AB 32 Scoping Plan

This page last reviewed January 8, 2018

In 2006, the Legislature passed the California Global Warming Solutions Act of 2006 [Assembly Bill 32 (AB 32)], which created a comprehensive, multi-year program to reduce greenhouse gas (GHG) emissions in California. AB 32 required the California Air Resources Board (ARB or Board) to develop a Scoping Plan that describes the approach California will take to reduce GHGs to achieve the goal of reducing emissions to 1990 levels by 2020. The Scoping Plan was first approved by the Board in 2008 and must be updated every five years. The First Update to the Climate Change Scoping Plan was approved by the Board on May 22, 2014. In 2016, the Legislature passed SB 32, which codifies a 2030 GHG emissions reduction target of 40 percent below 1990 levels. With SB 32, the Legislature passed companion legislation AB 197, which provides additional direction for developing the Scoping Plan. ARB is moving forward with a second update to the Scoping Plan to reflect the 2030 target set by Executive Order B-30-15 and codified by SB 32.

Scoping Plan Update

2030 GHG Reduction Target

- Senate Bill 32
- Executive Order B-30-15
- FAQs

Final 2017 Scoping Plan Update: The Strategy for Achieving California's 2030 GHG Target

- Executive Summary New!
- Final 2017 Scoping Plan New! (full plan)
- Appendices and Modeling Information
- Resolution 17-46

Schedule

- **January 27, 2017 - First Public Board Meeting on the Proposed Scoping Plan**
- **February 16-17, 2017 - Second Public Board Meeting on the Proposed Scoping Plan**
- **December 14, 2017 - Third Public Board Meeting on the Proposed Scoping Plan**
- Click here to see the timeline of the Scoping Plan development.
- View All Public Workshops

Resources

- News Release
- View All Previous Public Comments
- Environmental Justice Advisory Committee
- Stay in touch, sign up for the climate change listserve to receive email updates.

Archived: 2013 Scoping Plan

- Resolution 14-16 (posted June 10, 2014)
- First Update to the Climate Change Scoping Plan (posted May 15, 2014)

Governor's Climate Change Pillars Symposia

- Archived Public Meetings

Scoping Plan Update to Reflect 2030 Target

On April 29, 2015, the Governor issued Executive Order B-30-15 establishing a mid-term GHG reduction target for California of 40 percent below 1990 levels by 2030. All state agencies with jurisdiction over sources of GHG emissions were directed to implement measures to achieve reductions of GHG emissions to meet the 2030 and 2050 targets. ARB was directed to update the AB 32 Scoping Plan to reflect the 2030 target, and therefore, is moving forward with the update process. The mid-term target is critical to help frame the suite of policy measures, regulations, planning efforts, and investments in clean technologies and infrastructure needed to continue driving down emissions.

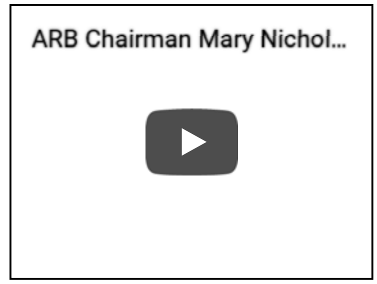
What is the status of AB 32 implementation?

The California Global Warming Solutions Act of 2006 (AB 32) has been implemented effectively with a suite of complementary strategies that serve as a model going forward. California is on target for meeting the 2020 GHG emission reduction goal. Many of the GHG reduction measures (e.g., Low Carbon Fuel Standard, Advanced Clean Car standards, and Cap-and-Trade) have been adopted over the last five years and implementation activities are ongoing. California is getting real reductions to put us on track for reducing GHG emissions to achieve the AB 32 goal of getting back to 1990 levels by 2020.

Video: AB 32 Now and in the Future

Background

First Update to the Climate Change Scoping Plan (2013 - 2014)



The 2013 Scoping Plan Update (2013 Update) builds upon the initial Scoping Plan with new strategies and recommendations. The 2013 Update identifies opportunities to leverage existing and new funds to further drive GHG emission reductions through strategic planning and targeted low carbon investments. The 2013 Update defines ARBâ€™s climate change priorities for the next five years and sets the groundwork to reach California's long-term climate goals set forth in Executive Orders S-3-05 and B-16-2012. The 2013 Update highlights Californiaâ€™s progress toward meeting the near-term 2020 GHG emission reduction goals defined in the initial Scoping Plan. These efforts put California on course to achieve the near-term 2020 goal, and have created a framework for ongoing climate action that can be built upon to maintain and continue economic sector-specific reductions beyond 2020, as required by AB 32.

In this 2013 Update, nine key focus areas were identified (energy, transportation, agriculture, water, waste management, and natural and working lands), along with short-lived climate pollutants, green buildings, and the cap-and-trade program.

These key focus areas have overlapping and complementary interests that will require careful coordination in Californiaâ€™s future climate and energy policies. These focus areas were selected to address issues that underlie multiple sectors of the economy. As such, each focus area is not contained to a single economic sector, but has far-reaching impacts within many economic sectors.

