraction companies to introduce energy efficiency measures and innovative extraction methods that reduce carbon emissions, while maintaining or even enhancing existing production levels.

The PATHWAYS assumption that the energy used to refine petroleum and extract oil and gas will decrease proportionally with demand for liquid fossil fuels likely over-states the GHG emission benefit of reduced petroleum consumption.

VMT Reductions

Assumptions about how much people will drive in the future are central to modeling transportation-related energy use in PATHWAYS, but it is extremely challenging to forecast long-term trends in travel behavior, which depend upon a web of factors including demographics, economic cycles, land use changes, vehicle technologies, and the availability of alternatives to driving. If people drive less over the long term, it supports progress toward California's energy use and GHG reduction targets, but if people drive more alternative vehicle fuels and technologies would need to make up the gap to help keep the state on track to meet its targets.

Transportation planners and analysts typically measure the amount that people drive in terms of per capita vehicle miles traveled (VMT). Generally speaking, over the past several decades per capita VMT has steadily increased due to increased sprawl, growth in the number of dual wage-earner households, and other factors. Recently, there have been reasons to think that this trend is reversing. California's Sustainable Communities and Climate Protection Act of 2008 (SB 375) makes VMT reduction a central part of the state's climate strategies by placing GHG reduction targets on the metropolitan planning organizations (MPOs) that are responsible for transportation planning in the urban areas where the vast majority of California's population lives. At the national level, VMT per capita underwent a sustained decrease for the first time in decades between 2007 and 2013. This decline, coupled with demographic projections showing growth among many groups (people in their 20s, single-parent households, older adults) who typically drive less, contributed to the notion that the U.S. had reached "peak VMT." However, national per capita VMT has begun to rise again, casting doubt on the idea that the U.S. will experience a long-term decline in driving.[2] These shifting trends serve more to illustrate the challenges in predicting VMT than they do to illuminate how VMT might change over time period forecast by PATHWAYS, but they suggest that a conservative approach is best when forecasting long-term VMT reductions.

How PATHWAYS Models VMT Reductions

PATHWAYS includes two different VMT scenarios: a baseline scenario and a VMT reduction scenario.

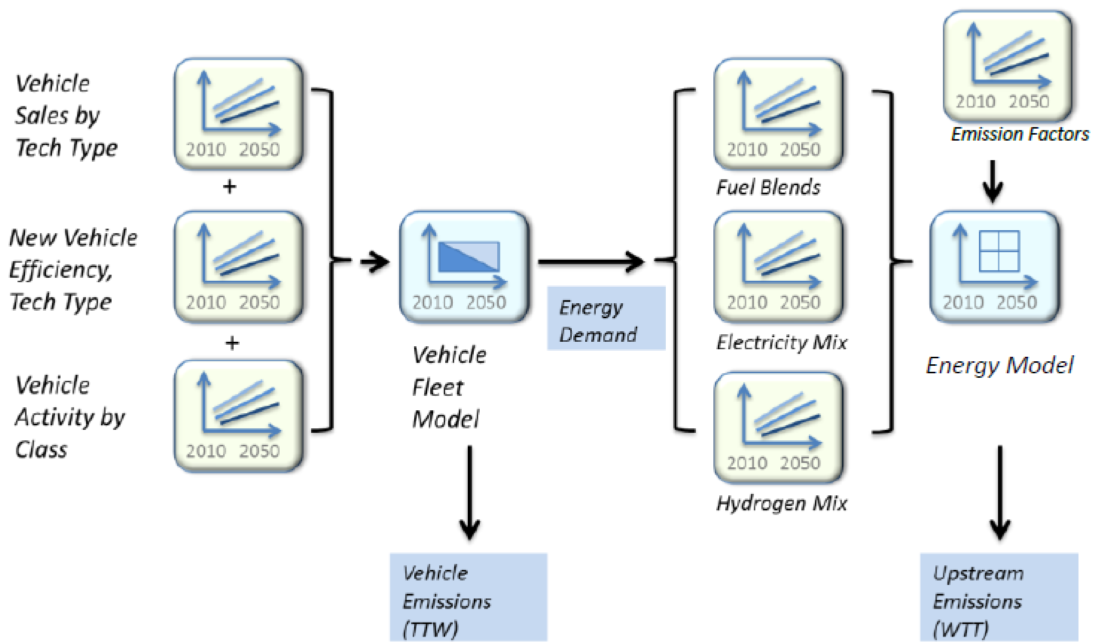
The **reference scenario** was produced by extrapolating data from EMFAC2011,[3] which includes VMT forecasts by region, vehicle type, fuel type, and model year through 2035, to 2050. EMFAC is the standard model used to model the air quality impacts of plans and projects in California under the California Environmental Quality Act and the federal Clean Air Act. The PATHWAYS documentation does not state what VMT trends result from using this data. Our analysis of VMT data from EMFAC2011 and from the latest release of EMFAC, EMFAC2014, which includes VMT estimates through 2050, and of population projections from the California Department of Finance suggests that the baseline scenario is equivalent to a five to eight percent increase in VMT per capita and a 40 percent increase in total VMT between 2012 and 2050.

The **vision scenario** assumes a 20 percent reduction in VMT by 2050. The PATHWAYS methodology notes that VMT reductions were modeled using CARB's Vision model. The Vision documentation notes that VMT forecasts in Vision have been modified from EMFAC outputs using VMT reductions derived from regional SB 375 targets.[4] The PATHWAYS documentation does not detail the process through which E3 derived the 20 percent VMT reduction in the vision scenario, but the Vision documentation suggests that this represents VMT reductions due to SB 375.

[2] For a summary of recent trends in per capita VMT, see Polzin, S., "So Much for Peak VMT, *Planetizen*, March 8, 2016, http://www.planetizen.com/node/84877/so-much-peak-vmt.
[3] Energy and Environmental Economics, California PATHWAYS Model Framework and Methods, June 5, 2015, p. 73-74, https://www.ethree.com/documents/California_PATHWAYS_Technical_Appendix_20150720.pdf.
[4] CARB, Draft Vision 2.0 Modeling System, General Model Documentation, October 9, 2015, p. 10, http://www.arb.ca.gov/planning/vision/docs/vision2.0lr_model_documentation.pdf.

The use of Vision also implies that the PATHWAYS vision scenario is more of a policy-based forecast than one that is grounded in land use patterns, demographic changes, the availability of transit and other alternatives to driving, and other factors that influence VMT. As the modeling framework (Figure 3) shows, VMT (Vehicle Activity by Class) is an input in VISION, and is used as a basis for estimating changes in vehicle emissions.

Figure 3. CARB VISION Model Framework[5]



It is important to note that the SB 375 targets were developed based on detailed scenario analysis conducted using MPO travel models, so to the extent that the vision scenario is grounded in SB 375, it draws upon this analysis. However, neither the PATHWAYS nor the Vision documentation discuss the assumptions or methodology that informed this analysis in detail.

It is also not clear from the PATHWAYS methodology documents or the assumptions stated in the model what exactly the 20 percent reduction in VMT included in the vision scenario represents. The PATHWAYS model describes the "ARB Vision Scenario 3 VMT reduction" as "20% reduction in [light duty vehicle] LDV VMT by 2050,"[6] but does not clarify two important issues that would help users to interpret the scenario:

- Whether 2050 reductions are relative to a base year—presumably the 2012 base year used throughout PATHWAYS, though the PATHWAYS methodology also suggests that the 20 percent reduction could be measured against a 2015 base year[7]—or relative to 2050 emissions under the reference scenario discussed above, under which VMT increases over time. Setting reductions

[5] Ibid. p. 3.
[6] Energy and Environmental Economics, PATHWAYS, Demand Side Input Sheet, TRA_DC_Measure_Sumry_TRA, row 9.
[7] Energy and Environmental Economics, California PATHWAYS Model Framework and Methods, June 5, 2015, p. 88, https://www.ethree.com/documents/California_PATHWAYS_Technical_Appendix_20150720.pdf

relative to the reference scenario is a more conservative approach (i.e., assuming fewer VMT reductions) than setting them relative to a base year, because both total and per capita VMT emissions increase under the reference scenario.

