Comparison of Medium- and Heavy-Duty Technologies in California

Summary for Policymakers

December 2019

California Electric Transportation Coalition
Natural Resources Defense Council

In Partnership With:

- Union of Concerned Scientists
- Earthjustice
- BYD
- Ceres
- NextGen Climate America

With Advisory Support From:

- University of California, Davis Policy Institute for Energy, Environment and the Economy
- East Yard Communities for Environmental Justice

Contents

I. Introduction

This Summary for Policymakers presents the results of a comprehensive study to compare the emissions, cost, and economic and jobs impacts of alternative technologies for the medium- and heavy-duty (MD and HD) transportation sector. The study was performed by the consulting firm ICF and was commissioned by the California Electric Transportation Coalition (CalETC) and the Natural Resources Defense Council (NRDC). The study was prepared in partnership with the Union of Concerned Scientists, Earthjustice, BYD, Ceres, and NextGen Climate America, with advisory support from the University of California, Davis Policy Institute for Energy, Environment and the Economy, and East Yard Communities for Environmental Justice.

The ICF report provided in-depth comparisons of:

- Emission reductions achieved by alternative fuel technology-based fleetwide scenarios.
- The total cost of ownership for various vehicle and fuel combinations.
- The economic and jobs impact in California of the alternative scenarios.

Another supporting element of the ICF report developed a suggested “balanced scorecard” for evaluating policy approaches.

This Summary for Policymakers, commissioned by CalETC and NRDC and prepared by Shulock Consulting, summarizes the ICF technical work. This summary is based on the ICF reports, and was reviewed by ICF for technical accuracy, but it is not an ICF work product.

This Summary for Policymakers describes the policy context and analytical needs that prompted CalETC and NRDC to undertake this work. It notes the new contributions made by the study to our understanding of the implications of alternative long-term technology trajectories, and how best to evaluate them. Finally, it highlights the major findings from the entire ICF technical report and describes in more detail the report’s analyses and conclusions.

II. Policy Context

Readers of this Summary for Policymakers will undoubtedly be aware of the need for significant emission reductions in California, particularly from MD and HD trucks and buses. Even so, a brief discussion of the challenges facing the state will help the reader understand the sense of urgency with which the sponsors of the ICF study view the need for aggressive policies in the MD and HD transportation sector.

The recently-released “Emissions Gap Report 2019” issued by the United Nations Environment Programme provides a stark assessment of, as it puts it, “the difference between ‘where we are likely to be’ and ‘where we need to be’” with respect to greenhouse gas (GHG) emissions. The report makes a number of sobering observations:

> *“The Intergovernmental Panel on Climate Change (IPCC) issued two special reports in 2019. …Both reports voice strong concerns about observed and predicted changes resulting from climate change and provide an even stronger scientific foundation that supports the importance of the temperature goals of the Paris Agreement and the need to ensure emissions are on track to achieve these goals.*

"…The challenge is clear. The recent IPCC special reports clearly describe the dire consequences of inaction and are backed by record temperatures worldwide along with enhanced extreme events.

"…Reflecting on the [Emissions Gap] report's overall conclusions, it is evident that incremental changes will not be enough and there is a need for rapid and transformational action."

At the regional rather than global level, there is an equally compelling need to reduce criteria pollutant emissions in California to reach health-based ambient air quality goals. The South Coast Air Quality Management District and the San Joaquin Valley Air Pollution Control District are currently in extreme non-attainment of the eight-hour federal ozone standard, and in non-attainment for the 24-hour PM2.5 standard.

California has been a global leader in responding to air pollution challenges and has established ambitious goals to continue that leadership and protect the health of its citizens. Under current commitments California must reduce GHG emissions at least 40 percent below 1990 levels by 2030 and 80 percent by 2050, while also reducing nitrogen oxide (NOx) emissions by approximately 80 percent by 2031. For the state to hit these goals, it must dramatically reduce its reliance on carbon-based fuels like diesel and natural gas in the coming decades. Clearly a transition to alternative fuels is needed.

