Economic Impacts of Deploying Low NOx Trucks fueled by Renewable Natural Gas

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Executive Summary

California is dealing with a challenge that is three-fold: reduce air quality pollutants, cut greenhouse gas emissions that drive climate change and reduce petroleum consumption. Heavy-duty truck transportation is a major contributor to the issues that comprise this challenge: They are a major source of criteria air pollutant emissions and greenhouse gas emissions; and more than 95 percent of the trucks on California roads currently use petroleum-based diesel fuel. Despite progress towards addressing these challenges, more aggressive strategies are required to achieve California's overlapping objectives. Renewable natural gas (RNG) produced in California and used in heavy-duty trucks outfitted with low NOx engines is one of these strategies.

The potential for the combination of low NOx trucks powered by RNG presents a compelling economic opportunity, and represents one of the few opportunities to develop a sustainable and robust alternative transportation fuel industry in California. ICF employed IMPLAN, an input-output model, to quantify the economic impacts of deploying low NOx natural gas trucks fueled by California produced RNG.

- This analysis considers low NOx natural gas trucks deployed through 2030 in various applications and vehicle classes. The number of trucks considered in the analysis is linked to one of two strategies:
  - Low NOx trucks deployed at the San Pedro Bay Ports in Southern California.
  - Low NOx trucks deployed in the California Air Resources Board's mobile source strategy.
- The California renewable natural gas production facilities are based on an illustrative portfolio of projects from landfills, wastewater treatment plants, dairies, and biomass resources (such as agricultural residues or forestry and forest product residues). ICF assumed that renewable natural gas is produced and upgraded for pipeline injection, and ultimately used as a transportation fuel.

Table 1 below summarizes the results of our analysis.

Table 1. Economic Contributions of Low NOx Trucks using RNG Produced in California

Economic Parameter	Port Trucks	Statewide Low NOx RNG Trucks, Market Share			Aggressive Scenario
		25%	50%	75%	
Trucks Deployed	17,000	172,000	344,000	516,000	516,000
RNG Produced (M DGE)	174 MDGE	526 MDGE			1,910 MDGE
Capital Expenditures ($M)	$2,703	$15,718	$27,326	$38,934	$43,163
Total Employment	23,459	80,981	107,594	134,206	233,892
Jobs Multiplier	1.99	2.02	2.03	2.03	2.08
Income per Worker	$68,960	$68,830	$68,660	$68,560	$67,950
Total Value Added ($M)	$2,512	$8,657	$11,483	$14,308	$24,618
Output Multiplier	1.83	1.82	1.81	1.80	1.84

In the statewide scenario, where 172,000—516,000 low NOx natural gas trucks are deployed and more than 500 million diesel gallon equivalents of RNG is produced in California, we observe the following:

- The deployment of natural gas trucks, natural gas fueling infrastructure, and California RNG production will produce a total of 81,000—134,000 cumulative jobs to California's economy from 2018—2030.
- These jobs have an expected labor income of nearly $68,500 per job created, more than twice the median salary in California today. These jobs are created in sectors such as construction, fabrication and manufacturing, engineering services, waste management, and service industries (e.g., restaurants).
- For every job created through investment in low NOx natural gas trucks, natural gas fueling infrastructure, and renewable natural gas production facilities, about 2.0 jobs are created in supporting industries (indirect) and via spending by employees that are directly or indirectly supported by these industries (induced).

ICF's economic modeling results provide quantitative insights into the potential for low NOx trucks powered by renewable natural gas produced in California. It is important to understand how this opportunity fits into a broader context related to economic growth and alternative transportation fuel production and consumption. Most importantly, there are few comparable opportunities to develop a robust alternative transportation fuel production industry in California. Low NOx trucks powered by California-produced renewable natural gas have the potential to displace 1 billion diesel gallon equivalents annually. This is the type of aggressive strategy that will help California meet the challenge of reducing air quality pollutants, greenhouse gas emissions, and consumption of petroleum-based fuels, while also making a significant contribution to a growing economy.

I. Introduction

California is dealing with a challenge that is three-fold: reduce air quality pollutants, including pollutants that cause smog[1] and toxic air contaminants; reduce greenhouse gas (GHG) emissions that drive climate change;[2] and reduce petroleum consumption.[3] Heavy-duty truck transportation is a major contributor to criteria air pollutant emissions (including diesel particulate emissions), and GHG emissions; and more than 95 percent of the trucks on California roads currently use petroleum-based diesel fuel. Progress has been made through regulatory action and technology advancement: New standards have helped reduce criteria pollutant emissions from diesel engines and recently promulgated federal phase two standards for medium- and heavy-duty vehicles will improve fuel efficiency and reduce GHG emissions. Despite these advances, more aggressive strategies are required to achieve California's overlapping objectives. In fact, South Coast Air Quality Management District has determined that the South Coast Air Basin will fail to meet federal health-based air quality standards even if every diesel truck meets the US Environmental Protection Agency's (EPA) most restrictive standard for diesel truck emissions.

Renewable natural gas used in heavy-duty vehicles can significantly reduce criteria air pollutant emissions, GHG emissions, and petroleum consumption. With regard to criteria air pollutants, the natural gas industry has been bolstered by the certification of the Cummins Westport ISLG engine at levels 90 percent below the current NOx limit of 0.2 g/bhp-hr—a standard set by the US EPA. This certification achieves compliance with the California Air Resources Board's (CARB) optional low NOx standard of 0.02 g/bhp-hr. Compliance with 0.02 g/bhp-hr is referred to as "low NOx" in this study. Cummins Westport is set to release a larger engine, the ISX12G, with similar prospects for low NOx certification by January 2018. Further, a recent report from University of California Riverside[4] indicates that these engines are actually out-performing their certification standards during a full range of duty cycles; consider this in contrast to previous findings that heavy-duty diesel trucks are emitting *higher* levels of NOx than their certification standards in the same duty cycles.[5]

The majority of research shows that conventional natural gas use in trucks can reduce GHG emissions by 10—20 percent.[6] More recently, however, the GHG reduction potential of natural gas as a transportation fuel has been amplified by the emergence of renewable natural gas (RNG, biomethane or upgraded biogas). RNG can be produced by capturing methane (CH_4)–a short lived climate pollutant that

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[1] Both the San Joaquin Valley and South Coast Air Basin are working to attain federal health-based air quality standards for ozone in 2023 and 2031.