- Whether reductions are stated in total or per capita VMT reductions. Because the state's population is growing, defining the scenario in terms of per capita reductions leads to more conservative VMT reductions than defining it in terms of total VMT reductions.

For the purposes of assessing the PATHWAYS vision scenario VMT assumptions, we convert all VMT reductions into per capita reductions relative to a 2012 base year based on our understanding of the assumptions and the VMT and population data that we used in assessing the reference scenario. Table 2 shows our estimates of how vision scenario VMT reductions could vary based on the issues discussed above.

Table 2. Per capita VMT reductions relative in the PATHWAYS vision scenario.

	If reductions are defined relative to 2012 base year	If VMT reductions are defined relative to the reference scenario
If reductions are defined in terms of total VMT	39.4%	13.5%
If reductions are defined in terms of per capita VMT	20.0%	13.5%

We estimate that the PATHWAYS vision scenario is equivalent to a 13 to 39 percent reduction in 2050 per capita VMT relative to 2012 levels. This is the basis on which we assess how reasonable these assumptions are in the following section.

Assessment of PATHWAYS Vision Scenario VMT Assumptions

Are PATHWAYS Vision Scenario Assumptions Consistent with SB 375 Targets?

Since the VMT reductions in the PATHWAYS vision scenario appear to be based on SB 375 GHG reduction targets—which MPOs are supposed to achieve by reducing passenger VMT—it follows that they should be within the range of GHG reductions that MPOs will likely achieve in 2050 under continued progress in implementing SB 375. SB 375 states GHG reduction targets in terms of per capita reductions compared to a 2005 baseline. It specifies a range of targets for different metropolitan areas, with targets for the four largest metro areas and the metropolitan San Joaquin Valley (which collectively account for a large majority of the state's population and of its projected population growth) ranging from five to eight percent in 2020 and ten to 16 percent in 2015. We extrapolated these targets to 2012 and 2050, assuming linear VMT reductions, and calculated the percent reduction in per capita VMT relative to a 2012 base year, with the results shown in Table 3 below.

Table 3. Extrapolation and analysis of SB 375 GHG reduction targets

Year	Minimum	Maximum
2005	0.0%	0.0%
2012*	2.3%	3.7%
2020	5.0%	8.0%
2035	10.0%	16.0%
2050*	15.0%	24.0%
% reduction, 2012-2050	13.0%	21.1%

Note: Percent reductions are extrapolated by ICF for starred (*) years.

Assuming SB 375 continues to reduce GHG emissions at the same rate through 2050, it will reduce per capita GHG emissions—and also per capita VMT reductions—by between 13 and 21 percent below 2012 levels. We estimate that the PATHWAYS vision scenario assumes 13 to 39 percent reductions in per capita VMT over the same time period. The lower end of this range is consistent with SB 375, but while the higher end appears ambitious by SB 375 standards.

Our analysis applies a simple assumption that GHG and VMT reductions under SB 375 continue on a linear trajectory through 2050. There are many reasons why GHG and VMT reduction trends may not be linear, and reductions could either increase or taper off between 2035 and 2050. Changes to the built environment take a long time to occur, and even longer to affect behavior change; our current auto-oriented transportation patterns are largely the result of freeway construction and growth that occurred during the 1950s and 1960s. SB 375 also does not affect the many transportation projects to which MPOs have already committed funding. As time goes by, SB 375 could have a greater impact on funding decisions or travel behavior, which would lead to greater VMT reductions in the out years of our analysis. If, on the other hand, MPOs have achieved early reductions by "picking low-hanging fruit;" it may be more challenging to reduce VMT and GHG emissions in the out years. Given this uncertainty, we assume that SB 375 produces a linear reduction in VMT between 2005 and 2050.

Are SB 375 Targets Likely to be Achieved?

Even if the PATHWAYS assumptions are reasonable by SB 375 standards, there is no guarantee that the sustainable communities strategies (SCSs) that MPOs are required to produce under SB 375 will be implemented as planned, nor that the VMT and GHG emissions forecast to result from SCSs will ever occur. Though requiring MPOs to produce plans that detail how they will meet long-term GHG reduction targets is an important first step, SB 375 does not give MPOs any additional authority to implement these plans. As a result, MPOs continue to face two major challenges in leveraging the resources that they do have to reverse a decades-long trend of increasing VMT:

MPOs have no authority to implement the land use vision in their SCSs. Under California law, local governments have exclusive authority over land use decisions. SCSs are based on land use patterns that are typically consistent with local zoning, and MPOs allocate growth within the constraints allowed by local governments to make their GHG targets. For example, an MPO may assume full implementation of local land use plans in compact, close-in communities, while assuming little to no development in more sprawling places, even if those local governments have zoned for large amounts of growth. Assumptions like these are aspirational; suburbs and exurbs have a fiscal incentive to develop new housing, denser urban areas may not be able to fund infrastructure or overcome community opposition to support new growth, and even where local governments zone in support of SB 375 the market may not support development as planned. SB 375 does create incentives for local governments to implement SCSs by allowing streamlined environmental review for development projects that are consistent with an SCS, and the state has made grant funding available to affordable housing projects that are consistent with SCSs. However, these incentives are likely to have a relatively minor impact development on the market forces and local zoning practices that drive development, often toward greater sprawl rather than less auto-oriented development.

MPOs control limited transportation funding with which to create new alternatives to driving. MPOs are responsible for creating regional transportation plans (RTPs) that identify how all transportation funding in a metropolitan area will be spent over the next 25 years and for programming certain state and federal transportation funds. Under SB 375, RTPs must be aligned with SCSs, which means that MPOs can use the millions of dollars in transportation funding that they control to invest in transit and active transportation projects that will support the growth pattern envisioned in their SCSs. However, MPOs only control roughly ten percent of transportation funding in California’s metro areas, and much of this funding is already committed to existing projects for the next several decades, needed to operate the mature transit systems and maintain aging infrastructure, or constrained by federal regulations to funding specific types of projects.[8] This makes it very challenging for MPOs to fund the type of major capital investments—particularly in transit—that will likely be necessary to shape growth.

SCSs outline a way for California’s metropolitan areas to reduce VMT and GHG emissions over the course of the next several decades. Significant changes are needed to how public agencies make land use and transportation funding decisions are needed in order to ensure that these targets are realized, and these changes may be difficult to make. Any proposal to give MPOs more authority over land use decisions will likely be met with stiff political opposition from cities and counties, while a major investment in transit and alternatives to driving would be very costly. PATHWAYS appears to assume that SB 375 will be implemented as forecast by MPOs’ SCSs; it would be more conservative to include VMT scenarios that assume varying levels of SB 375 implementation.

Opportunities for Improvement

PATHWAYS is a complex model. VMT reductions are one input among many used to forecast California’s energy use and GHG emissions under future scenarios, and appear to be consistent with SB 375, which is the most important policy on VMT and planning. At the same time, VMT is a major driver of transportation sector GHG emissions and has been steadily increasing over the past several decades, so it is ambitious to assume, as PATHWAYS does, a “significant reduction in vehicle-miles-traveled (VMT) & transportation energy demand in all compliant scenarios [i.e., scenarios that comply with the state’s GHG reduction targets].”[9] In order for PATHWAYS to serve as a basis for evaluating transportation-

[8] Rose, E., Leveraging a New Law: Reducing Greenhouse Gas Emissions under Senate Bill 375, May 20, 2011, p. 17, http://www.crec.berkeley.edu/LeveragingNewLaw.pdf

[9] Energy and Environmental Economics, California PATHWAYS: GHG Scenario Results presentation, April 6 2015, slide 36, https://ethree.com/documents/E3_PATHWAYS_GHG_Scenarios_Updated_April2015.pdf.

sector GHG targets and strategies, the model needs to document and estimate VMT changes in a more thorough and nuanced way. We offer the following recommendations:

Clearly document VMT-related assumptions. It is not clear from the PATHWAYS documentation what assumptions were used 20 percent VMT reduction included in the vision scenario, nor how these reductions are defined. At a minimum, PATHWAYS should clearly document VMT assumptions so that can be evaluated and refined as trends in how much people drive continue to shift and as the state continues to make progress in implementing SB 375 and other VMT reduction measures.