In June 2013, ARB held a kickoff public workshop in Sacramento to discuss the development of the 2013 Update, public process, and overall schedule. In July 2013, subsequent regional workshops were held in Diamond Bar; Fresno; and the Bay Area, which provided forums to discuss region-specific issues, concerns, and priorities. In addition, ARB accepted and considered informal stakeholder comments from June 13, 2013 through August 5, 2013. ARB also reconvened the Environmental Justice Advisory Committee to advise, and provide recommendations on the development of, this Update. On October 1, 2013, ARB released a discussion draft of the 2013 Update to the AB 32 Scoping Plan for public review and comment.   On October 15, 2013, ARB held a public workshop and provided an update to the Board at the October 24, 2013 Board Hearing. Extensive public comment and input was received at the October Board Hearing. In addition, over 115 comment letters were submitted on the discussion draft.

On February 10, 2014, ARB released the draft proposed first update. On February 20, 2014, ARB held a Board meeting discussion that included opportunities for stakeholder feedback and public comment. On March 14, 2014, ARB released the Appendix F - Environmental Analysis including the 45-day review public notice, Appendix B - Status of Scoping Plan Measures, and Appendix C - Focus Group Working Papers. On May 15, 2014, ARB released the First Update to the Climate Change Scoping Plan, staffâ€™s written responses to comments received on the Draft EA and the Final EA. On May 22, 2014, the First Update to the Climate Change Scoping Plan was approved by the Board, along with the finalized environmental documents.

Initial Scoping Plan (2007 - 2008)

The initial AB 32 Scoping Plan contains the main strategies California will use to reduce the greenhouse gases (GHG) that cause climate change. The initial Scoping Plan has a range of GHG reduction actions which include direct regulations, alternative compliance mechanisms, monetary and non-monetary incentives, voluntary actions, market-based mechanisms such as a cap-and-trade system, and an AB 32 program implementation fee regulation to fund the program. Those initial measures were introduced through four workshops between November 30, 2007 and April 17, 2008. A draft scoping plan was released for public review and comment on June 26, 2008 followed by more workshops in July and August, 2008. The Proposed Scoping Plan was released on October 15, 2008 and considered at the Board hearing on December 12, 2008. In August 2011, the initial Scoping Plan was re-approved by the Board, and includes the Final Supplement to the Scoping Plan Functional Equivalent Document.

For questions or comments regarding the Climate Change Scoping Plan, please contact:

Stephanie Kato

Trish Johnson

Jakub Zielkiewicz

April 19, 2018

Riverside County Planning
4080 Lemon Street, 12th Floor
Riverside, CA 92501
Attention: Mr. Russell Brady

Subject: PP25837 & PP25838 Dust Control

Mr. Brady,

Due to comments received by the County of Riverside about silica dust generated during "rock crushing," I am writing to provide information that would be helpful for the public and the County to understand this issue.

First some background as I am the Senior Vice President and Development Manager for the applicant. In that position I am responsible for overseeing construction, including site preparation, demolition, and grading on this project. I have nearly 40 years of experience in the construction business, including 25 years of experience as a project manager. I have been a development manager in charge of overseeing construction for the applicant for the last 13 years. In my professional experience I have overseen numerous grading jobs, including projects involving blasting and grading procedures similar to those proposed for this project.

Since the time the FEIR was published for PP25837 and PP25838 the Applicant has confirmed its intent to avoid the use of a mechanical rock crusher due to success with in-situ rock blasting fragmenting on very nearby projects within the same geologic formation. The in-situ blasting process has been shown to adequately fragment the bedrock into pieces suitable for grading without further crushing. For pieces of anomalous rock fragments and oversize rock that does not fragment into small enough pieces (estimated at <2% of the total rock undergoing this process) those shall be resized using an excavator mounted breaker or hydraulic jaws (or similar equipment) to crack these pieces of oversize rock. Thus, the particulate air pollutants (including dust & silica dust) that would have been emitted by operation of large mechanical rock crusher will not occur. A letter prepared by Southern California Geotechnical, the geotechnical engineer of record for the proposed Project, dated April 17, 2018, confirms based on their experience working on other construction projects in the local area, and the known and studied subsurface conditions of the Project site, that it is reasonable to expect that blasting without the need for an extensive rock crushing operation may be utilized to successfully accomplish the proposed Project's grading (SoCalGeo, 2018). Further, approximately 5-feet of soil cover shall be maintained or placed over areas to be blasted to act as a "blanket" keeping the blasted rock in place as is the industry-standard. Soils and rocky areas shall be watered down before each blasting event, and routine application of water during grading operations will serve as the primary means of dust control. The presence of moistened soil cover substantially reduces the potential to generate dust (Drake, 2018). Also refer to FEIR Regulatory Requirement RR-4 (FEIR pp. S-15 and 4.3-35), which specifies the mandatory requirement to comply with SCAQMD Rule 403 "Fugitive Dust." Silica is the name given to a group of minerals composed of silicon and oxygen, the two most abundant elements in the earth's crust, thus it is a component soil and any dust derived from soil in any construction grading project. Compliance with the dust control measures required by SCAQMD Rule 403 (a Condition of Approval for the project) thus addresses this concern. Among other things, SCAQMD Rule 403 prohibits visible dust beyond the property line, and requires best available control measures including watering of disturbed areas at least three times per day, as well as prohibition of earth-moving and excavation activities when winds exceed 25 mph. Additionally, operations must meet all applicable OSHA requirements including Title 29 Code of Federal Regulation (CFR) requirements where OSHA's "Crystalline Silica Rule: Construction" is present, as well as the California Code of Regulations (CCRs), Title 8, Section 1532.3, Subchapter 4. Construction Safety Orders, Article 4. Dusts, Fumes, Mists, Vapors, and Gases, as applicable. To ensure compliance with these regulations, a grading plan containing a section specific to implementation of dust control measures will be produced and utilized during grading operations and will be made a part of the contract issued for the grading operations. Thus, impacts from silica dust generated during demolition and grading operations will be less than significant.