[2] Senate Bill 32 (Pavley, 2016) legislates a 2030 GHG emissions reduction target of 40 percent below 1990 levels.

[3] Governor Brown has established the goal of reducing petroleum consumption by 50 percent by 2030 as one of his pillars of climate change. See https://www.arb.ca.gov/cc/pillars/pillars.htm.

[4] Johnson, K.; Jiang, Y.; and Yang, J. Ultra-Low NOx Natural Gas Vehicle Evaluation: ISL G NZ, November 2016. Available online at http://www.cert.ucr.edu/research/efr/2016%20CWI%20LowNOx%20NG_Finalv06.pdf.

[5] Miller,W.; Johnson, K.; Durbin, T.; and Dixit, P. In-Use Emissions Testing and Demonstration of Retrofit Technology, Final Report Contract #11612 to SCAQMD December 2013.

[6] The California GREET model used by the California Air Resources Board in the regulation of the Low Carbon Fuel Standard Program reports a default carbon intensity of fossil compressed natural gas of about 78 g/MJ. After accounting for an EER of 0.9 for spark-ignited engines compared to diesel engines, and a carbon intensity of 102 g/MJ for diesel fuel, fossil CNG yields a benefit of 15%.

has a global warming potential 84 times higher than carbon dioxide on a 20-year time scale.[7] The methane that is captured comes from organic waste resources, and would otherwise be flared or escape fugitively into the atmosphere. RNG can also be made from the biogas produced from the gasification of organic waste and then "methanized" to convert that raw biogas to biomethane.

RNG currently accounts for about 60 percent of the natural gas used in the transportation sector in California. The majority of this RNG is coming from out-of-state, and is captured from landfills. In California, several projects focused on converting organic waste to transportation fuel have been developed in the past few years, including projects in Riverside County, Sacramento, and South San Francisco. These projects are converting food and yard waste, food processing waste, landfill gas and other organic material to RNG that is used to power garbage trucks, school buses, transit buses and other heavy-duty vehicles. The recent passage of SB 1383 (Lara, 2016) and approval of CARB's Short Lived Climate Pollutant (SLCP) Strategy,[8] which are focused on reducing the emissions of black carbon (soot) and methane, and fluorinated gases, positions California over the next 10—15 years to harness significant in-state resources to capture biogas and produce RNG for transportation fuel and pipeline injection.

The potential for the combination of low NOx trucks powered by RNG presents a compelling economic opportunity for California. ICF reviewed a variety of deployment scenarios to assess the economic impacts in California, as outlined in the following subsections. This analysis focuses on the production of RNG for use as a transportation fuel; which includes upgrading and conditioning the fuel for injection into the common carrier pipeline. ICF notes that RNG does not have to be injected into the pipeline, and there are cases where the fuel is used on-site. There are also cases where the RNG is trucked from the production facility to the end-use customer without being injected into or transported via a pipeline. However, this report considers a more expanded role of RNG as a transportation fuel, which we assume will ultimately require significant volumes be injected into the pipeline for delivery to natural gas trucks in various applications around the entire state.

Low NOx Truck Deployment

ICF developed multiple scenarios to illustrate the impacts of low NOx RNG truck deployment in California, linked to two sources:

- **Port Truck Scenario.** ICF was provided a low NOx RNG truck deployment scenario at the San Pedro Bay Ports, courtesy of the California Natural Gas Vehicle Coalition (CNGVC).[9]
- **Statewide Scenarios**. ICF reviewed the truck populations and corresponding fuel consumption of the mobile source strategy that CARB developed for the State Implementation Plan (SIP).[10] More

[7] Methane has a global warming potential 25 times higher than carbon dioxide on a 100-year time scale.

[8] CARB, Short-Lived Climate Pollutant Reduction Strategy, March 2017. Available online: https://www.arb.ca.gov/cc/shortlived/meetings/03142017/final_slcp_report.pdf

[9] Advanced Clean Trucks (ACT) Now Plan, A Plan for Near-term Clean Air, Economic Investment and Job Creation, and Increased Port Competitiveness, available online: http://cngvc.org/wp/wp-content/uploads/2017/02/ACT-Now-Plan-FINAL_02-17-2017.pdf

[10] CARB, Mobile Source Strategy, May 2016. Available online at: https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf.

specifically, ICF retrieved the truck populations by vehicle class (linked to EMFAC) from the VISION modeling.[11] In that analysis, low NOx trucks are deployed in 32 different vehicle classes, using gasoline, diesel, and natural gas—about 900,000 trucks in total, consuming about 3.34 billion diesel gallon equivalents (DGE) of fuel in 2030. Of these low NOx trucks, about 4.5 percent are identified as natural gas trucks, consuming an equivalent percentage of total fuel (on an energy equivalent basis). ICF worked with stakeholders to identify the vehicle classes for which natural gas vehicles could capture a larger share of the truck market. This subset of truck classes totals about 690,000 trucks and 2.73 billion DGE by 2030. ICF developed scenarios in which low NOx natural gas trucks accounted for 25 percent, 50 percent, and 75 percent of this market.

ICF also estimated the new natural gas fueling infrastructure that would be required to support the expansion of the natural gas truck market. We assumed that the average station would manage a throughput of about 1—1.5 million DGE of fuel annually, with that number increasing with the market to account for saturation of stations and the potential for larger capacity stations to come online. ICF estimates that 130 new fueling stations and between 500—1,500 stations would be required in the Port Truck Scenario and each of the Statewide Low NOx Truck Scenarios, respectively. Consider, by contrast, that as of 2015 there were more than 4,000 retail diesel outlets in California selling about 1.6 billion gallons of diesel fuel; these include stations that have only 1—2 diesel pumps and are not necessarily dedicated diesel retail fueling outlets. It also does not account for non-retail outlets (which dispense an additional 1.2 billion gallons of diesel fuel according to the Board of Equalization's (BOE) taxable sales estimates).

Table below summarizes the number of low NOx natural gas trucks deployed in each of the scenarios considered, the fuel consumption (in units of million DGE, MDGE), and additional fueling stations required.