Conduct a sensitivity analysis of how different levels of VMT reduction would affect progress toward California's GHG reduction targets. Given the high levels of uncertainty involved in forecasting VMT patterns and the apparently ambitious nature of some of the assumptions in the PATHWAYS vision scenario, it would be informative to create multiple input scenarios that include a range of VMT reductions rather than simply including a reference scenario under which VMT increases and a vision scenario with an ambitious 20 percent VMT reduction. There are several resources that could serve as a basis for this analysis:

- *MPO travel models*: When SB 375 targets were being created, CARB worked with the four largest MPOs to model VMT and GHG reductions under a range of assumptions under a variety of potential strategies, while using consistent assumptions regarding fuel prices, vehicle efficiency, population growth, and transportation funding.[10] State agencies could conduct a similar exercise to define a range of VMT reduction scenarios that could be input into PATHWAYS. This may even allow for identification of synergistic effects between demand for driving and transportation technology if assumptions about how the various transportation technology and policy assumptions included in PATHWAYS might affect the price of driving or vehicle mix could be input into travel models.
- *Research on strategies to reduce VMT/GHG emissions*. Multiple research efforts, including the Urban Land Institute's Moving Cooler[11] and Growing Cooler[12] reports and Dr. Susan Handy's work for CARB on Impacts of Transportation and Land Use-Related Policies,[13] have assessed the potential of different transportation and land use strategies to reduce VMT and/or related GHG emissions. This research could be used as a basis for assembling packages that consist of different strategies at different levels of deployment and estimating the resulting VMT reductions.

Simple assumptions. Instead of drawing on more in-depth analysis of VMT reductions, PATHWAYS could simply include input scenarios that assess VMT reductions under different levels of SB 375 implementation—e.g., if MPOs only achieve half of the VMT reductions called for in SCSs; if MPOs exceed their GHG reduction targets by 50 percent.

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[10] Heminger, S. et. al., Preliminary Report on Metropolitan Planning Organization (MPO)/Air Resources Board (ARB) Senate Bill 375 (SB 375) Target Setting Analysis, May 18, 2010, http://www.arb.ca.gov/cc/sb375/mpo/prelimreport.mtc.sacog.sandag.scag.pdf.
[11] Urban Land Institute, Moving Cooler, July 2009, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/MovingCoolerExecSummaryULI.pdf.
[12] Urban Land Institute, Growing Cooler, September 2007, http://www.smartgrowthamerica.org/growing-cooler.
[13] California Air Resources Board, Senate Bill 375 – Research on Impacts of Transportation and Land Use-Related Policies, http://arb.ca.gov/cc/sb375/policies/policies.htm.

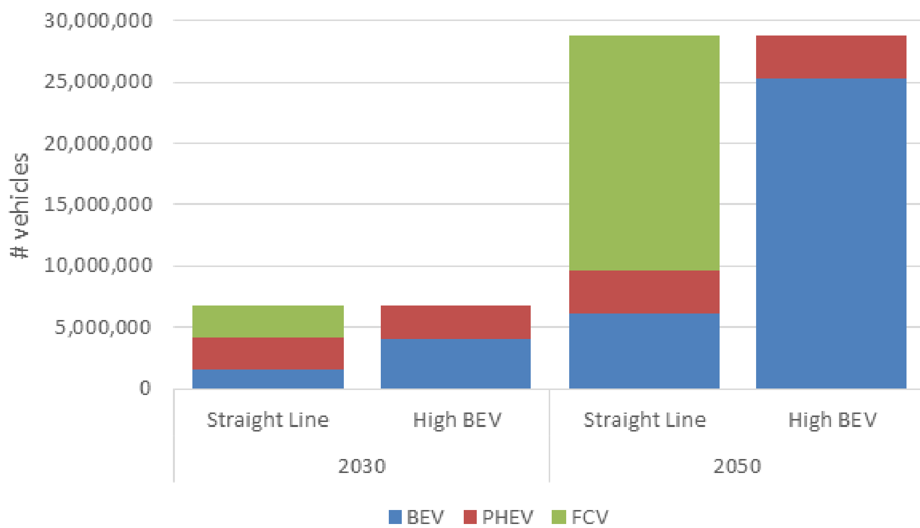
Results Evaluation–Transportation

ICF selected two scenarios for comparison to illustrate the impacts of key inputs on the modeling outputs. Since our team is not explicitly running the model, this is the only way for us to determine how sensitive the outputs are to respective inputs.

High BEV Populations: Straight Line vs. High BEV Scenarios

Both the Straight Line and High BEV Scenarios assume very high penetration rates of ZEVs. BEVs, PHEVs, and FCVs combined make up 57% of new light-duty vehicle sales in 2030, which then climbs to 87% by 2050. While the High BEV Scenario assumes no FCVs are deployed, the Straight Line Scenario assumes that FCVs represent 23% of the total ZEV population in 2015, 37% in 2030, and 66% in 2050. Figure 4 below shows the difference in ZEV make up between these two scenarios.

Figure 4. CA PATHWAYS- ZEV Vehicle Stock Assumptions between Straight Line and High BEV Scenarios



The main difference between these scenarios, in terms of the LDV sector, are the cost impacts to households and the electricity sector. Table 4 shows that non-fossil vehicle fuel costs for the Straight Line scenario are greater than the High BEV scenario, however, that incremental cost is offset by lower vehicle capital costs. This is due to the higher price of hydrogen compared to electricity as a vehicle fuel, as well as the assumption FCVs will be cost competitive with PHEVs by 2020, and with BEVs by 2050. If FCV costs were higher, then households would likely face both increases in fuel and vehicle capital costs in the Straight Line Scenario (as compared to the High BEV Scenario).

Table 4. Household Transportation Cost Impacts - Straight Line and High BEV Scenarios

	2020	2030	2050
Monthly Household Costs for Non-Fossil Vehicle Fuel ($/mo./HH)			
Straight Line	$1.2	$21.6	$131.9
High BEV	$1.1	$15.6	$76.8
Delta	*$0.0*	*-$6.0*	*-$55.1*
Monthly Household Costs for Vehicle Capital ($/mo./HH)			
Straight Line	$479.5	$536.2	$640.3
High BEV	$479.8	$545.0	$693.9
Delta	*$0.3*	*$8.8*	*$53.6*

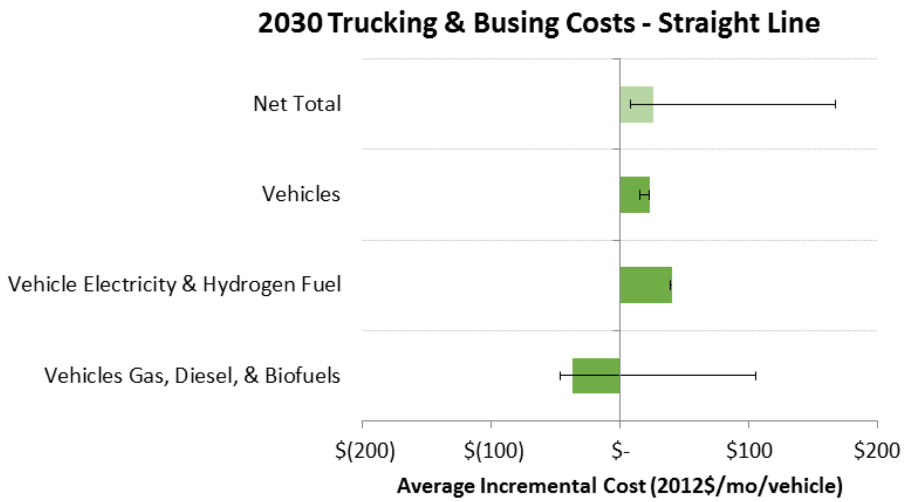
The biggest cost difference between these two scenarios is for the electricity sector (as shown in Table 5). The High BEV scenario has significantly higher electricity costs than the Straight Line—$3 billion more by 2030 and over $19 billion more by 2050. Much of these higher costs are associated with the grid impact and electricity needs of BEVs coupled with RPS targets.