We therefore look forward to completing this development and building an important asset for the Community in Riverside County.

Sincerely,

David Drake
Senior Vice President
Trammell Crow Company

BUSINESS

The Inland Empire is leading California in job creation

Amazon employee Steve Morgan sorts through merchandise at a company fulfillment center in San Bernardino. FILE (John Valenzuela/Staff Photographer)

By KEVIN SMITH | kvsmith@scng.com | San Gabriel Valley Tribune
PUBLISHED: March 7, 2018 at 1:01 am | UPDATED: March 7, 2018 at 1:50 am

California is outperforming the nation in job growth, and the state's inland regions are leading the way, according to the latest UCLA Anderson Forecast.

In a turnaround from the norm, the report shows that the Inland Empire, San Joaquin Valley and Sacramento are outpacing some of California's tech-heavy regions, which traditionally see the bigger job gains. And that's not necessarily a bad thing, according to the report.

More balanced growth

"Growth is now more balanced and the diversification of employment makes the state less vulnerable to one sector imploding," the report said. "To be sure, if tech imploded as in 2001, it would be a serious blow to the state, but unlike 2001, the more balanced growth of today would focus the pain in one region rather than more generally."

California employment hit an all-time high in January with more than 16 million nonfarm payroll jobs, the forecast said. That was 9.9 percent higher than the state's pre-recession peak and 20.2 percent higher than at the depth of the last recession.

The biggest job creator

The study's charts show that the Inland Empire is the state's biggest job creator.

In December, the two-county region posted year-over-year job growth of 3.4 percent. The Silicon Valley grew by 2.2 percent during the same period, followed by the Sacramento Delta (2 percent), San Francisco (1.9 percent) and the San Joaquin Valley (1.7 percent). The nation's job growth was 1.5 percent.

Orange County also expanded its payrolls by 1.5 percent and Los Angeles County ranked second to the bottom on the list with a gain of just 1.2 percent. All of those numbers are subject to revision, however, when new figures are released Wednesday from the state Employment Development Department.

California's biggest employment gains have come in health care and social services, as well as leisure and hospitality. Technology and administrative services, which in past combined to be a major contributor to job growth, have now become only minor ones, the report said. And temporary workers are no longer being added in significant numbers, adding further confirmation that job markets are tight.

Why the shift occurred

Jerry Nickelsburg, director and senior economist for the Anderson Forecast, explained the shift in job creation:

"Back in 2008, we characterized the California economy as a bifurcated economy, where the coastal economy was beginning to grow and grew rapidly, leading the U.S. in the recovery," he said. "The inland parts of the state were mired in recession for a very long time."

The latest report shows that California is "in a time of convergence," according to Nickelsburg.

"The inland parts of the state are growing more rapidly and are leading the state to outperform the U.S. economy," he said. "The fact that the inland parts of the state are growing faster than most coastal regions suggests that the inland areas have room to continue to grow."

The report ties the turnaround in job creation to a number of factors. San Francisco's job growth has been hampered by the high cost of housing and limited office space, the study said, while a similar trend has been seen in the Silicon Valley, although to a lesser extent. The North Bay region of the San Francisco area has likewise been impacted by devastating wildfires. All of those areas are technology centers which typically fuel some of California's stronger employment growth.

Playing catch-up

Nickelsburg said it's largely a matter of playing catch-up after the last recession.

"The Inland Empire lost a lot of jobs in manufacturing and housing," he said. "Manufacturing is not rebounding, but we're seeing continued growth in construction, and housing is a big part of that."

Inland Empire economist John Husing said much of the region's construction activity involves the building of roadways, other transportation projects and massive e-commerce centers.

"Almost all of the e-commerce centers in Southern California have been built out here because they are big and require a lot of land," he said. "Amazon has more than 16,000 employees in the Inland Empire. They have 10 e-commerce centers out here now and they're in the process of building two more."

Husing said the region's logistics sector — which includes wholesale trade, transportation and warehousing — is the Inland Empire's biggest job creator.

"About 20 percent of all our direct job gains have been in logistics," he said. "And that doesn't include the multipliers. When someone works for Amazon, they go to places like Stater Bros., so some of the jobs at Stater Bros. are indirectly supported by Amazon. And there are also commercial laundry companies where workers pick up their uniforms. All of that brings more money and jobs into the region."

Future growth

The forecast predicts that California's employment base will expand by 2.2 percent this year, 1.7 percent in 2019 and 0.9 percent in 2020. Home building is expected to accelerate to about 138,000 units per year by the end of 2020.

The study additionally notes that the ongoing increase in the federal deficit will put pressure on international trade, increasing the likelihood of trade actions that would depress California's logistics and export industries.

Tags: economy, housing, jobs, technology, Top Stories Breeze, Top Stories IVDB, Top Stories LADN, Top Stories LBPT, Top Stories OCR, Top Stories PE, Top Stories PSN, Top Stories RDF, Top Stories SGVT, Top Stories Sun, Top Stories WDN

smith_kevi **Kevin Smith**

Kevin Smith handles business news and editing for the Southern California News Group, which includes 11 newspapers, websites and social media channels. He covers everything from employment, technology and housing to retail, corporate mergers and business-based apps. Kevin often writes stories that highlight the local impact of trends occurring nationwide. And the focus is always to shed light on why those issues matter to readers in Southern California.