Table 2. Low NOx Natural Gas Truck Deployment Scenarios

Truck Deployment Scenario		Statewide Market Share of Low NOx Trucks	No. of Trucks	Fuel Consumption	Additional CNG Fueling Stations
Port Truck Scenario		n/a	17,000	174 MDGE	130
Statewide Truck Scenarios	Low	25%	172,000	680 MDGE	512
	Medium	50%	344,000	1,365 MDGE	1,023
	High	75%	516,000	2,047 MDGE	1,535

RNG Production in California

RNG is produced over a series of steps depending on the type of organic waste being processed. At landfills and wastewater treatment facilities, the raw biogas must be collected and purified for pipeline injection or on-site transportation fuel use. Food, yard, construction, and wood waste must be collected and separated from recyclables and other parts of the urban waste stream, delivered to an anaerobic

[11] *Ibid*.

digestion or gasification facility,[12] then purified and compressed for on-site fueling or injection into the pipeline for transmission and delivery to a dedicated end-use customer. Dairy, agricultural, and forest waste must also be collected and converted to biogas through anaerobic digestion or gasification and then either purified or converted to biomethane for use on-site or injection into the pipeline. There are several studies that have assessed the availability of in-state, renewable waste streams and feedstock resources that can be developed to produce RNG. These studies typically consider RNG production from feedstocks such as landfill gas (LFG), wastewater treatment plants (WWTPs), municipal solid waste (MSW), animal manure (e.g., from dairies), agricultural residues, and forestry and forestry product residues. Table 3 below summarizes the RNG production potential from various feedstocks (shown in units of MDGE) from multiple studies, including work by the University of California, Davis,[13] the American Gas Foundation (AGF),[14] and the Department of Energy's Billion Ton Study (DOE BT).[15]

[12] Biomass-to-gas conversion takes place via anaerobic digestion or thermal gasification. Anaerobic digestion is the process whereby microorganisms break down organic material in an environment without oxygen, and the gaseous products of that process contain a large fraction of methane and carbon dioxide. Thermal gasification describes a broad range of processes whereby carbon-containing feedstocks are converted into a mixture of gases referred to as synthetic gas or syngas. The process occurs at high temperatures (650—1,350 °C) and varying pressures.

[13] An Assessment of Biomass Resources in California, 2013 DRAFT for the California Energy Commission under Contract 500-11-020, March 2015. Available online: http://biomass.ucdavis.edu/files/2015/04/CA_Biomass_Resource_2013Data_CBC_Task3_DRAFT.pdf. Additional information from Decarbonizing the Gas Sector: Why California Needs a Renewable Gas Standard, Bioenergy Association of California, November 2014. Available online: http://www.bioenergyca.org/wp-content/uploads/2015/03/BAC_RenewableGasStandard_2015.pdf

[14] American Gas Foundation (AGF), The Potential for Renewable Natural Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality (September 2011).

[15] U.S. Department of Energy (DOE), Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.

Table 3. Summary of RNG Production Potential in California

<table>
<tr><th rowspan="3">Feedstock</th><th colspan="5">RNG Production Potential in CA (MDGE)</th></tr>
<tr><th rowspan="2">UC Davis</th><th colspan="2">AGF[a]</th><th colspan="2">DOE BT[b, c]</th></tr>
<tr><th>low</th><th>high</th><th>low</th><th>high</th></tr>
<tr><td>Agricultural Residue</td><td>243</td><td>33</td><td>83</td><td>241</td><td>264</td></tr>
<tr><td>Animal Manure</td><td>152</td><td>68</td><td>228</td><td>18</td><td>81</td></tr>
<tr><td>Fats, Oils and Greases</td><td>50</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Forestry and Forest Product Residue</td><td>635[d]</td><td>38</td><td>96</td><td>72</td><td>118</td></tr>
<tr><td>Landfill Gas</td><td>409</td><td>223</td><td>446</td><td>n/a</td><td>n/a</td></tr>
<tr><td>MSW, food, leaves, grass</td><td>95</td><td rowspan="2">61</td><td rowspan="2">183</td><td>95</td><td>111</td></tr>
<tr><td>MSW, lignocellulosic</td><td>313</td><td>81</td><td>139</td></tr>
<tr><td>WWT Gas</td><td>59</td><td>0.3</td><td>0.8</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Total Potential</td><td>1,956</td><td colspan="2">424—1,306</td><td colspan="2">507—712</td></tr>
</table>

a. The low and high values in the AGF study represent what the study refers to as *non-aggressive* and *aggressive* scenarios. The low/non-aggressive scenario assumes roughly 5-25% (depending on resource) of biomass is processed into RNG. The high/aggressive scenario assumes 15-75% (depending on resource) of biomass is processed into RNG.
b. The DOE BT study did not estimate yields of biogas. The focus of the study is on the *feedstock* rather than the *finished fuel*. ICF used conversion efficiencies from the UC Davis work to estimate the tBtu of finished fuel (in this case, biogas) based on the feedstock potential reported in the DOE BT study.
c. The low and high values from the DOE BT study represent the available feedstock assuming a price of $40/ton in 2015 and a price of $80/ton in 2030.
d. It is highly likely that this estimate is considerably lower than what might be available today. This estimate was developed prior to California's current Tree Mortality Crisis. Consider, for instance, that in November 2016 the US Forest Service confirmed that the number of dead trees in California since 2010 now exceeds 100 million.

ICF also considered pathways outlined via the SLCP Strategy prepared by CARB; although the SLCP Strategy is not explicitly a resource assessment, it provides a useful overview of various paths forward for RNG production in California. For instance, the strategy document outlines pathways for the anaerobic digestion of dairy manure and municipal solid waste:

- For dairy manure, the SLCP Strategy envisions two pathways: de-centralized or centralized production of RNG. In the former, it is assumed that around 540 dairies install digesters on-site for RNG production and subsequent pipeline injection. In the latter, it is assumed that the feedstock (i.e., manure) from the same 540 dairies is transported to 55 centralized RNG production facilities (referred to as clusters) in the state, where it is subsequently conditioned for and injected into the nearest common carrier pipeline.
- For MSW, the SLCP Strategy outlines a strategy to divert 4.7 million wet tons annually of organic waste to 47 new facilities (processing 100,000 tons per year at each facility).