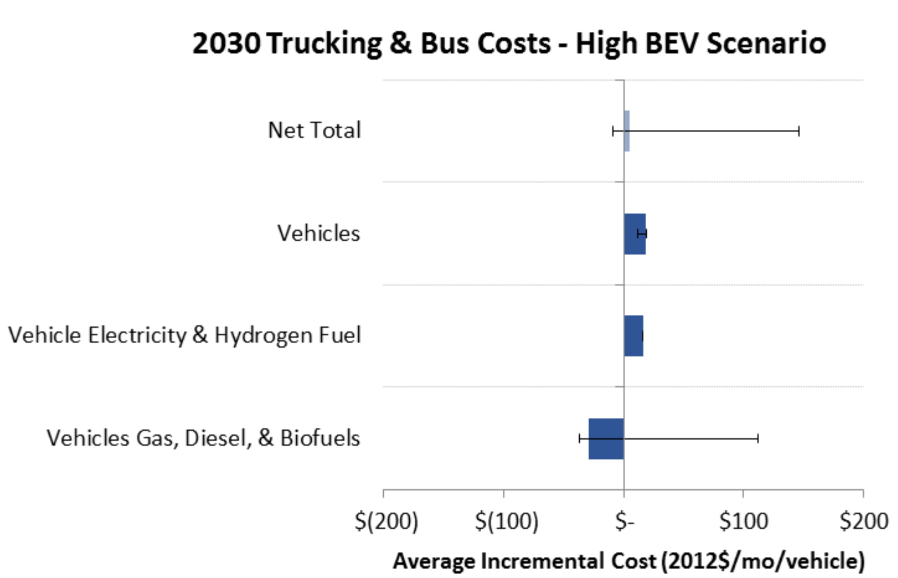
Table 5. Electricity Sector Cost Impacts - Straight Line and High BEV Scenarios

	Total Electricity Costs ($millions/yr)		
Scenario	**2020**	**2030**	**2050**
Straight Line	$50,590	$60,460	$135,200
High BEV	$50,620	$63,620	$154,800
Delta	*$30*	*$3,160*	*$19,600*

It is important to note that the cost of producing electricity and hydrogen as a vehicle fuel are included in the PATHWAYS model, however, the cost of the infrastructure required to refuel these vehicles is not. The omission of electric vehicle charging and hydrogen refueling stations costs are significant and should be considered as part of the economic modeling.

The total transportation sectors costs of the High BEV scenario is $100 million dollars less than Straight Line in 2030 and $13.2 billion less in 2050. This is mostly due higher costs in the commercial trucking sector for the Straight Line Scenario:





Downstream/ Fueling Infrastructure Costs

The PATHWAYS model does not consider the costs of deploying infrastructure to refuel alternative fuel vehicles, including hydrogen fuel cell vehicles, natural gas vehicles, and electric vehicles. It also does not consider the implications of stranded assets. In some cases, the modeling deploys significant volumes of electric vehicles to 2030 before another transition to hydrogen fuel cell vehicles post-2030. There is no discussion of the buildout of charging infrastructure that might be required to sustain the corresponding electric vehicle populations; which in turn precludes a substantive discussion about idled or stranded assets (charging infrastructure) as electric vehicles are presumably replaced by fuel cell vehicles via fleet turnover.

5. Renewable Energy

Review of PATHWAYS Inputs–Renewable Energy

There are a number of important renewable inputs and assumptions that drive and enable renewable energy deployment in the PATHWAYS model. The most critical are reviewed in the following sub-sections.

Renewable Technology Capital Costs and Performance

The PATHWAYS model included assumptions regarding operating lifetime, all-in capital costs, and solar degradation.

- **Operating Lifetime:** PATHWAYS includes an operating lifetime of 120 years for conventional hydro and an operating lifetime of 20 years for biomass/biogas, geothermal, utility-scale solar, and wind. The National Renewable Energy Laboratory suggests a useful life of 20 years for wind and 25 to 40 years for solar photovoltaics (PV).
- **All-In Capital Costs:** The all-in capital costs in the PATHWAYS analysis are derived from a 2013 study by Black and Veatch on renewable capital costs. This study also served as the input to the California Public Utilities Commission's (CPUC) Renewable Portfolio Standard Cost Calculator, which makes the PATHWAYS analysis more consistent with the RPS Cost Calculator than if different capital costs were used. However, the renewable capital costs used for utility-scale wind and solar PV could be considered somewhat conservative compared to other industry projections, such as NREL's 2015 "Standard Scenarios Annual Report".[14] Table 6 provides a comparison between the capital costs for wind and solar PV in the PATHWAYS analysis and NREL's projections in their 2015 Standard Scenarios Report.

Table 6. Wind and Solar PV Capital Cost Comparison ($2012/kW)

Year	Wind		Solar PV	
	NREL 2015 Standard Scenarios	E3 PATHWAYS Analysis	NREL 2015 Standard Scenarios	E3 PATHWAYS Analysis
2016	1,847	2,337	2,001	3,350
2018	1,826	2,328	1,853	3,290
2020	1,806	2,319	1,706	3,231
2025	1,773	2,298	1,421	3,098
2030	1,760	2,277	1,137	2,980
2040	1,755	2,233	1,137	2,777
2050	1,755	2,190	1,137	2,609

[14] NREL's 2015 Standard Scenarios Annual Report can be accessed here: http://www.nrel.gov/docs/fy15osti/64072.pdf

- **Solar Degradation:** Neither the California PATHWAYS Model Framework and Methods document nor the California PATHWAYS Supply Inputs spreadsheet suggest that any degradation factor has been applied to the solar projections provided in the PATHWAYS model. A 2012 review sponsored by NREL entitled "Photovoltaic Degradation Rates — An Analytical Review" analyzed nearly 2,000 degradation rates from individual modules or collections of modules and found a median degradation rate of 0.5% per year.

Hourly Renewable Generation Profiles

The model includes hourly generation profiles for solar PV and wind, incorporated as follows:

- **Solar PV:** Hourly generation profiles for solar PV and solar thermal were simulated using NREL's System Advisor Model (SAM). SAM is a publicly available tool that, "makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model". A conference paper presented by NREL in June 2012 compared SAM projected data and real-life measured data for four projects and found, "good match (delta of less than 6% for any month) between measured and simulated data".[15] SAM is widely used by researchers, consultants, policy analysts, and more.
- **Wind:** An hourly generation profile for wind was obtained from the Western Wind Dataset. The Western Wind Dataset was created by 3TIER in concert with NREL, using a rigorous, multi-step modeling process to create wind plant output for more than 32,000 locations. Short of using measured data, the Western Wind Dataset represents a viable, public resource for wind generation profiles.

Renewable Capacity Build Locations

Per the PATHWAYS Supply Inputs spreadsheet, renewable capacity builds for all non-Baseline and Reference Scenarios may be sited throughout the WECC footprint.

Transmission and Distribution Costs Associated with Renewable Energy Development

Per the PATHWAYS Supply Inputs spreadsheet, transmission and distribution costs of $18.25/MWh ($2012) are added for all renewable energy generation. These costs are approximated from the CPUC's 2010 Long Term Procurement Planning process.