Transportation accounts for about 50 percent of all GHG emissions in California and 80 to 90 percent of smog-forming pollutants when fuel production emissions are included. While much attention and many resources have appropriately been spent on transitioning passenger vehicles to cleaner technologies, this report is focused on the importance of commercial vehicles. Buses, delivery trucks and semi-trucks account for more than 8 percent of the state's GHG emissions and 32 percent of NOx emissions. These NOx emissions contribute to both smog and particulate pollution, which have been linked to asthma and other serious illnesses in communities with significant truck and bus traffic.

Improving our understanding of the type and pace of alternative vehicle technology and fuel implementation required for California to achieve its public health goals is extremely important as policymakers develop future policies and regulations.

III. New Contributions from This Study

Traditional approaches to evaluating alternative-fuel policies have tended to focus on short-term objectives and/or a single policy dimension rather than offer a wide-ranging analysis of the necessary broad-based transformation. The narrower approach has led to incrementalism, or "business as usual", which will not achieve the state's policy goals.

Ultimately, as the state embarks on establishing additional policies and making supporting investments to reduce pollution from the freight sector, it will need to target the policies and investments to best achieve both short- and long-term goals. The ICF study offers a comprehensive, multi-dimensional evaluation of varying alternative-fuel vehicle deployment trajectories and their attributes. This will substantively inform existing analyses and the development of tools to further our understanding of the efficacy and real-world impacts of future policies and regulations.

The ICF work advances the state of the art in two major ways. First, it develops several detailed, internally consistent and reality-based scenarios for future alternative fuel vehicle deployment, and provides a rigorous comparison of their emissions, costs, and economic and jobs impacts. The analysis is grounded in an extensive literature review and uses the most authoritative and up-to-date assumptions available. Second, based upon input from the study sponsors and advisors, it outlines a "balanced scorecard" approach that allows a more complete and nuanced evaluation of different policy options than has typically been the case. This scorecard approach is tested here and can provide a useful framework for similar evaluations elsewhere.

IV. Major Findings

This section provides an overview of the primary findings of the ICF work. Additional conclusions from the analysis are discussed in Section V below on a topic-by-topic basis. The most noteworthy findings from this study are:

- Widespread electrification beyond existing and proposed policies is required to meet both 2030 and 2050 GHG goals and to significantly help in achieving the NOx reductions required to meet federal ambient air quality standards.
- The necessary deep emission reductions are achieved only through a zero-emissions truck scenario and full implementation of existing NOx-reduction policies. Battery electric trucks and buses are the only feasible path to achieve California's emission reduction goals while also achieving a favorable total cost of ownership.
- Costs for electric MD and HD vehicles are falling, largely due to the rapidly declining costs of batteries. While the value of Low Carbon Fuel Standard (LCFS) credits, along with direct vehicle incentives such as the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) make the economics attractive for fleet operators and owners now, by 2030 battery electric trucks and buses are projected to achieve a favorable total cost of ownership across almost all classes evaluated, even absent incentives.
- ICF modeled aggressive use of renewable natural gas (RNG), renewable diesel, and biodiesel, but found that constraints on the availability of low-carbon-intensity renewable natural gas and renewable diesel limit the GHG emission reductions that can be achieved by using those fuels. Of the 3.1 billion diesel equivalent gallons of fuel that will be needed in 2030 to power the state's large vehicles, ICF concluded that the supply of renewable natural gas and renewable diesel from low-carbon intensity sources in California would be limited to 750 million and 1,500 million diesel equivalent gallons respectively.
- Demand for these renewable fuels and feedstocks from other sectors of the economy could further limit their overall potential to significantly offset the use of conventional diesel in trucks and buses.

- Truck electrification provides greater benefits to the economy as a whole relative to other alternatives evaluated. Investment in battery-electric trucks and charging infrastructure results in greater employment, Gross Regional Product, and industrial activity per dollar spent compared to natural gas vehicles and infrastructure.

No matter which pathway is chosen, significant public and private investment will be needed for vehicles and infrastructure until the technologies reach total cost of ownership parity relative to diesel-based technologies. It is appropriate to target government investment and policy towards electrification, especially given the large investments worldwide in electric trucks and buses. Individual vehicle manufacturers are making or are planning significant private investments for MD and HD electric vehicles. Worldwide, vehicle and engine manufacturers (including light-, medium- and heavy-duty) are expected to invest at least $90 billion in electrification. This does not include significant investments that have already been made by established MD/HD ZEV manufacturers such as BYD, Proterra, Zenith, and Motiv.