Given the many opportunities for in-state RNG production, ICF worked with the project team to develop an illustrative in-state RNG production profile that reconciles total production potential with what is likely to actually be produced, based on consideration of factors such as criteria for developer interest, including the ability to obtain project financing. The project team agreed upon an illustrative scenario whereby RNG was produced in California from 50 landfills, 100 wastewater treatment plants, and 200 dairies. It is important to emphasize that this scenario is illustrative and not intended to be a definitive portfolio of RNG projects in California. ICF also modeled three scenarios from the SLCP Strategy document: RNG production from centralized manure management at dairies, decentralized manure management at dairies, and the anaerobic digestion of the organic fraction of MSW at new facilities.[16]

Lastly, ICF notes that the next generation of RNG production facilities will likely focus on thermal gasification of biomass e.g., agricultural residue or forestry and forest product residues. While these feedstocks account for a significant portion of the long-term potential for RNG production in California, they are not explicitly considered in the illustrative in-state RNG production profile nor the scenarios taken from SLCP Strategy. There remains considerable uncertainty surrounding the deployment timeline of thermal gasification facilities designed to produce synthetic gas suitable for upgrading to vehicle fuel. There are several smaller thermal gasification projects deployed in California, typically for use in electricity generation or combined heat and power applications. The California Energy Commission and Placer County have supported a successful demonstration project to gasify forest waste, and then converted the raw biogas to transportation fuel.[17] However, there are not currently any thermal gasification facilities that are dedicated to producing RNG as a transportation fuel. For illustrative purposes, ICF considered the economic impacts of deploying one thermal gasification facility capable of processing 1,000 tons per day (tpd) of biomass.

Table 4 below summarizes the RNG production profiles considered in the economic analysis. The far right column includes the maximum potential for each feedstock, based on the studies reviewed previously in Table 3.

Table 4. Scenarios Considered for RNG Produced in California

Scenarios	Feedstock & Description	No. of Digesters	RNG Produced	RNG Potential, Maximum
Illustrative In-State RNG Production Profile	Landfill Gas	50	224 MDGE	446 MDGE
	Wastewater Treatment Plants	100	248 MDGE	467 MDGE
	Dairies	23	54 MDGE	228 MDGE
SLCP Strategy	Dairies, Centralized Manure Management	55	110 MDGE	228 MDGE
	Dairies, Decentralized Manure Management	543		228 MDGE
	MSW, Organic Fraction	47	147 MDGE	408 MDGE
Thermal Gasification	Illustrative, 1,000 tpd processing capacity	1	19 MDGE	878 MDGE

[16] These scenarios are not included in this report.

[17] California Energy Commission, Grant Agreement Number ARV-10-023. More information available online at http://www.energy.ca.gov/drive/projects/ARV-10-023.html

II. Economic Modeling Methodology

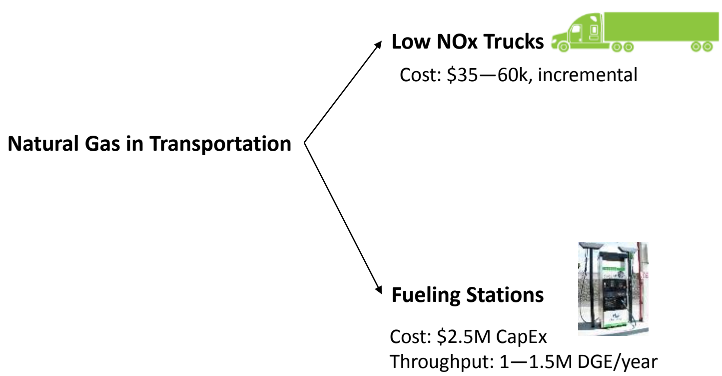
IMPLAN Model Overview

In this analysis, the economic impacts were calculated using the IMPLAN[18] (IMpact analysis for PLANning), Version 3.0 input-output model. IMPLAN is developed and maintained by the Minnesota IMPLAN Group. The IMPLAN model is a static input-output framework used to analyze the effects of an economic stimulus on a pre-specified economic region; in this case, the State of California. IMPLAN is considered static because the impacts calculated by any scenario by the model estimate the indirect and induced impacts for one time period (typically on an annual basis). More information is available in the Appendix regarding the IMPLAN model.

Modeling Inputs

ICF considered the following cost elements associated with the deployment of low NOx natural gas trucks and in-state RNG production, as show in Figure 1 and Figure 2 below. In the case of natural gas, we included the incremental costs of purchasing a low NOx NG truck relative to a conventional diesel truck, ranging from $35,000—60,000 per truck. We also accounted for the capital expenditures required to deploy compressed and liquefied natural gas fueling stations with a throughput of 1—1.5 million DGE annually and a cost of $2.5 million.

Figure 1. Natural Gas: Truck and Fueling Station Investments Considered



In the case of RNG production, we accounted for the multiple expenditures including digester equipment, biogas conditioning equipment, miscellaneous support equipment, and construction/engineering costs; as well as pipeline for utility interconnection. In the case of dairy digesters, we also estimated the capital expenditures associated with scrape conversion, a mitigation measure identified in the SLCP Strategy document. Scrape conversion is a dairy manure management strategy, yielding lower methane emissions than the most common practice today, which is lagoon storage of flushed manure. CARB reports the cost for conversion at $350 per milking head.

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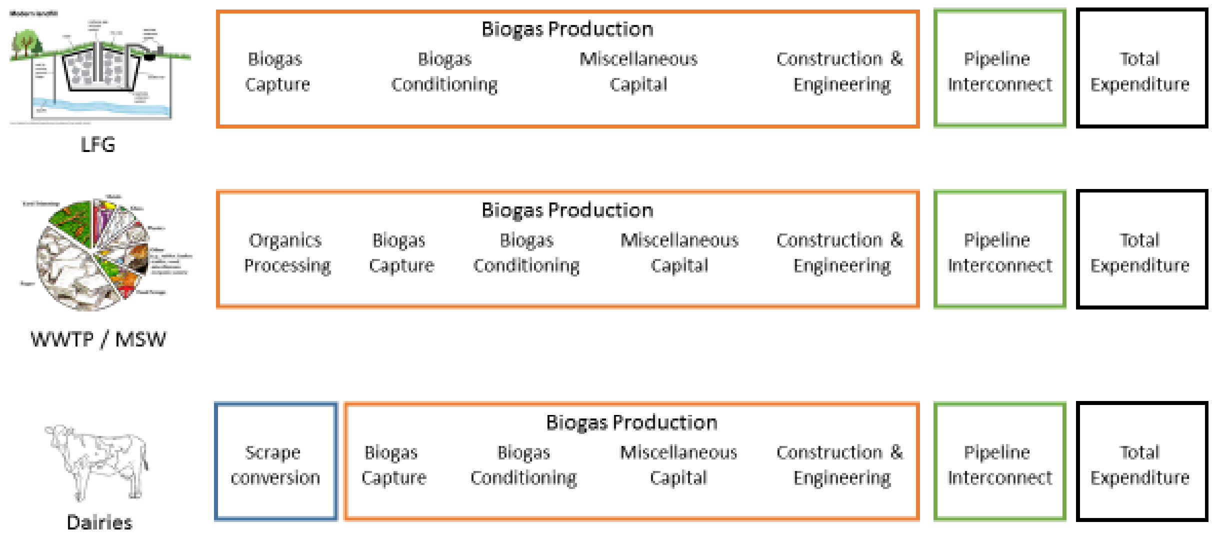
18 IMPLAN was developed by the Minnesota IMPLAN Group (MIG). There are over 1,500 active users of MIG databases and software in the United State as well as internationally. They have clients in federal and state government, universities, as well as private sector consultants. More information is available at www.implan.com.