Follow Kevin Smith @sgvnbiz

VIEW COMMENTS

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INNOVATING FOR A BETTER TOMORROW

SOUTHERN CALIFORNIA
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I. SUMMARY

The Southern California Association of Governments (SCAG) is soliciting proposals in response to Request for Proposal (RFP) No. 18-032, Paths to Clean Vehicle Technology and Alternative Fuels Implementation in San Bernardino County.

The RFP is comprised of the following parts presented herein as Attachments:

Attachment 1 – Proposal Information, Organization, and Content
Attachment 2 – Scope of Work
Attachment 3 – Proposal Evaluation Form
Attachment 4 – Interview Evaluation Form
Attachment 5 – Line Item Budget (Cost Proposal)
Attachment 6 – Debarment and Suspension Certification
Attachment 7 – Conflict of Interest Form
Attachment 8 – Disadvantaged Business Enterprise (DBE)
Note: Any proposal submitted without meeting the thirteen percent (13%) DBE goal or demonstrating good faith efforts to meet the DBE goal will automatically be disqualified.
Attachment 9 – Vendor Information
Attachment 10 – Notice Regarding California Public Records Act

II.

PROPOSAL TIME LINE (Subject to Change)	**DATE**	**TIME** (Pacific Standard)
RFP Released	April 11, 2018	
Pre-Proposal Conference:	N/A	
Deadline to Submit Questions to Contracts Administrator	April 23, 2018	10:00 a.m.
Posting of Answers to Questions (if any)	April 27, 2018	5:00 p.m.
Proposal Due Date	**May 11, 2018**	**10:00 a.m.**
Evaluation of Proposals	Week of May 14, 2018	
Consultant Interviews	Week of May 21, 2018	
Final Selection	June 2018	
Contract Execution/NTP	July 2018	

III. PROPOSAL SUBMISSION

Upload one (1) PDF copy of your proposal **(file cannot exceed 10MB and should be one complete document without multiple parts)** into SCAG's solicitation management system (PlanetBids) at *http://www.planetbids.com/portal/portal.cfm?CompanyID=14434#*. You **MUST** upload your submittal via PlanetBids. No other means of submission shall be accepted by SCAG. If you need assistance, contact the Contracts Administrator identified in Section IV below before the Due Date/Time (allow sufficient time before the due Date/Time).

SCAG must receive proposals by the Proposal Due Date/Time (time to be determined by SCAG's/PlanetBids time clock). Any proposal received after the Proposal Due Date/Time will be rejected.

All submissions are considered a matter of public record.

Note: "proposer," "consultant," and "firm" may be used interchangeably throughout this document.

IV. CONTRACTS ADMINISTRATOR

Leyton Morgan, Manager of Contracts
Southern California Association of Governments
900 Wilshire Blvd., Suite. 1700
Los Angeles, CA 90017
(213) 236-1982
Email: morganL@scag,.ca.gov

The Contracts Administrator is the only person to contact during the selection process, and may be contacted at any time during the process.

V. QUESTIONS AND ANSWERS

Questions must be submitted in writing **via PlanetBids** under this solicitation number. Answers to the questions will be posted on SCAG's solicitation management system under the corresponding RFP typically no later than three (3) working days after the deadline to submit questions.

VI. PRE-PROPOSAL CONFERENCE

N/A

VII. CONTRACT TYPE

Contract Type: Cost Plus Fixed Fee. Consultants must propose in United States currency and shall be paid with the same.

Funding for this project is contingent upon availability of funds at the time of contract award. As directed by the Regional Council, it is SCAG's policy not to disclose a project's budget.

VIII. PERIOD OF PERFORMANCE

The estimated period of performance for this contract is 21-months. Cost proposals should be prepared for the entire 21-month period.

IX. DBE PROGRAM

The requirements of 49 Code of Federal Regulations (CFR) Part 26, entitled Participation by Disadvantaged Business Enterprise in Department of Transportation Financial Assistance Programs, applies to this RFP. See Attachment 8 for additional information.

X. SELECTION PROCESS

1. Proposals will be ranked in accordance with the criteria described in Attachments 3 and Attachment 4.
2. Proposers may or may not be invited for an interview.

3. SCAG does not reimburse proposers for any cost of proposal preparation (including but not limited to parking, printing, postage, travel, etc.), even in the event of RFP cancellation.

4. Communication between the proposer and any member of the Proposal Review Committee during the selection process is prohibited, except when and in the manner expressly authorized in this RFP. Violation of this restriction is grounds for disqualification.

5. SCAG shall award the contract for this RFP to the firm that it deems to have provided the best value to SCAG or the firm SCAG deems to be the best qualified for contract award (or both).

6. Every proposal submitted is considered a firm offer that must be valid for a minimum of ninety (90) calendar days.

7. All proposers should be aware of the Insurance Requirements for contract award. The Certificate of Insurance must be provided by the successful proposer prior to contract award. A contract may not be awarded if insurance requirements are not met. The insurance requirements may be viewed on SCAG's website at: http://scag.ca.gov/business/ under Section 43 of SCAG's Contract Template.

   Endorsements for the following are necessary as a part of meeting the insurance requirements:

   - Commercial General Liability
   - Business Auto Liability
   - Workers' Compensation/Employer's Liability

   Endorsements shall include:

   - Additional Insured
   - Primary, Non-Contributory
   - Waiver of Subrogation
   - Notice of Cancellation

   THE ENDORSEMENTS TO ALL OF THE POLICIES MUST BE ATTACHED TO THE CERTIFICATE OF INSURANCE.