V. Additional Analysis from the ICF Report

The remainder of this Summary for Policymakers provides additional detail on the analysis in the ICF report, and summarizes findings not already reported under Major Findings above. The complete report is available https://caletc.com/comparison-of-medium-and-heavy-duty-technologies-in-california/.

1. Emission Impacts Scenario Analysis

The emission impacts scenario analysis constructed and then evaluated five scenarios that illustrate possible future deployment trajectories for alternative-fuel technologies. The number of vehicles of each type (e.g. Class 3, Class 4) sold each year is the same across all scenarios; what varies is the predominant fuel type used and the rate of penetration of alternative fuels into the fleet. The fuels examined included biodiesel and renewable diesel, natural gas (both fossil and renewable), and electricity. (Hydrogen fuel and fuel cell vehicles were included in the TCO analysis described below, but due to ongoing projected high costs for vehicles and infrastructure and limitations on data, the results of the TCO analysis for hydrogen-fueled vehicles were not carried forward into this emission impacts scenario analysis or the economic analysis.)

As noted in the introduction, California law requires the state to meet ambitious goals for GHG emission reductions as well as reductions in criteria pollutant emissions to protect public health. ICF analyzed whether each of the five alternative fuel scenario evaluated can meet its necessary fair share of California's near- and long-term policy objectives.

The individual regulatory and policy strategies operative within each scenario are discussed in detail in the ICF report. For purposes of this Summary for Policymakers we provide a more general characterization. The scenarios considered in the report are:

1. **Current Policies (baseline)**. The Current Policies scenario includes currently adopted policies (state and federal laws, regulations, and legislative actions adopted as of December 2017), and the Sustainable Freight Action Plan. Renewable diesel and biodiesel are assumed to reach up to 1.5 billion gallons annually. The Current Policies scenario provides the baseline against which the remaining scenarios are compared.

2. **Diesel**. The Diesel scenario examines how close current fuels and infrastructure could bring California to its 2030 and 2050 targets. It adds low NOx diesel engines starting in 2024, and additional diesel fuel economy improvements post 2027, to the suite of policies contained in the baseline. These changes are also carried over into each of the remaining scenarios.
3. **Electricity**. The Electricity scenario attempts to meet 2030 and 2050 GHG and NOx emission targets with an emphasis on greater penetration of electric trucks and buses relative to Natural Gas and Diesel scenarios.
4. **Natural Gas**. The Natural Gas scenario attempts to meet 2030 and 2050 targets with an emphasis on greater penetration of natural gas trucks and buses relative to the Electricity scenarios.
5. **Electricity Max**. The Electricity Max scenario is intended to illustrate the upper limit of new MD and HD electrification in helping to meet the 2031 NOx target and in achieving additional GHG reductions. This scenario assumes 100 percent of MD and HD sales are electric starting in 2024.

Each scenario then was evaluated to determine the resulting GHG and criteria pollutant emissions, broken down by tailpipe and upstream, as well as in-state and out of state. Additional findings of the emission impact scenario analysis include:

- Vehicle electrification is particularly attractive because the electric sector is rapidly decarbonizing. Upstream emissions from charging vehicles will be much lower in 2030 and 2050 than they are today.
- Accelerating electric truck and bus deployment beyond what is required to meet 2030 climate targets, as illustrated by the Electricity Max scenario, would provide greater NOx reductions by 2031.
- For MD and HD vehicles to achieve their proportional NOx reductions to meet 2031 requirements, regulations or policies to retire pre-2024 engines are likely necessary, or additional NOx reductions from other sectors are needed to make up the gap. In addition, full implementation of current policies and new diesel regulations on NOx and GHG are essential to getting close to the 2031 NOx requirements.