Figure 2. In-State RNG Production Steps Considered in Analysis



In each case, we also included the annualized cost of operating and maintaining refueling stations, digester-related equipment, and pipelines.

ICF estimated the costs for each RNG pathway by developing illustrative facilities for each feedstock type (as shown in Table 5 below). For landfills, we reviewed data from the Landfill Methane Outreach Program (LMOP) and developed a profile of California landfills based on the amount of biogas captured. For wastewater treatment plants, we reviewed facility data available via the US EPA to estimate the amount of biogas throughput at each facility. Lastly, for dairy digesters, we developed a cluster-approach akin to the one developed for the SLCP Strategy, whereby dairies cluster to develop centralized manure management systems to achieve a larger biogas production scale. Table 5 below includes the assumed biogas throughput for illustrative facilities by RNG production facility type (four landfills, three wastewater treatment plants, and four dairy digesters), in units of standard cubic feet per minute (SCFM).

Table 5. Illustrative RNG Production Facilities Considered, by Feedstock Type

Feedstock Type	Illustrative Facility			
	A	B	C	D
Landfill Gas				
Throughput (SCFM)	840	1,680	2,880	4,800
Share of Facilities	35%	25%	15%	25%
WWTPs				
Throughput	525	1,167	2,917	n/a
Share of Facilities	40%	50%	10%	n/a
Dairy Digesters				
Throughput	615	910	1,035	1,320
Share of Facilities	20%	35%	40%	5%

ICF developed the modeling inputs on a modular basis, so that the results could be considered in different combinations. In order for this modular approach to apply, ICF tested and confirmed the following two hypotheses.

- First, ICF assumed that the IMPLAN model outputs would scale linearly with model inputs.
- Second, ICF assumed that the IMPLAN model outputs do not have any non-linear interactions resulting from combining truck deployment scenarios and RNG production scenarios.

ICF also considered potential negative impacts to the refinery industry. Although reducing petroleum consumption can correlate with improved energy independence, security and increased fuel diversity, decreased petroleum consumption will also have direct negative impacts on the refining industry. ICF broadly categorizes these negative impacts into two areas: 1) lost refinery margin and 2) reduced refinery margins as a result from having to export product. To estimate the impacts, ICF assumed that there were lost margins on 50 percent of those crude runs that are assumed to be displaced entirely as a result of the natural gas consumption linked to each scenario.[19] ICF assumed that the remaining 50 percent of crude runs representing the reduction in gasoline and diesel consumption in California are exported, rather than displaced entirely. For these exports, ICF assumed a corresponding decrease in revenue in the export markets because of increased freight costs and competitiveness on pricing.[20]

[19] These margins were estimated based on an ICF analysis of the 3-2-1 crack spread for California-based refiners (estimated at about $15/barrel)

[20] ICF estimates this at a cost of $5/barrel.

III. Economic Impacts of Deploying Low NOx Trucks Fueled by RNG Produced in California

The economic impacts of low NOx natural gas truck deployment and RNG production are characterized by employment, labor income, value added, and industry output impacts.

- ***Employment*** is reported in terms of annualized job-years. The employment numbers are broken down by direct, indirect, and induced. We also present an employment metric referred to as a ***jobs multiplier***, which is the sum of job-years (included direct, indirect, and induced) divided by the direct job-years. This is an indicator of the type of employment activity statewide that is generated by investment in a technology. We also present ***labor income*** and ***labor income per worker***. The latter is a coarse estimate of the value of jobs created by the corresponding investment. Lastly, we report the estimated number of jobs (not job-years) created per RNG production facility developed in California.
- **Economy-wide Impacts**. We present several metrics measuring the impacts to California's economy, including value added and industry output.
  - ***Value Added*** measures the value of goods and services and is a measure comparable to net measurements of output such as gross state product (GSP).
  - The ***output multiplier*** mirrors the ***jobs multiplier*** and represents the total industry activity (including direct, indirect, and induced) divided by the direct industry activity. This is an indicator of the type of industry activity statewide that is generated by investment in a technology.

Table 6 below summarizes the results for the combination of the various truck scenarios—port trucks and 25 percent, 50 percent, and 75 percent of the low NOx truck market—with the Illustrative California RNG Production Profile (with 50 landfills, 100 WWTPs, and 200 dairies). For the Port Truck Scenario, the Illustrative California RNG Production Profile was scaled to match the renewable natural gas required to fuel the port trucks.

Table 6. Summary of Economic Impacts: Low NOx RNG Trucks using California Produced RNG

Economic Parameter	Port Trucks	Statewide Low NOx RNG Trucks, Market Share		
		25%	50%	75%
Capital Expenditures ($Millions)	$2,703	$15,718	$27,326	$38,934
Trucks & Fueling Infrastructure	$1,348	$11,608	$23,216	$34,824
RNG Production	$1,355	$4,109		
Landfill gas	*$206*	*$625*		
WWTP	*$805*	*$2,442*		
Dairy Digesters	*$344*	*$1,042*		
Employment (job-years)				
Direct	*11,802*	*40,051*	*53,062*	*66,072*
Indirect	*4,634*	*16,723*	*22,438*	*28,153*
Induced	*7,023*	*24,207*	*32,094*	*39,980*
Total	23,459	80,981	107,594	134,206
Jobs Multiplier	1.99	2.02	2.03	2.03
Labor Income ($M)	$1,618	$5,574	$7,387	$9,201
Income per Worker	$68,960	$68,830	$68,660	$68,560
Jobs/Digester	26	26		
Statewide Activity				
Total Value Added ($M)	$2,512	$8,657	$11,483	$14,308
Output Multiplier	1.83	1.82	1.81	1.80
The values are shown as cumulative over the analysis period (2018-2030). ICF notes that by reporting these numbers cumulatively, we may be double-counting jobs. Consider, for instance, a single job created for years 2026—2030 as a result of economic activity modeled in the analysis. That single job will yield 5 job-years, one for each year in the analysis.				