Energy Storage Capacity

According to the PATHWAYS Supply Inputs spreadsheet, specific amounts of energy storage charge/discharge capacity were input to the PATHWAYS model for each scenario. Table 7 provides the energy storage capacity specified for the Baseline, Straight Line, and High Battery Electric Vehicle (High BEV) Scenarios.

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[15] Blair, N; Dobos, A; Sather, N. *Case Studies Comparing System Advisor Model (SAM) Results to Real Performance Data*, 2012 World Renewable Energy Forum, May 13—17, 2012. NREL/CP-6A20-54676. Available online: http://www.nrel.gov/docs/fy12osti/54676.pdf.

Table 7. Energy Storage Charge/Discharge Capacity by Scenario (MW)

Scenario	Year			
	2015	2020	2025	2030
Baseline	2,427	2,427	2,427	2,427
Straight Line	2,593	3,421	3,752	3,752
High Battery Electric Vehicle (BEV)	2,593	3,421	6,552	9,052

Generation Planning

Generation planning in the PATHWAYS analysis is conducted through a three step process.

- **Specified Resources:** The first step in generation planning for any scenario is to allow the user to specify the capacity or generation for each generating resource (i.e. nuclear, geothermal, wind, etc.). The specified capacity and generation for all renewable generating resources, other than conventional hydro, is labeled as "N/A" in the PATHWAYS supply inputs spreadsheet for all years, which presumably means that no capacity or generation was specified.
- **Renewable Energy Compliance:** According to the PATHWAYS Technical Appendix, the second step in generation planning for any scenario is to allow the model to simulate, "renewable resource procurement to meet a user-specified renewable portfolio standard (RPS)". The model calculates the renewable net short for each year as the difference between the generation needed to meet the RPS goal (retail sales times the percentage RPS goal) and the renewable generation that is already online. Then, the model fills in the net short with additional renewable generation. The user can also define the resource composition to be used in a given year. The PATHWAYS Supply Inputs spreadsheet shows that the resource composition for all scenarios, other than the Distributed Energy scenario, was specified as 50% utility-scale solar PV and 50% wind for all years after 2030.
- **Reliability Procurement:** The final step in generation planning for a scenario is to ensure that there is adequate capacity to meet peak demand. This step does not have an appreciable effect on the renewable energy composition of each scenario.

System Operations

The PATHWAYS model relies on a number of operational rules and abilities to shape and meet load obligations in ways that affect renewable operations and generation (see Table 8 below).

Table 8. Overview of Operational Rules and Abilities for System Operations in PATHWAYS Model

Operational Rules and Abilities	Description
Must-Run Resources	Nuclear, combined heat and power, geothermal, and small hydro are all characterized as must-run resources.
Variable Renewable Resources	Variable Renewable Resources
Flexible Load Shaping	Raw net load may be shaped based on flexible loads that are determined at the subsector level (i.e. Commercial Lighting, Residential Water Heating, etc.)
Energy-Limited Resource Dispatch	Conventional hydro, biomass, and biogas are all characterized as energy-limited resources, which are constrained by temporally-limited energy budgets.
Energy Storage Simulation	Aggregated energy storage may be charged or discharged for a given time interval, with associated energy losses
Dispatchable Resources	Coal, combined cycle, steam turbine, and combustion turbine plants, as well as imports, are considered dispatchable resources that may be used to meet demand after previous operations have been carried out.
Energy Imbalance	The last step in system operations is determining whether or not there is an energy imbalance. Imbalances are first mitigated through exports to other regions and then through curtailment of wind and sola

Results Evaluation–Renewable Energy

The renewable assumptions and inputs mentioned above are obviously some of the main drivers of the renewable energy projections in the PATHWAYS analysis. However, some of these assumptions or inputs may cause the outputs in the PATHWAYS analysis to be misleading or incorrect. This section discusses some of the implications of the renewable assumptions and inputs described above and how they are manifested in the PATHWAYS modeling process.

Near-Term Renewable Projections

As previously mentioned, the PATHWAYS analysis does not specify renewable resource capacity or generation in the near-term, but instead simulates renewable resource procurement to meet California's RPS. However, since 2015 is the first year of the PATHWAYS analysis, we already have a basic idea of what California's renewable energy generation and capacity will be in 2015. Table 9 provides a comparison between 2015 actual renewable generation from the California Energy Commission (CEC)[16] and the 2015 projected renewable generation for the Straight Line Scenario in the PATHWAYS analysis.

[16] CEC, CA Energy Almanac, Available online: http://energyalmanac.ca.gov/electricity/total_system_power.html

Table 9. 2015 Actual Renewable Energy Generation vs. 2015 PATHWAYS Projections, GWh

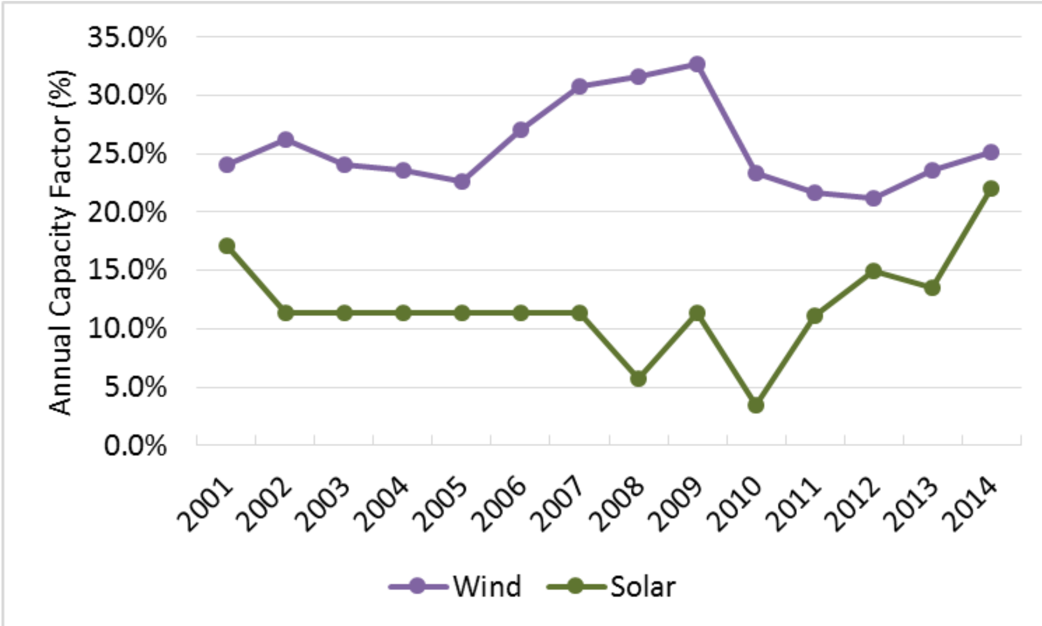
Capacity Type	2015 Actual Generation	2015 Projected Generation
Hydro (Large and Small)	18,564	30,040
Biomass	7,546	6,078
Geothermal	12,883	12,110
Solar	17,629	21,250
Wind	24,107	33,280
Total	**80,729**	**102,758**

2015 renewable generation in the PATHWAYS analysis is over 22,000 GWh higher than 2015 actual generation, and still about 10,500 GWh when hydropower is excluded from both totals. The increase in generation in the PATHWAYS analysis is driven mainly by wind and solar. Using the capacity factors for wind and utility solar provided in the PATHWAYS Supply Inputs spreadsheet, which are 33% and 31% respectively, an additional 3,170 MW of wind and an additional 1,330 MW of utility solar would have had to come online and serve California in 2015 to replicate the PATHWAYS analysis.