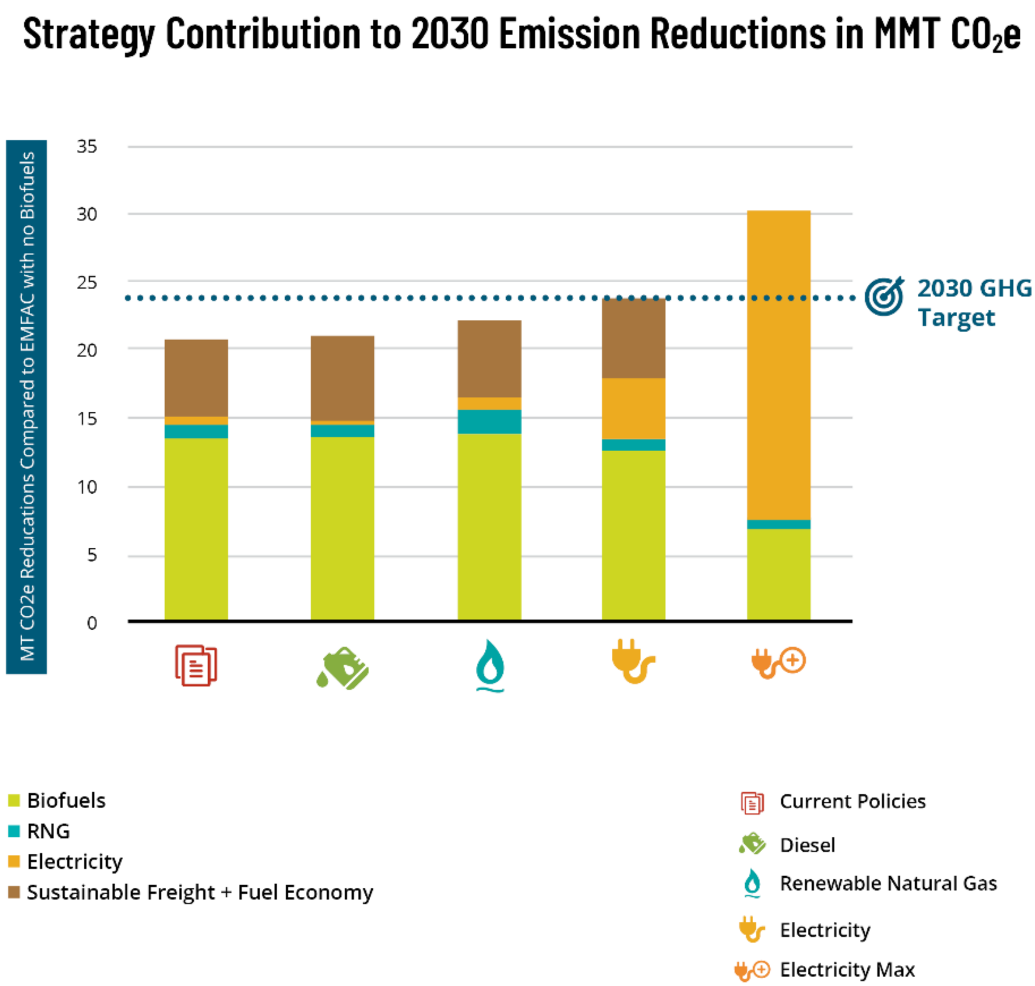
Figure 1 shows GHG and NOx emissions for all the scenarios examined, as compared to the state's GHG 2050 and NOx 2031 targets. The only scenarios that fully achieve the state's GHG goals are Electricity and Electricity Max. The Diesel and Natural Gas scenarios achieve significant GHG reductions around 2030, but transportation emissions in these scenarios do not substantially decline afterwards due to the sector exhausting the availability of renewable fuels. None of the scenarios examined achieve the state's 2031 NOx target. The Electricity Max scenario meets the target in 2033, and the Electricity, Natural Gas, and Diesel scenarios achieve the 2031 NOx target between 2036 and 2037.

The NOx emissions shown in Figure 1 are for in-state tailpipe emissions only. When upstream and out-of-state NOx emissions are included, the Electricity and Electricity Max scenarios have an even larger advantage over other fuels.

Figure 1. Scenario GHG and Tailpipe NOx Emission Comparison

Figure 2 shows for each scenario the GHG emission reductions from each fuel source. For example, the Electricity and Electricity Max scenarios have the greatest total reductions, driven by large reductions from electrification. The Natural Gas scenario similarly has large reductions from RNG. Only the Electricity and Electricity Max scenarios achieve the 2030 target.