8. The successful proposer will be required to sign SCAG's standard Contract Template (available at http://scag.ca.gov/business/) in order to receive the contract award. **Proposer must identify in their proposal the specific requested modification(s), if any, to the terms and conditions in SCAG's Contract Template**. Any request to modify the terms and conditions must also include an explanation or reason for the proposed change. **If the proposer does not include the specific requested modification(s) along with the explanation or reason for the proposed change at the time they submit their proposal, SCAG shall not consider, review, allow or accept any deviation from the terms and conditions of SCAG's Contract Template**. If SCAG is unable to negotiate final contract terms and conditions that are acceptable to SCAG, SCAG reserves the right to award the contract to another proposer.

   Please be advised that, SCAG may only consider minor modifications that clarify clauses in its existing contract template, and shall not entertain making major/substantive changes to or removing any clause, specifically:

10. Invoicing for Payment
11. Invoicing Format and Content
15. Penalty
18. Work Products and Related Work Materials
19. Ownership, Confidentiality, and Use of Work Products
27. Indemnity
43. Insurance

CONTRACT LANGUAGE IS SUBJECT TO CHANGE BY SCAG PRIOR TO CONTRACT EXECUTION.

9. **SCAG shall only award a contract to a offeror who SCAG determines has an adequate financial management and accounting system as required by 48 CFR Part 16.301-3, 2 CFR Part 200, and 48 CFR Part 31 or successors there to.**

XI. SCAG RIGHTS

1. SCAG reserves the right to:
   A. Disqualify any and all proposals that are not submitted in accordance with the required format described in this RFP;
   B. Disqualify any and all proposals that don't comply with SCAG's Conflict of Interest Policy;
   C. Reject any and all proposals submitted;
   D. Waive what SCAG deems to be a minor irregularity in a firm's submission;
   E. Request additional information;
   F. Award all or part of the work contemplated in this RFP;
   G. Remedy errors in the RFP;
   H. Cancel the entire RFP;
   I. Issue subsequent RFP;
   J. Approve or reject the use of a particular subconsultant/supplier;
   K. Negotiate with any, all or none of the proposers. If SCAG is unable to negotiate final contract terms and conditions that are acceptable to SCAG, SCAG reserves the right to award the contract to another proposer;
   L. Award a contract to other than the lowest priced proposal;
   M. Award a contract without interviews, discussions or negotiations;
   N. Award a contract to one or more proposers;
   O. Only award a contract or any portion thereof to a firm that possesses a valid business license. Firms **must** possess the license from any city or state by the RFP due date. SCAG must be provided with a copy of this license, if requested; and
   P. Only award a contract or any portion thereof to a firm that passes any references checks.

2. If applicable, SCAG reserves the right to have software developed under SCAG's contract, not incorporate proprietary and/or third party software components. This does not preclude the development of deliverables which interface with commonly-available off-the-shelf software. However, consultants must determine in advance whether SCAG already has, or is willing to procure, appropriate licenses for any proprietary and/or third party software that would be required. Consultants must also provide the impacts of any enhancements and upgrades. SCAG will require delivery of documentation and source code for all electronic intellectual property developed under a SCAG contract prior to releasing final payment to the consultant.

XII. NOTIFICATION OF RIGHT TO PROTEST CONTRACT AWARD

Proposers have the right to protest the contract award in compliance with SCAG's Policy on Contract Award Protests, which can be viewed online at SCAG internet home page www.scag.ca.gov under "Doing Business with SCAG." A written protest must be filed with SCAG's Executive Director, or designee (Chief Operating Officer or Deputy Executive Director) within five (5) working days after posting of the Notice of Intent to Award. SCAG will not accept any verbal protests. The protest must be a detailed, written statement of the protest grounds and reference the RFP number and name of the designated Contracts Administrator. The protest must be submitted to SCAG's Executive Director or designee via certified mail using the following address:

Executive Director
Southern California Association of Governments
900 Wilshire Blvd, Suite 1700
Los Angeles, CA 90017-3435

The contract award is held up when SCAG's Executive Director or designee receives the protest on time. The contract may not be awarded until the protest is either withdrawn or SCAG's Executive Director or designee has rendered a decision.

PROPOSAL INFORMATION, ORGANIZATION, AND CONTENT

All proposals shall contain the following information, at a minimum:

1. **TITLE PAGE**

   Provide the following on the Title Page:

   - RFP Number
   - Title of the Project
   - Name and Address of Firm
   - Phone Number of Firm - **Do not include non-business (personal) phone numbers or address in as this information may become public under the California Public Records Act** (see Attachment 10)
   - Prime Contact Person
   - Email Address of the Prime Contact Person
   - Signature of the Individual Authorized/Obligated to Commit the Firm to this Project

   Cover letter should be addressed to the attention of the Proposal Review Committee

2. **TABLE OF CONTENTS**
   - A clear identification of the materials by section and page numbers.

3. **TECHNICAL APPROACH**
   - A statement and discussion of the project objectives, concerns, and key issues.
   - The technical approach for performing the tasks must include a detailed Scope of Work along with the process for executing the requirements and objectives of the project.
   - A discussion of the difficulties expected or anticipated in performing the tasks, along with a discussion of how the consultant proposes to overcome or mitigate against those difficulties.
   - A detailed schedule for completion of the work, including performance and delivery schedules indicating phases or segments of the project, milestones, and significant events.
   - A statement of the extent to which the consultant's proposed approach and Scope of Work will meet or exceed the stated objectives discussed in this RFP. Furthermore, a discussion of how the consultant would modify the project, and/or schedule to better meet these objectives.