Clearly, California's actual 2015 renewable energy generation does not align with the 2015 renewable generation projected in the PATHWAYS analysis. The primary reason for this is that the capacity factors used in the PATHWAYS analysis do not align with the capacity factors of existing capacity. According to the CEC Energy Almanac, the annual capacity factor for in-state California wind averaged 26.3% from 2007-2014, including an average capacity factor of 25.2% in 2014. The annual capacity factor for in-state California wind peaked at 32.7% from 2001-2014, but has been about 7% lower, on average.

The same is true for solar. While the capacity factor of in-state California solar has been climbing since 2010, the average capacity factor for in-state California solar was just 22% in 2014, well short of the 31% capacity factor used for all solar in the PATHWAYS analysis. Figure 5 provides the average annual capacity factors for in-state California wind and solar from 2001-2014.

Figure 5. Average Annual Capacity Factor, California Wind and Solar, 2001-2014



As technology improves for wind (greater hub heights, larger rotor blades) and solar (higher panel and inverter efficiencies), it may be reasonable to assume that new solar and wind resources that come online could reach the capacity factors used in the PATHWAYS analysis (although this may be less true for wind, as new wind plants are sited in less optimal locations). However, there is a large amount of existing wind and solar resources that do not appear to be reaching those benchmarks.

Systems Operations

There are a number of issues with the systems operations process that may be enabling an artificially high amount of renewable energy capacity and generation in the PATHWAYS analysis. These include large amounts of grid electrolysis or energy storage, a lack of representation of operational realities in building the supply curve, and no representation of congestion. These issues are discussed in detail below.

Grid Electrolysis and Energy Storage

In the Straight Line Scenario of the PATHWAYS analysis, large amounts of grid electrolysis capacity consume large amounts of renewable energy generation when generation peaks and exceeds base load. Grid electrolysis is a process that uses an electrolyzer to form hydrogen gas. In the PATHWAYS analysis, this hydrogen gas is used in fuel cell vehicles, as 27% of new vehicle sales in the Straight Line Scenario come from fuel cell vehicles. Since the renewable energy used for the electrolysis does not result in any greenhouse gas emissions, the fuel cell vehicles do not produce any emissions.

Grid electrolysis is an unproven technology. The largest grid electrolysis system in the world, which is just six megawatts, was brought online by Siemens on July 2, 2015 at the Energiepark Mainz near Frankfurt, Germany.[17] The projects converts excess wind energy to hydrogen fuel. California also kicked

[17] http://www.siemens.com/press/en/feature/2014/corporate/2014-05-energiepark-mainz.php

off a grid electrolysis in 2015, with a project of 200 kilowatts that uses solar energy instead of wind. The project is being run by Southern California Gas, and the company expects to increase the project to one megawatt sometime in 2016.[18]

In contrast, the Straight Line Scenario of the PATHWAYS analysis contains large amounts of grid electrolysis capacity and uses that capacity to balance renewable energy generation and consumption, with 36.4 MW of capacity modeled for 2016 and over 9 gigawatts (GW) of online capacity by 2030. Table 10 contains the cumulative grid electrolysis capacity in the Straight Line Scenario from 2016 to 2030.

Table 10. Straight Line Scenario Grid Electrolysis Capacity, 2016-2030 (MW)

	2016	2018	2020	2025	2030
Grid Electrolysis Capacity	36.4	65.4	149.2	1,711	9,232

When large amounts of grid electrolysis are not used to absorb excess renewable energy generation, the PATHWAYS analysis relies on large amounts of energy storage to balance supply with demand instead. As seen in Table 11, nearly 6,500 MW of incremental energy storage capacity is added in the High Battery Electric Vehicle (High BEV) Scenario. This storage capacity is not determined endogenously to the PATHWAYS model, but rather included as a supply input.

Table 11. Energy Storage Capacity by PATHWAYS Scenario, 2015-2030 (MW)

Scenario	Year			
	2015	2020	2025	2030
Baseline	2,427	2,427	2,427	2,427
Straight Line	2,593	3,421	3,752	3,752
High Battery Electric Vehicle (BEV)	2,593	3,421	6,552	9,052

While the energy storage market is certainly more developed in the U.S. than the grid electrolysis market, especially considering the long history of pumped storage, there was still only 221 MW of new energy storage deployed in the entire U.S. in 2015.[19]

In California, energy storage is being driven by the state's mandate of 1,325 MW of total storage for California's three investor-owned utilities (Pacific Gas and Electric, Southern California Energy, and San Diego Gas & Electric) by 2020. California utilities are just starting to sign contracts to meet the mandate. Pacific Gas & Electric (PG&E) requested approval from CPUC for 75 MW of energy storage contracts, while Southern California Edison (SCE) requested approval 16.3 MW of storage contracts, and San Diego Gas & Electric has yet to file with the commission.[20] All of the projects would begin operation from 2017

[18] http://www.bloomberg.com/news/articles/2015-04-13/california-utility-to-make-gas-from-solar-for-pipeline-storage
[19] http://www.greentechmedia.com/articles/read/us-energy-storage-market-grew-243-in-2015-largest-year-on-record
[20] https://www.snl.com/interactivex/article.aspx?ID=34725215&KPLT=2

to 2020. In contrast, California energy storage additions in the High BEV Scenario would average 563 MW per year from 2020 to 2030.

Relying on energy storage instead of grid electrolysis also makes electricity more expensive in the PATHWAYS analysis. The average cost of electricity in the High BEV Scenario is higher than the Straight Line Scenario by an average of 2.9% from 2020-2030. The difference between the two cases also rises over time, with the High BEV Scenario about 6.7% higher by 2030.

Other System Operations Deficiencies

The electricity system operations logic in the PATHWAYS model is a multi-step process that uses supply resources to meet shaped demand for each hour. One of the last steps in the system operations process is to run a stack model of dispatchable resources, which include thermal generation and imports. Essentially, thermal generation and imports are used to meet remaining demand once all other processes have been exhausted.

In addition to the stack model of dispatchable resources, the PATHWAYS model contains a minimum thermal constraint where, "the user specifies the minimum generation constraint as a fraction of the total hourly gross load in each electric service territory". This constraint is meant to approximate real-life operational constraints that are, "related to voltage, inertia, and transmission flows". Per the Supply Inputs spreadsheet, all thermal generating resources may contribute to the minimum generation constraint, but nuclear, combined heat and power, and conventional hydro resources contribute as well.

However, this approach to system operations does not fully capture many of the nuances of system and grid operations, which may be causing the PATHWAYS analysis to overestimate system flexibility. Potential oversights include:

- Specific thermal generating resources are needed for grid stability and should be modeled as must-run generation rather than as dispatchable generation.
- Certain operational characteristics of thermal generation. For instance, according to Black and Veatch's 2012 study, "Cost and Performance Data for Power Generation Technologies", combined cycle plants have a minimum load of 50% a ramp rate of 2.5% per minute.[21]

While the minimum thermal constraint may capture some of these characteristics, it cannot do so fully.

Representation of Congestion

Similar to the previous point, a lack of representation of congestion in the PATHWAYS analysis may be causing the model to overestimate the operational flexibility of the California system. The California Independent System Operator (CAISO), which operates 80% of California's power grid, is a nodal market, where generators in the day-ahead forward market receive locational marginal pricing (LMP). According to CAISO, "LMP is a mechanism for using market-based prices for managing transmission congestion".[22]

[21] Black & Veatch, Cost and Performance Data for Power Generation Technologies, 2012. Available online: http://bv.com/docs/reports-studies/nrel-cost-report.pdf

[22] Locational Marginal Pricing (LMP): Basics of Nodal Price Calculation, presentation from CALISO, Available online at: http://www.caiso.com/docs/2004/02/13/200402131607358643.pdf

When prices differ from one node to another, there is congestion preventing lower cost generation from meeting load.