Figure 2: Strategy Contribution to 2030 Emission Reductions in MMT CO_2e



The Scenario Analysis shows that aggressive electrification beyond existing and proposed policies, as shown in the Electricity and Electricity Max scenarios, is required to meet both 2030 and 2050 GHG goals and to significantly help in meeting 2031 NOx requirements. Moreover, all scenarios assume increased diesel fuel efficiency starting in 2027, use of biodiesel and renewable diesel for compliance with the LCFS, and fuel consumption reductions per CARB's Sustainable Freight Action Plan requiring a 25 percent improvement in freight efficiency. If these assumptions are not borne out, electric vehicles will have to play an even more important role in achieving 2030 and 2050 GHG reduction goals.

2. Total Cost of Ownership Technology Assessment

The Technology Assessment assesses the "total cost of ownership" (TCO) of MD and HD technologies, today and projected into the future. The TCO as calculated here is the cumulative cost to the first owner of the vehicle, including vehicle capital (purchase price minus residual value), operation and maintenance (which includes the cost of fuel), and any necessary infrastructure, minus any applicable incentives and regulatory requirements. Electric vehicles today have a higher up-front purchase price but lower operating costs than conventional vehicles, largely due to savings in electricity fuel cost. However, up-front costs are decreasing as technology matures. Thus, one key question addressed by the technology assessment is the point at which electric vehicles reach parity with new diesel trucks or buses from a TCO perspective.

Additional messages and findings from the TCO analysis include:

- Due primarily to lower battery cost, reductions in vehicle prices and lower fuel prices for electricity compared to other fuels, electric trucks and buses will likely become economic from a TCO perspective across almost all evaluated categories by 2030 in California even without vehicle purchase price incentives like the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). Some electric vehicle classes will have a lower TCO compared to conventional technologies prior to 2030.
- Utility programs providing low- and off-peak rate periods and mitigating demand charges for MD and HD technologies are critical for electric vehicle and fleet owners. Current programs offered by utilities in California are allowing fleet owners to take advantage of the potentially lower fuel costs compared to diesel or natural gas vehicles.

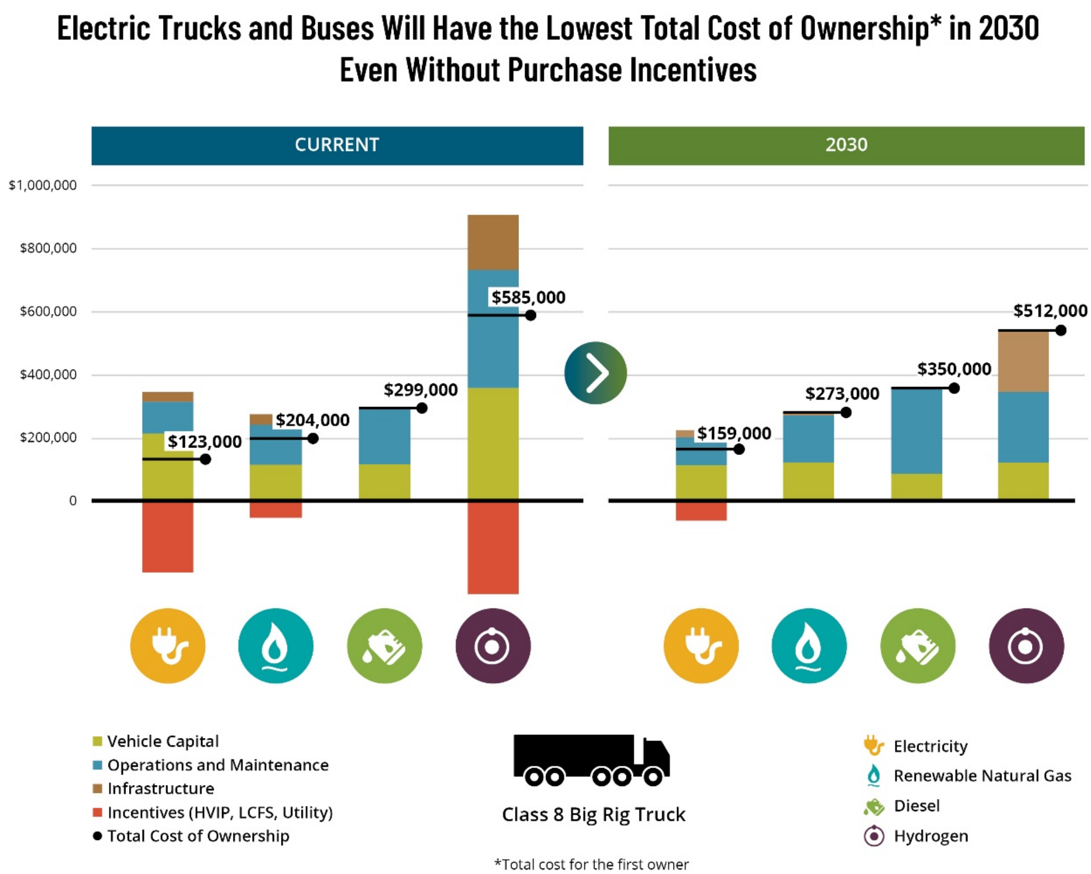
The TCO analysis was performed for various vehicle types from Class 2b to Class 8 trucks and buses, and across fuels including diesel (renewable and conventional), natural gas (renewable and conventional), electricity, and hydrogen.