4. **LINE ITEM BUDGET (COST PROPOSAL)**
   - Proposals **must** include a Line Item Budget in the format and detail shown in Attachment 5 (in United States currency). The same detailed budget is required of each subconsultant. Be sure to show the total price proposed for the entire project as a separate amount (TOTAL only), as well as the detail required in Attachment 5.

5. **PROFILE OF FIRM**
   - A statement indicating if the firm is local or national and a summary of representative experience relevant to the work described in the Scope of Work for this RFP.
   - The location and telephone number of the office from which the work is to be done.
   - Identification of the individuals who will perform the work, including officers, project manager and key staff. State the time commitment and include resumes for key individuals. **Do not include social security numbers, non-business (personal) phone numbers or address in a resume as this information may become public under the California Public Records Act** (see Attachment 10).

6. REFERENCES

- Provide a list of at least three references, including the names of contact persons within the firms. References should not include any SCAG staff or SCAG Regional Council Members.

7. REQUIRED FORMS

- The Debarment and Suspension Certification (Attachment 6) **must be fully completed by all parties to the proposal (prime and all subconsultants).**

- The SCAG Conflict of Interest Form (Attachment 7) **must be fully completed by all parties to the proposal (prime and all subconsultants).**

- Award of this RFP is conditional upon satisfying the Disadvantaged Business Enterprise (DBE) requirements (Attachment 8). A Letter of Intent (Attachment 8A) must be completed for each DBE subconsultant, and a copy of the DBE certification must be included in the proposal. **DVBE, SBE, SDB, MBE, or WBE certifications do not apply and shall not be substituted for DBE requirements**.

- If the DBE contract goal was not attained, or when partial goals have been attained, the bidder/offeror shall submit determination of good faith efforts (Attachment 8B). **Any proposal submitted without meeting the DBE goal or demonstrating good faith efforts to meet the DBE goal will automatically be disqualified.**

- All proposers must ensure that they have fully completed a Vendor Information Form (Attachment 9).

- All proposers must fully complete the Notice Regarding California Public Records Act (Attachment 10) – regardless of whether or not proposer is requesting to exempt proposal from disclosure under the California Public Records Act.

The selected consultant may be required to complete a Federal Form W-9 (for payment purposes) which may also be obtained on-line at www.scag.ca.gov under "Doing Business with SCAG."

IMPORTANT NOTE:

The selected consultant (awardee) must be prepared to provide SCAG any of the following documents if requested:

- Time Sheet (that must account for the total activity for which each employee is compensated not just SCAG time)
- Payroll register
- Indirect cost audit
- U.S. federal tax return

INTRODUCTION

The State of California, and southern California in particular, have some daunting goals for greenhouse gas (GHG) reduction and achievement of federal standards for criteria pollutants. The Global Warming Solutions Act of 2006 (AB 32) requires California to reduce its GHG emissions to 1990 levels by 2020, using technologically feasible and cost-effective means. Subsequent Executive Orders by Governors Schwarzenegger and Brown stated the need for dramatic reductions of 80% in GHG emissions from the transportation sector by 2050 and 40% by 2030. The legislature confirmed the commitment to the 40% goal by passing SB 32 in September 2016.

A 2015 executive order (B-32-15) focuses on emissions reduction from the freight sector. This has culminated in the California Sustainable Freight Action Plan (CSFAP) focusing on the environment, efficiency, and economic competitiveness. In addition, The California Air Resources Board (ARB) has produced the Mobile Source Strategy, and the South Coast Air Quality Management District (SCAQMD) prepared the 2016 Air Quality Management Plan (AQMP) to address federal standards for criteria pollutants.

This study is being funded by a FY 17/18 Caltrans grant received by SCAG and the San Bernardino County Transportation Authority to identify implementation strategies for clean vehicle and fuels technology (for both passenger vehicles and freight) that can be accomplished at the local level, while also supporting the economy.

The 2016 AQMP indicates that, for attainment of federal ozone standards, NOx emissions will need to be reduced by approximately 43% in 2023 (beyond projected 2023 baseline emissions) and 55% beyond currently projected 2031 levels. This will require adoption of technologies and fleet turnover rates that will be challenging to achieve within the timelines prescribed by the Environmental Protection Agency (EPA). See Figure 1.

As indicated in the goals of Executive Order B-32-15, reductions in greenhouse gases and attainment of federal standards for criteria pollutants need to be approached in a way that is coupled with economic progress. The Executive Order highlights a three-pronged strategy to: 1) improve freight efficiency, 2) transition to zero-emission technologies, and 3) increase the competitiveness of California's freight system. A vibrant economy is needed for the public and private sectors to be able to afford the investments needed in vehicles and the fueling infrastructure necessary for this transformation.