Importantly, congestion can lead to renewable curtailment, and in 2014, congestive curtailment (labeled “economic curtailment” by CAISO) was responsible for nearly 94% of all curtailed electricity across CAISO. In contrast, manual curtailment, which is due to system-wide over-supply events, was responsible for less than 7% of the curtailed energy in CAISO. Without a detailed representation of the California transmission system, it is unlikely that the system operations process in the PATHWAYS analysis is capturing all of the congestive/economic curtailment that would occur with significantly higher penetration of variable generating resources like wind and solar.

Regional Context

In addition to California’s 50% RPS, several other states have clean energy standards that will increase significantly in the coming years. Table 12 provides the mandatory renewable portfolio standard goals for other WECC states from 2016 to 2030.

Table 12. Renewable Portfolio Standard Goals in WECC, 2016-2013 (% of Retail Sales)

State	Year			
	2016	2020	2025	2030
Oregon*	15.0%	20.0%	27.0%	35.0%
Washington	9.0%	15.0%	15.0%	15.0%
Nevada**	16.0%	19.8%	25.0%	25.0%
Arizona	6.0%	10.0%	15.0%	15.0%
New Mexico	15.0%	20.0%	20.0%	20.0%
Colorado	20.0%	30.0%	30.0%	30.0%

*Target for Portland General and Pacificorp. Smaller utilities have smaller goals.

**Net of maximum energy efficiency allowance

Similar to California, over time, these states are planning obtain more of their electricity from variable generation sources, like wind and solar. This continued demand for renewable energy in other WECC states may have several implications for California’s ability to meet their own RPS, including issues such as imports/exports and siting, permitting, and land use.

Imports and Exports

As wind and solar grows across the WECC region and dispatchable resources (e.g., coal plants) retire, the region will become more reliant upon variable generation. Since wind and solar capacity across the WECC region will generate following a similar profile to the renewable capacity serving California, there may be fewer opportunities to balance California’s supply and demand with imports and exports to the rest of the region. In the Straight Line Scenario, California imports about 20% of its power in 2030.

Siting, Permitting, and Land Use

While the technical and economic potential to meet California and other WECC state’s renewable energy goals through 2030 does exist, facilities still need to be sited, permitted, and connected before they can begin delivering their renewable energy, and project developers may meet a number of challenges that could delay and postpone projects in the region. For example, the 199.8 MW Rising Tree

Wind Farm took nearly 10 years to build, due to challenges in acquiring the land necessary for the project, amongst other challenges.[23]

Large amounts of land will be needed to meet the wind and solar capacity additions detailed in the Straight Line Scenario in the PATHWAYS analysis, particularly for wind. According to an NREL analysis of 161 projects, total affected area for wind projects averages 34.5 hectares per megawatt, or about 0.133 square miles per megawatt.[24] Using that figure, wind capacity additions through 2030 in the Straight Line Scenario (which would only be used to meet California's clean energy goals) would affect an additional 1,240 square miles of land (Table 13). For comparison, Joshua Tree National Park in Southern California encompasses about 1,235 square miles.

Table 13. Land Use for Wind and Solar Capacity Additions, Straight Line Scenario

Capacity Type	Capacity Additions, 2015-2030	Hectares per MW	Square Miles per MW	Total Land Use, 2015-2030 (Sq. Miles)
Wind	9,310	34.5	0.1332	1,240.1
Solar	12,951	34.5	0.0123	159.9

While the solar capacity additions in the Straight Line Scenario would have lower land requirements than the wind additions, they would still require at least 160 square miles of land.[25]

[23] http://nawindpower.com/online/issues/NAW1505/FEAT_06_EDP-Renewables-Is-Undeterred-By-Rising-Tree-s-Colorful-Past.html
[24] Land Use Requirements of Modern Wind Power Plants in the United States, NREL/TP-6A2-45834, 2009. Available online: http://www.nrel.gov/docs/fy09osti/45834.pdf
[25] Calculated using the, "Capacity Weighted Average Land Use" for large PV facilities, defined as greater than or equal to 20 MW: http://www.nrel.gov/docs/fy13osti/56290.pdf

6. REMI Modeling

Overview of the Strengths and Weaknesses of REMI

REMI is a structural economic forecasting and policy analysis model that integrates several analytic techniques including input-output, computable general equilibrium (CGE), econometric, and economic geography methodologies. The model is dynamic, with forecasts and simulations generated on an annual basis that include behavioral responses to wage, price, and other economic factors. The dynamic modeling framework supports the option to forecast how changes in the economy, and adjustments to those changes, will occur on a year-by-year basis. Sectoral and regional detail allow the REMI model to identify winners, losers, and distributional changes which are likely to exist when considering disruptive technological changes. The model, as a result of being based on strong economic theory, is an effective policy analysis tool which allows users to estimate how the economy might look under alternative policies compared to a base case. Users can see the ripple impact of policies across industrial sectors, consumers, and macroeconomic indicators such as GDP, employment, and household income. As a hybrid economic model, REMI benefits from the ability to forecast changes through time, allowing changes in the economy to have persistent impacts as they would in the real world.

The REMI model has been the go-to model for policy analysis for many agencies, researchers, and companies. As with any model it cannot perfectly forecast the future or changes to the economy. This is due to weaknesses inherent in the model, economics, and modelers. One of the strengths of the model is the sectoral and regional detail contained in the model. However, even the version of the model with 4-digit NAICS-code sectoral detail has drawbacks which come with having to assign technologies to sectors. This weakness is highlighted when considering technologies which are not currently well defined in the NAICS codes within REMI such as renewable technologies. The REMI model may not properly capture intermediate demand impacts of manufacturing newer technologies like batteries or solar power. When modeling current technologies, like construction of a new renewable power plant, it is up to the modeler to identify and assign the investment money to the appropriate sectors.

Another weakness of the model comes from the general equilibrium framework. General equilibrium assumes that markets always clear back to a long-term equilibrium. So, a policy which negatively impacts an industrial sector may cause the sector to initially decline, and then rebound to a new, lower economic output equilibrium. This assumption is generally a strength, but if one is modeling large and disruptive technological changes, general equilibrium can misrepresent reality. A problem with all models forecasting the future and especially for modeling large disruptive changes is that the use of historical data to estimate or calibrate parameters defining economic relationship may not be able to reflect accurately relationships in the future.

Modelers are another source of weakness. The REMI model can only provide robust results dependent on modelers making realistic assumptions and doing robust work. For example, modeling investment directed into a specific sector can result in large economic benefits if the modeler does not take into account where the investment money comes from.

CARB and REMI Modeling

Given that CARB has indicated that one of the next steps related to the Updated Scoping Plan is to tie the PATHWAYS results to REMI modeling, ICF sought to identify and review examples of CARB staff using the REMI model. The most recent example which we could find was done as part of the re-adoption process of the Low Carbon Fuel Standard in 2015. This section will briefly discuss how they modelled the impacts of the LCFS in REMI, what was done well, and what could have been done better.

The first impact of the LCFS is to change the mixture of fuels consumed to reach compliance. CARB recognized that as a market mechanism, LCFS will not result in a defined strategy or mixture of fuels to achieve compliance. Instead there are many strategies which could yield least cost compliance. Therefore CARB constructed one potential compliance scenario with input from stakeholders and experts. This compliance scenario estimates the changes in fuel consumption by types of fuels in physical units.

To model the change in fuel consumption CARB needed to determine the change in consumer spending on these fuels. Although REMI does have endogenous prices, because it does not deal in physical inputs, and the physical amount of fuel consumption changes deterministically, the prices must be determined outside of the model. To determine the prices they used EIA forecasts, slightly modified to be specific to California, of each fuel type. The prices of conventional gasoline and diesel were further increased to reflect the LCFS credit value, although the methodology used to do this is vague. Alternative fuels to gasoline and diesel are only adjusted by EIA forecasts because CARB assumed that their price is directly linked to the conventional fuel prices. Using these prices and the amount of fuel consumed expenditures on each fuel type were calculated. CARB then converted these expenditures to changes in fuel prices faced by consumers in REMI. However, the method used to convert expenditures to price inputs is not clear.