The results of the TCO analysis show that incentive policies are required now for the TCO of electric trucks and buses to be competitive with diesel and natural gas technologies, but that by the 2030 timeframe BEVs can compete by themselves on a TCO basis without large vehicle purchase incentives. The LCFS, which provides electric fleet owners credits for their GHG emission reductions, is an important source of additional annual value for electric technologies for both the current and 2030 timeframes.

Figure 3 provides an example of the results of the TCO analysis, in this case for Class 8 drayage trucks. Results are shown for drayage trucks operating on diesel, electricity, CNG, LFG (compressed natural gas sourced from landfill gas), and hydrogen, today and in 2030. Cost components (vehicle, operation and maintenance, infrastructure) are shown as positives above the $0 line, and policies that reduce the cost (HVIP, LCFS, utility incentives) are shown as negatives below the $0 line. The black circles and related dollar amounts denote the total cost of ownership--the total of the cost components minus any incentives. The full report provides similar analysis for fourteen vehicle classes and applications.

As Figure 3 shows, HVIP incentives are currently critical for electric Class 8 drayage trucks to have the lowest TCO. By 2030, however, even without HVIP the electric truck achieves the lowest TCO as a result of reductions in vehicle purchase price and lower operating costs. New rate structures combined with optimized charging around low- or off-peak periods could result in significant fuel cost savings for electric trucks and buses. To maximize these potential fuel savings, it will be important to assist fleet operators, especially operators of smaller truck fleets, in understanding and taking advantage of these lower rates.

Figure 3: Example--Class 8 Drayage Truck TCO Analysis Results



3. Economic Analysis

The economic analysis assesses the net economic impact of the previously-defined scenarios (Current Policies, Diesel, Natural Gas, Electricity, and Electricity Max), taking into account direct, indirect and induced effects and the impact of contraction in the gasoline and diesel sectors. The economic modeling considered spending on vehicles, infrastructure and fuel, and reinvestment of a portion of fuel savings into increased production by the industry sectors most involved in MD and HD trucking.

Using the IMPLAN model (a regional input-output economic model), ICF obtained results for four commonly used metrics, consistent with best practices across economic impact analyses:

1. **Employment**: The job-years created in each industry, based on the output per worker for each industry.
2. **Labor income**: Includes all forms of employment income generated by the direct input, including employee compensation (wages and benefits) and proprietor income.
3. **Gross regional product (GRP)**: The net value of output, including labor income, indirect business taxes, and business income.
4. **Industry activity**: The total value of industry activity generated by the direct spending.

Stated most simply, transitioning away from petroleum fuels allows funds that would otherwise flow out of California's economy to be retained here, which increases jobs and local economic activity. The Economic Analysis quantified those impacts, and found that:

- Electrification scenarios result in about a doubling of incremental GRP and jobs in the MD/HD truck sector relative to natural gas or diesel. The Electricity scenario adds about 50 percent more jobs economy-wide per million dollars invested than the Natural Gas scenario, and the Electricity Max adds almost 100 percent more.
- The Natural Gas scenario and both Electricity scenarios show a reduction in net direct spending, and overall positive employment and economic impacts, compared to the Current Policies scenario.
- Decreased fossil fuel consumption reduces employment in the retail gas station, oil and gas, and crude petroleum extraction sectors, but 4 to 5 times more jobs are created in other sectors of the economy, resulting in net employment gains.
- The increased electric vehicle deployment in the Electricity Max scenario (approximately 800,000 in 2030 as compared to100,000 in the Electricity scenario) resulted in additional positive economic impacts, including greater employment, gross regional product (GRP), and industrial activity per dollar spent.