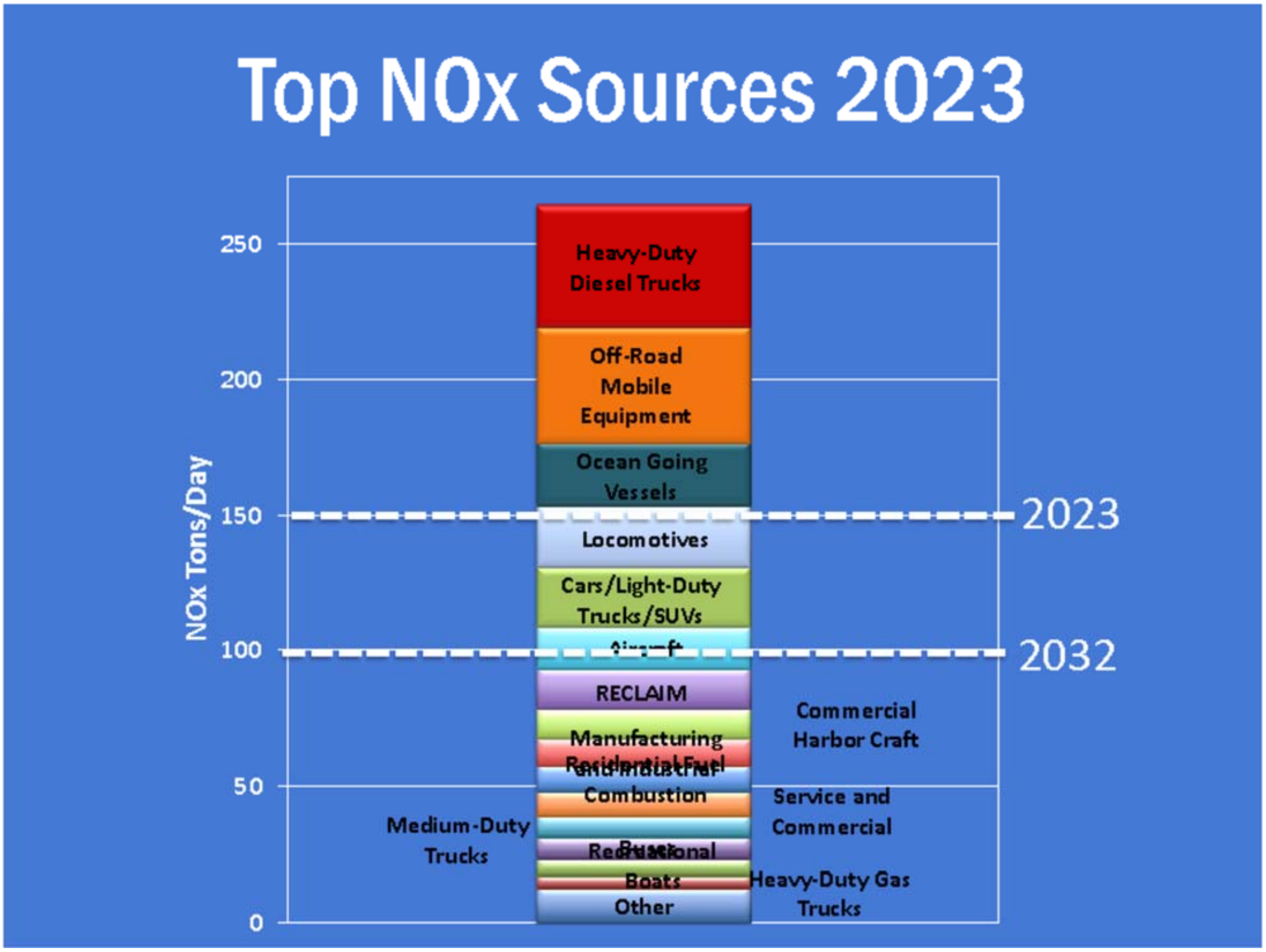


Figure 1. Top Sources of NOx, in the South Coast Air Basin and Reductions Required for 2023 and 2032 to Meet Ozone Standards (Source: SCAQMD)

San Bernardino County is an excellent setting within which to design approaches that will achieve this balance. The county has a logistics-oriented economy that is responsible for almost one third of the county's economic output and for generating over 20 percent of the county's jobs. Although tremendous progress has been made in cleaning up the air, the county still has some of the worst air quality in the U.S., and has the worst Air Quality Index (AQI) readings in the region. See Figure 2. San Bernardino County also has one of the highest concentrations of disadvantaged communities in the state, and air quality strategies need to be sensitive to both the health effects of emissions as well as the economic well-being of those who staff the warehouses, drive the trucks, operate the off-road equipment, install and maintain logistics systems, and generally support the Inland Empire economy.