Inputting the changes in fuel prices to consumers in the model will result in the market adjustments to consumers when they are faced with paying higher prices for fuels. Secondary impacts such as reduced disposable income to spend on other goods will occur in the model and be reflected in results. Since the fuel prices are determined outside of the model they could be a source of bias to modeling results. It is unclear what methodology is used to combine the EIA forecasts and LCFS credit impacts and if the conversion of expenditures into prices is robust. Additionally, the consumption of fuels and fuel prices in REMI is aggregated into only three categories: motor vehicle fuels, natural gas, and electricity. All six of the liquid fuels; gasoline, diesel, renewable diesel, renewable gasoline, ethanol, and biodiesel fall within the motor vehicle fuels category. Any differences in the economic impacts between the consumption of gasoline and diesel versus the consumption of renewable diesel, renewable gasoline, ethanol, and biodiesel will not be reflected in the REMI results.

The above discussion only captures the impact to consumers of the LCFS. Fuel producers are also impacted through changes in revenue. Revenue is impacted by changes in fuel prices and transfers in LCFS credits. Conventional fuel producers are forced to purchase LCFS credits from alternative fuel producers and electricity providers. REMI does not allow for a direct change in revenue and again, due to the aggregated nature of fuel categories, cannot differentiate between conventional and alternative fuel producers. Therefore, CARB modeled the impact of the LCFS on producers as changes in production cost which simulates the transfer of credits from electric and natural gas sectors to conventional gasoline and diesel producers. This increases the production cost for producers of conventional gasoline and diesel caused by the requirement to purchase LCFS credits, and decreases the production cost for producers of natural gas and electricity from selling LCFS credits. Potential sources of inaccuracy in this portion of the modeling come from the two main assumptions made by CARB; assumed changes to fuel consumption under the illustrative compliance scenario and the assumed LCFS credit value which is modeled as a constant of $100 per metric ton of CO_{2e}.

Finally, CARB's modeling exercise accounted for a few more impacts of the LCFS. One is that the LCFS will increase administrative costs for regulated entities. This is modeled as a decrease in labor productivity to account for the increase in time required to be spent on actions like record-keeping. It is not clear how this is modeled in REMI. CARB also modeled the reduction in domestic demand for transportation fuels, as an increase in exports at a price lower than the California price. This is an important inclusion; lower demand for conventional fuels in California can be counteracted by increased exports to other regions. However, CARB likely over-simplifies the lost revenue to California producers of gasoline and diesel assuming that the lost revenue is equivalent to the price between the adjusted price of gasoline and diesel in California and the average price of gasoline and diesel reported by EIA. This excludes the lost revenue as a result of having to transport the fuel a longer distance (this is not bundled into the EIA price for finished gasoline and diesel). It also ignores the potential for overseas export markets, which also must include price adjustments and transportation costs accounting.[26]

Much of the modeling of the LCFS is done robustly and critiques of it can generally be directed at the assumptions behind the numbers put into REMI. The modeling of inputs reflects, as best it can, the benefits and costs to consumers and producers. Whether those inputs reflect an accurate LCFS credit price, accurate forecast of future fuel prices, or a realistic compliance scenario may be drawn into question. There are a few areas that we identified which warrant further consideration, especially as CARB considers using PATHWAYS results as inputs into REMI. REMI does not make a connection between consumer expenditure in fuels and changes to vehicle purchasing behavior. It seems plausible that an increase in fuel prices and changes in types of fuel consumed will force consumers to make new, or different, consumption choices regarding vehicle purchases. Changes in these choices are not being captured in REMI in the modeling framework described by CARB.

Difficulties in modeling PATHWAYS

E3's PATHWAYS model shows technological changes resulting in decarbonization of the economy. The modelers acknowledge the fact that they do not specify a mechanism for these changes to occur and instead describe the types of technologies that are possible and available to use today. Several aspects of the PATHWAYS model results create problems when trying to model PATHWAYS outputs in REMI.

Some of the PATHWAYS outputs are difficult to translate into REMI inputs. One of the difficulties is the physical nature of changes to consumption. The outputs are very specific in regards to the amount of

[26] ICF notes that the PATHWAYS modeling assumes that the energy used to refine petroleum and extract oil and gas decreases proportionally with demand for liquid fossil fuels. In other words, CARB's assumption regarding reduced revenue as a result of exports in the analysis of the LCFS program cannot be used when PATHWAYS outputs are linked to REMI because they effectively reduce refinery runs proportional to decreasing demand.

each type of fuel consumed and at the same time have prices for these fuels. This is similar to the LCFS compliance scenario where prices were estimated separately from fuel consumption. However, it is at a much larger scale and it is unclear, given the lack of detail on how the LCFS turned expenditures on fuel (price multiplied by quantity consumed) into just a price change, if it is possible to turn expenditures from PATHWAYS into a single price input to REMI. If it was possible, it is not clear that the price would result in the kind of transformational changes that exist in PATHWAYS outputs. For example, there is no energy price that could be input into REMI which would result in the coal sector, specifically, declining. Similarly, if motor vehicle fuel prices were increased in REMI, it would not result in a switch in the model to an economy reflective of one which also switched to electric vehicles.

Another difficult aspect of modeling PATHWAYS outputs is the specifics to the technological change occurring. This is important because of the different sectoral impacts of constructing, for example, a solar-powered generating unit compared to a coal-powered generating unit. There is a lot more capital involved in the construction of a coal-powered generating unit where a solar-powered generating unit might require more labor. Furthermore, different industrial sectors will make up different proportions of inputs to each such as NAICS 335: electrical equipment, appliance, and component manufacturing, for solar compared to NAICS 332: fabricated metal product manufacturing, for a coal-powered generating unit.

PATHWAYS results require a modeling choice between the use of prices or modeling investments directly. The outputs of PATHWAYS describe the change in amount of money invested in, for example, a renewable generator and a conventional generator. Since it is not an optimization the model incorporates the increase in cost, to build a more expensive renewable generator, into energy prices. Therefore a modeler must choose between accurately modeling the differences in building different generator types as described in the previous paragraph or inputting changes to energy prices. Modeling both is not possible because it would result in double-counting. The choice of modeling only energy prices may not result in an economy reflecting the transformational changes that occur in PATHWAYS. It is also unclear how accurate the energy prices would be, if used, given that they are not determined by an optimization framework.

The difficulty in using energy prices from PATHWAYS in REMI creates another issue with modeling PATHWAYS outputs. If prices were used, a story could be told that consumer and industrial preferences changed to be willing to pay higher prices for cleaner technologies. By modeling the different investment increases and decreases directly, there is no mechanism to bring about the technological changes and it is problematic. This is because modeling the raw data of technological investments results in a net economic benefit because the investments are in more expensive technologies than those that would have been built in the base case. Therefore, it is up to the modeler to try and bring in reality and this is inherently a subjective process. The increased investments in clean technologies and fuels, compared to the higher carbon emitting technologies that they replace, requires the investment money come from somewhere. To model it otherwise is to assume free money. Therefore, the investment money must be modeled as provided by the government (increased taxes), industry (modeling a decrease in investments elsewhere), or consumers (decrease their ability to spend on goods). This inherently enforces a policy or mechanism, which PATHWAYS was careful not to do. Additionally, it is unclear from the PATHWAYS outputs, the extent to which any of these adjustments should be done. For example, different assumptions could be made about the debt to equity ratio of the increased investments. Different assumptions on the borrowing of money to finance increased investments could have dramatically different implications for economic impacts.

The PATHWAYS model may show what technologies are needed to decarbonize the economy but the model does not indicate how this can be done. In addition, inputting PATHWAYS into REMI will not necessarily result in an economy indicative of the transformational changes that occur in PATHWAYS. It is strongly up to the modeler to develop a realistic representation of the PATHWAYS world in REMI to justify that world through careful modeling decisions and deep understanding of both the PATHWAYS model and its outputs.