Figure 4 shows the incremental employment impact, cumulative direct spending, and ratio of employment to spending for each scenario relative to the Current Policies scenario. For example, the Diesel scenario shows about 630,000 incremental job-years resulting from about $300,000 million in spending, or a ratio of just over 2 to 1. The other scenarios all show higher (more attractive) ratios.

Figure 4. Ratio of Employment to Million$ Direct Spending

Investment in Electric Buses and Trucks Results in Greatest Economic Impact and Number of Job Years

2019-2050 Scenario	Vehicle and Infrastructure Employment	Cumulative Vehicle and Infrastructure Direct Spending in Millions	Ratio of Employment to Million$ Direct Spending
Diesel	630,012	$300,101	2.1
Renewable Natural Gas	864,868	$354,467	2.4
Electricity	1,355,326	$352,437	3.8
Electricity Max	1,851,520	$394,969	4.7

4. Balanced Scorecard

The objective of the balanced scorecard was to develop a framework to compare different alternative fuel technologies across a number of dimensions. The comparison includes technical, economic, environmental, and regulatory considerations, using a combination of quantitative (where available) and qualitative factors.

As was noted above, many current emission reduction and technology funding mechanisms use scoring and ranking systems focused on a singular pollutant or goal, followed by determining cost-effectiveness around reducing that pollutant or meeting that singular goal (e.g., diesel particulate matter (PM) reduction policies). Sometimes, these previous frameworks have even favored fossil fuel technologies over advanced vehicle technologies because their analysis was limited in scope. With California's near-term and long-term goals for multiple pollutant reductions, it is necessary to be able to evaluate technologies not just for singular pollutant or emissions goals, but also for how they fit into the broader landscape of California policies.

The project team developed a comprehensive yet workable set of measures that collectively capture the many dimensions important to long term policy formulation. That effort resulted in a Balanced Scorecard that is divided into five sections, and combines both quantitative and qualitative technological, economic, and policy assessments. The five categories of the Balanced Scorecard are:

- Commercialization status
- Barriers today

- Environmental considerations
- Policy alignment
- Cost considerations

The Balanced Scorecard is rated using a combination of qualitative and quantitative analytical and market assessments made by ICF, and then reported out using a five-color scheme. The five-color scheme is shown in the following spectrum—with red the lowest rating on the left and green the highest rating on the right.

Where appropriate, the analytical assessment is reported out on an absolute basis in the context of the cell, but the rating will typically be determined on a relative basis. Additional detail regarding the key components of ICF's assessment for each element of the Balanced Scorecard is provided in the ICF report.

Table 1 provides an example of the application of the Balanced Scorecard to the Class 8 tractor, short haul and drayage truck applications. An explanation of the rationale for the scoring is provided in the full ICF report, along with scorecards developed for all of the vehicle categories included in this analysis.

Table 1. Class 8 Tractor, Short Haul and Drayage Truck Balanced Scorecard

Categories	Class 8 Tractor, Short Haul, and Drayage Truck						
	Diesel	Diesel Hybrid	Renewable Diesel	Electricity	Fossil NG - Low NOx	LFG /RNG – Low NOx	Hydrogen
Commercialization status							
Today				Availability			Demonstration
To 2030							
Barriers today							
Vehicle				Availability			Availability
Fuel			Feedstock, Availability	Infrastructure		Feedstock	Fuel Cost
Environmental considerations							
Criteria air pollutants		-20%	No Diesel PM	Zero Tailpipe	-90%	-90%	Zero Tailpipe
Air toxics							
GHG emission reductions		-20%	-50 to -70%	-80 to -100%	-20%	-60+%	-50%
Policy alignment							
To 2030							
To 2050							
Cost considerations							
Today							
In 2030							
Infrastructure							