It is difficult to compare job creation across industries, especially without knowing in explicit detail the input parameters and boundary conditions applied in other studies utilizing input-output models. For instance, one study notes that there are 188,500 direct jobs and 468,000 total jobs linked to the oil and gas industry.[21] The 18 petroleum refineries accounted for 12,760 direct jobs or about 710 jobs per facility. A study of the liquid biofuel industry estimate about 300 jobs per ethanol facility producing 50

[21] Oil and Gas in California: The Industry and Its Economic Contribution in 2012, LAEDC, April 2014, http://laedc.org/wp-content/uploads/2014/04/OG_Contribution_20140418.pdf

million gallons per year and 267 jobs per biodiesel facility producing 30 million gallons per year.[22] By comparison, the 26 jobs per RNG production facility in California may seem modest to these more established industries. However, when normalizing for the size of these production facilities, RNG production in California compares more favorably:

- California RNG production facilities would generate about 8.5—11.2 jobs per MDGE of transportation fuel.
- The petroleum refinery industry yields about 1.6 jobs per MDGE of transportation fuel.
- The ethanol and biodiesel industries yield about 9.8 and 9.9 jobs per MDGE of transportation fuel, respectively.

Despite the differences in potential and nuances associated with RNG production in California from various feedstocks, our modeling results suggest that there are only modest differences with regard to economic impacts. Similarly, deploying more low NOx trucks and supporting fueling infrastructure increases the economic activity, by increasing spending. However, this spending has little impact on parameters such as income per worker and output multiplier.

The estimated income per worker (a proxy for salary) compares favorably with California's median household income and median individual's earnings, as reported in 2015 by the American Community Survey at $61,820 and $31,300, respectively.[23] For every job that is created via investment in natural gas trucks, fueling infrastructure, and in-state RNG production, our results indicate another two jobs will be created in supporting industries (indirect) and via spending by employees that are either directly or indirectly supported by these industries (induced).

The economic multipliers for natural gas trucks and RNG production in California—around 2.0 and 1.8 for the employment multiplier and the output multiplier, respectively—compare favorably with other industries. For instance, in a previous study, ICF reviewed the economic potential of innovative crude production technologies[24]—solar steam generation and solar photovoltaics deployed at oil fields—and we reported output multipliers in the range of 1.53—1.74 and a jobs multiplier of 2.56—2.73. A study by the Los Angeles Economic Development Council on the oil and gas industry in California[25] indicates an output multiplier of 1.19 and a jobs multiplier of 2.48.

[22] Farming Fuel, Ethanol and Biodiesel Impacts in Missouri, 2007. Available online https://www.missourieconomy.org/pdfs/farming_fuel_brochure.pdf

[23] U.S. Census Bureau, 2011-2015 American Community Survey 5-Year Estimates.

[24] The Impact of Solar Power Oil Production on California's Economy, ICF, 2015. Available online: https://www.icf.com/perspectives/reports/2015/solar-powered-oil-production-california-economy

[25] Oil and Gas in California: The Industry and Its Economic Contribution in 2012, LAEDC, April 2014, http://laedc.org/wp-content/uploads/2014/04/OG_Contribution_20140418.pdf

Summary of Economic Contributions

Direct: Impacts of capital expenditures to deploy low NOx trucks and produce RNG and the employees hired by the corresponding industries.

Indirect: Impacts that stem from the employment and business revenues motivated by the purchases made by the industry and any of its suppliers.

Induced: Impacts generated by the spending of employees whose wages are sustained by both direct and indirect spending.

ICF also developed a scenario that pushed the upper limit of RNG production in California (as shown in the previous table), with an in-state production volume of around 1,900 million DGE. ICF increased the production potential of each RNG feedstock and introduced 46 thermal gasification facilities capable of processing agricultural residues and forestry residues. This RNG production scenario is paired with the upper limit of the truck deployment scenario, which reaches 75 percent of the low NOx truck market by 2030. Table 7 below summarizes these results.

Table 7. Economic Impacts of Aggressive Low NOx Trucks fueled by California RNG

75% Market Share + Max In-State RNG Production			
Capital Expenditures ($Millions)	$43,163	Employment	233,892
Trucks & Fueling Infrastructure	$34,824	*Direct*	*112,718*
RNG Production		*Indirect*	*52,139*
Landfill gas	*$1,250*	*Induced*	*69,035*
MSW / WWTP	*$4,273*	Jobs Multiplier	2.08
Dairy Digesters	*$2,815*	Labor Income ($M)	$15,893
Thermal Gasification	*$10,388*	Income per Worker	$67,950
		Jobs/Digester	34
Statewide Activity			
Total Value Added ($M)	$24,618		
Output Multiplier	1.84		

The IMPLAN model includes more than 500 industry sectors; Table 8 below highlights the sectors that experienced the highest employment impacts in all scenarios. These sectors have been grouped broadly into three categories: trucks and fueling infrastructure, RNG production facilities, and indirect and induced sectors. As noted previously, the indirect and induced sectors are those that are impacted by direct investments in the deployment of low NOx natural gas trucks fueled by RNG produced in California.

Table 8. Industry Sectors with Highest Increased Employment

Economic Grouping	IMPLAN Sectors
Trucks & Fueling Infrastructure	• Construction • Metal tank manufacturing • Vehicle parts manufacturing • Heavy-duty truck manufacturing
RNG Production Facilities	• Repair & maintenance of commercial equipment • Construction • Waste management • Metal tank manufacturing • Architectural and engineering services • Environmental and technical consulting services • Truck transportation
Indirect & Induced Sectors	• Wholesale trade • Real estate • Restaurants • Building services and management services • Accounting services • Hospitals

Our economic modeling results provide quantitative insights into the potential for low NOx trucks powered by RNG produced in California. However, it is important to understand how this opportunity fits into a broader context related to economic growth and alternative transportation fuel production and consumption. Most importantly, there are few comparable opportunities to develop a robust alternative transportation fuel production industry in California like the one outlined in this analysis. There are a handful of ethanol production facilities in California, with the potential to expand incrementally their existing production capacity. And efforts to build a new facility have been planned for nearly a decade without breaking ground.[26] The biodiesel industry produces about 40 million gallons at 9 facilities in California, with modest expansion plans.[27] Renewable diesel is imported to California from locations as far afield as Singapore and Louisiana; there is at least one company pursuing production of renewable diesel from waste grease in California, with a capacity of 30 million gallons per year.[28] By comparison, low NOx trucks powered by California-produced RNG have the potential to stand-up an industry capable of producing and consuming upwards of 1 billion diesel gallon equivalents annually.

[26] The California Ethanol and Power, LLC was reportedly in the permitting stage of building a sugarcane ethanol plant in Imperial County in 2008; http://www.californiaethanolpower.com/media/managed/newspdfs/Ethanol_from_sugar_cane_in_Valley_IV_Press_1.pdf.

[27] Based on information provided by the California Biodiesel Alliance, http://www.californiabiodieselalliance.org/.

[28] UrbanX Renewables reports that they are hoping to produce renewable diesel fuel in the 4th quarter of 2017.

Appendix

Background on Low NOx Natural Gas Truck Deployment

EMFAC vehicle classes in which low NOx natural gas trucks were deployed.

EMFAC Vehicle Class	EMFAC Description	%Fuel
T6 Public	Medium-Heavy Duty Public Fleet Truck	0.4%
T6 CAIRP Small	Medium-Heavy Duty CA International Registration Plan Truck (GVWR<=26000 lbs)	0.2%
T6 CAIRP Heavy	Medium-Heavy Duty CA International Registration Plan Truck (GVWR>26000 lbs)	0.1%
T6 Instate Small	Medium-Heavy Duty instate Truck (GVWR<=26000 lbs)	10.9%
T6 Instate Heavy	Medium-Heavy Duty instate Truck (GVWR>26000 lbs)	4.4%
T6TS	Medium-Heavy Duty Truck (Gasoline)	2.6%
T6 OOS Small	Medium-Heavy Duty Out-of-state Truck (GVWR<=26000 lbs)	0.1%
T6 OOS Heavy	Medium-Heavy Duty Out-of-state Truck (GVWR>26000 lbs)	0.0%
T6 Utility	Medium-Heavy Duty Utility Fleet Truck	0.1%
T7IS	Heavy-Heavy Duty Truck (Gasoline)	0.5%
T7 Public	Heavy-Heavy Duty Public Fleet Truck	0.9%
T7 CAIRP	Heavy-Heavy Duty CA International Registration Plan Truck	12.8%
T7 Utility	Heavy-Heavy Duty Utility Fleet Truck	0.1%
T7 NNOOS	Heavy-Heavy Duty Non-Neighboring Out-of-state Truck	15.1%
T7 NOOS	Heavy-Heavy Duty Neighboring Out-of-state Truck	5.2%
T7 Other Port	Heavy-Heavy Duty Drayage Truck at Other Facilities	0.4%
T7 POAK	Heavy-Heavy Duty Drayage Truck in Bay Area	0.9%
T7 POLA	Heavy-Heavy Duty Drayage Truck near South Coast	6.0%
T7 Single	Heavy-Heavy Duty Single Unit Truck	4.5%
T7 Tractor	Heavy-Heavy Duty Tractor Truck	13.6%
T7 SWCV	Heavy-Heavy Duty Solid Waste Collection Truck	0.9%
T7 SWCVng	Heavy-Heavy Duty Solid Waste Collection Truck	1.4%

IMPLAN Model Description

In this analysis, the economic impacts were calculated using the IMPLAN[29] (IMpact analysis for PLANning), Version 3.0 input-output model. IMPLAN is developed and maintained by the Minnesota IMPLAN Group. The IMPLAN model is a static input-output framework used to analyze the effects of an economic stimulus on a pre-specified economic region; in this case, the State of California. IMPLAN is considered static because the impacts calculated by any scenario by the model estimate the indirect and induced impacts for one time period (typically on an annual basis).

The modeling framework in IMPLAN consists of two components–the descriptive model and the predictive model.

- The **descriptive model** defines the local economy in the specified modeling region, and includes accounting tables that trace the "flow of dollars from purchasers to producers within the region".[30] It also includes the trade flows that describe the movement of goods and services, both within, and outside of the modeling region (i.e., regional exports and imports with the outside world). In addition, it includes the Social Accounting Matrices (SAM) that trace the flow of money between institutions, such as transfer payments from governments to businesses and households, and taxes paid by households and businesses to governments.
- The **predictive model** consists of a set of "local-level multipliers" that can then be used to analyze the changes in final demand and their ripple effects throughout the local economy. IMPLAN Version 3.0 uses 2008 data and improves on previous versions of model by implementing a new method for estimating regional imports and exports - a trade model. This new method of estimating imports looks at annual trade flow information between economic regions; thereby allowing more sophisticated estimation of imports and exports than the traditional econometric RPC estimate used by the previous, Version 2. Additionally, this new modeling method allows for multi-regional modeling functions, in which IMPLAN tracks imports and exports between selected models allowing the users to assess how the impact in one region can impact additional regional economies.

The IMPLAN model is based on the input-output data from the U.S. National Income and Product Accounts (NIPA) from the Bureau of Economic Analysis. The model includes 440 sectors based on the North American Industry Classification System (NAICS). The model uses region-specific multipliers to trace and calculate the flow of dollars from the industries that originate the impact to supplier industries. These multipliers are thus coefficients that "describe the response of the economy to a stimulus (a change in demand or production)."[31] Three types of multipliers are used in IMPLAN:

- Direct–represents the impacts (e.g., employment or output changes) due to the investments that result in final demand changes, such as investments needed to deploy trucks and fueling infrastructure or install RNG production facilities.

[29] IMPLAN was developed by the Minnesota IMPLAN Group (MIG). There are over 1,500 active users of MIG databases and software in the United State as well as internationally. They have clients in federal and state government, universities, as well as private sector consultants. More information is available at www.implan.com.

[30] IMPLAN Pro Version 2.0 User Guide.

[31] Ibid.

- Indirect–represents the impacts due to the industry inter-linkages caused by the iteration of industries purchasing from industries, brought about by the changes in final demands.
- Induced–represents the impacts on all local industries due to consumers' consumption expenditures arising from the new household incomes that are generated by the direct and indirect effects of the final demand changes.

The total impact is simply the sum of the multiple rounds of secondary indirect and induced impacts that remain in California (as opposed to "leaking out" to other areas). IMPLAN then uses this total impact to calculate subsequent impacts such as total jobs created and tax impacts. This methodology, and the software used, is consistent with similar studies conducted across the nation.

Inputs and Model Parameters

The direct economic impacts presented in the report are based on the investments required to deploy low NOx natural gas trucks and RNG production in California. ICF modeled the impacts over the period 2018—2030.

Output

Whenever new industry activity or income is injected into an economy, it starts a ripple effect that creates a total economic impact that is much larger than the initial input. This is because the recipients of the new income spend some percentage of it and the recipients of that share, in turn, spend some of it, and so on. The *total spending impact* of the new activity/income is the sum of these progressively smaller rounds of spending within the economy. This total economic impact creates a certain level of value added (GSP), jobs, called the *total employment impact*, and also tax revenue for state and local governments.

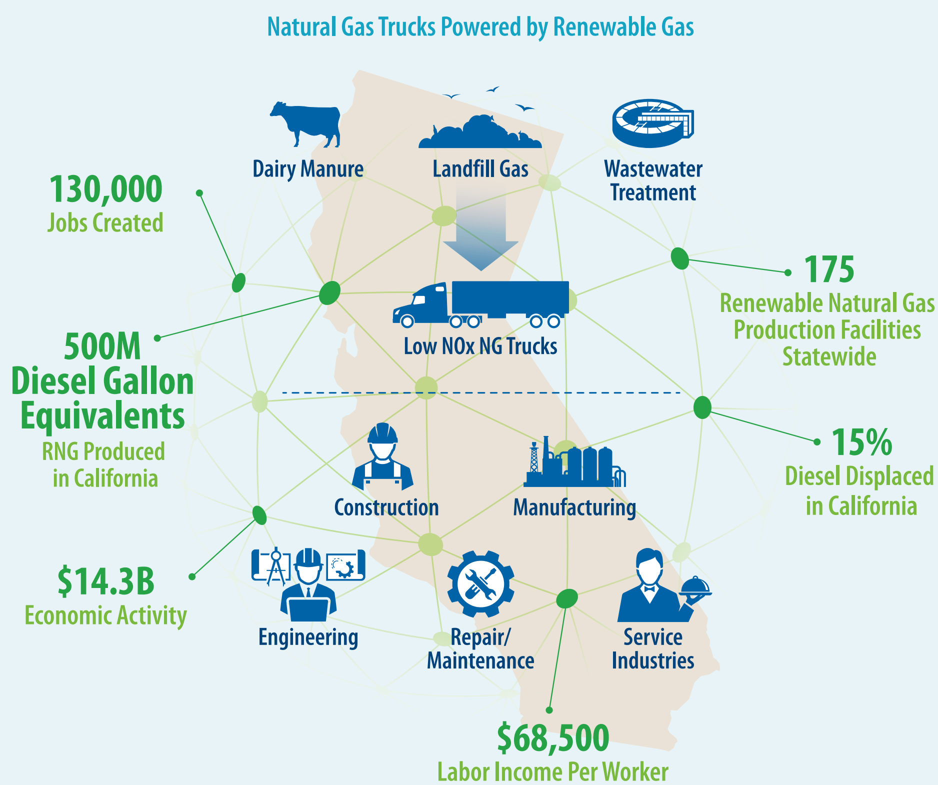
Due to the static nature of the IMPLAN model, the employment impacts must be presented in terms of annual job-years as the model calculates the annual impact of an annual investment. It is likely that once the job is created, it will be sustained, however to ensure that the impact is not overstated; it is conservatively assumed that the job impact is annual. The annualized GSP and tax impacts can be accrued over the program's duration to identify the total impact of the investments in low NOx trucks powered by California produced RNG. These dollar values represent the investments that were placed into the economy each year aggregated over time.

List of Abbreviations and Acronyms

CARB	California Air Resources Board
CNG	Compressed natural gas
CNGVC	California Natural Gas Vehicle Coalition
DGE	Diesel Gallon Equivalent
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
I-O Model	Input-Output Model
LCFS	Low Carbon Fuel Standard
LFG	Landfill Gas
MIG	Minnesota IMPLAN Group
MSW	Municipal Solid Waste
NAICS	North American Industry Classification System
NOx	Oxides of nitrogen, a criteria air pollutant
RNG	Renewable natural gas
SCAQMD	South Coast Air Quality Management District
SCFM	standard cubic feet per minute
SIP	State Implementation Plan
SLCP	Short Lived Climate Pollutant
WWTP	Wastewater Treatment Plant

Low NOx Engines and Renewable Natural Gas Fuel the Economy

Renewable natural gas (RNG) produced in California and used in heavy duty trucks outfitted with low NOx engines can **drive economic growth and create jobs while helping achieve environmental goals**.



A new report by ICF finds that low NOx trucks fueled by renewable natural gas produced in California will drive economic growth in multiple market segments, help create jobs with competitive salaries, and make significant contributions to California's economy.

- Dedicated investments in deploying low NOx trucks powered by renewable natural gas could **create up to 134,000 jobs**, and provide up to **$14 billion of added economic value** by 2030.
- The ICF report considered a Port Truck Scenario and several Statewide Truck Scenarios, deploying 17,000 and 172,000—516,000 low NOx trucks fueled by RNG, respectively.
- By taking advantage of waste streams—from landfills, wastewater treatment plants, and dairies—ICF estimates that a modest investment scenario could yield more than **500 million diesel gallon equivalents** of renewable natural gas produced at **175 facilities around the state** (which is just a fraction of the in-state production potential for RNG). That is enough renewable natural gas to **displace 15% of the petroleum-based diesel fuel** consumed in California.
- ICF finds that the sectors experiencing the highest job creation include construction, manufacturing, repair and maintenance of equipment, engineering services, environmental consulting services, and service industries (e.g., restaurants, accounting services, etc.).
- ICF reports that the average labor income per job created is about **$68,500—more than twice the median salary of California's current workers**.

California Natural Gas Vehicle Coalition
cngvc.org

THE COALITION FOR RENEWABLE NATURAL GAS
www.rngcoalition.com