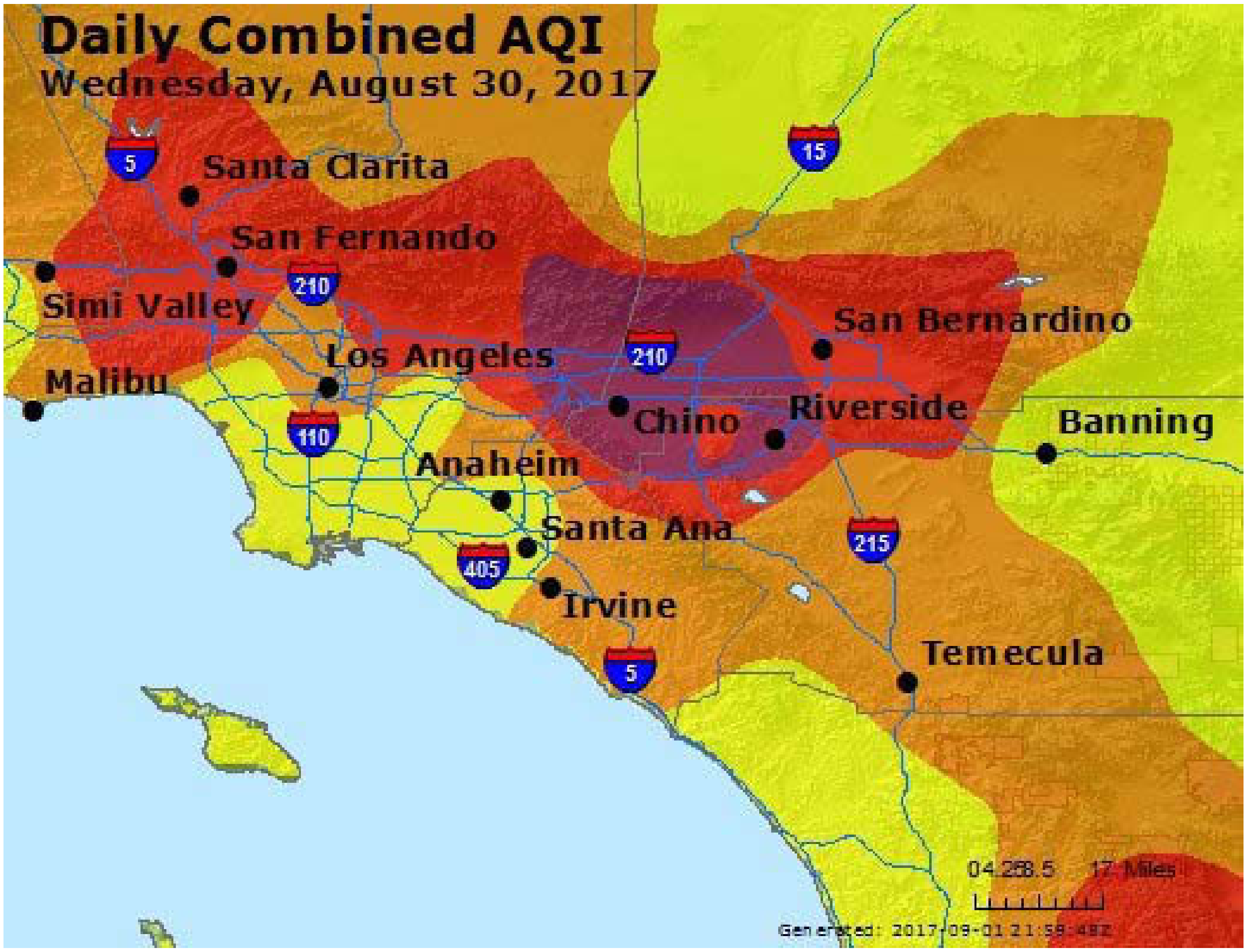


Figure 2. Daily Combined Air Quality Index for the South Coast Air Basin (Source: SCAQMD)

This project will look at the vehicle-based portion of achieving GHG reduction goals and attaining federal criteria pollutant standards in the South Coast Air Basin, with a focus on San Bernardino County. The basic question to be addressed in this project is: "How can local and regional agencies and the private sector advance the rate of penetration of clean vehicle and fuels technology locally to proactively achieve both air quality and economic goals, and what is a feasible timeline for that progress to occur?" The project will also examine efficiency measures that can have numerous co-benefits for the state's transportation system in terms of mobility, safety, and system preservation. It should be noted that prioritizing more efficient and cost-effective strategies for increasing the penetration of clean vehicles and their fueling infrastructure could provide economies that will benefit both health outcomes and the competitiveness of industry in San Bernardino County.

The central question above leads to a number of other more specific questions that will need to be addressed in this effort. The scope of work for this project is intended to address the following questions, among others:

- What are the most technologically feasible and cost-effective strategies available for reducing NOx emissions from the freight and passenger vehicle fleets to the point where federal ozone standards could be achieved in the South Coast Air Basin (with San Bernardino County having among the most difficult attainment challenges)? What are the costs, benefits, and impacts of these approaches?

- What are the most technologically feasible and cost-effective strategies available for reducing GHG emissions from freight and passenger vehicle fleets to the point where their share of SB 32 GHG reduction goals can be achieved? What are the costs, benefits, and impacts of these approaches?
- What might represent optimal investment strategies when considering both NOx and GHG reduction goals for San Bernardino County? What are the tradeoffs of prioritizing state GHG reduction goals as opposed to prioritizing attainment goals for criteria pollutants in the South Coast Air Basin?
- What risks are inherent in the alternative paths to achieving air quality improvement goals? What does the near-term and long-term future look like for private sector progress on clean freight and passenger vehicles in terms of engine certification? Expected purchase price? Powertrain reliability? Engine life? Cost of operation?
- Is it possible to forecast tipping points where technological progress enables significant reductions in the cost of vehicle production, resulting in more rapid increases in clean vehicle penetration rates? How would the cost curve for attaining ozone standards or GHG reduction goals be affected if some flexibility was provided in attainment dates? Are there ways to capture those savings to focus on reducing the most serious localized air quality impacts in San Bernardino County more quickly?
- What can be done to improve freight efficiency and increase the competitiveness of the freight system regionally and in San Bernardino County, per Executive Order B-32-15?
- Making the assumption that substantial incentive funding is available to accelerate the turnover of vehicle fleets, what would be the most optimal strategy for investing those funds to attain ozone standards in San Bernardino County? To achieve GHG reduction goals?
- What strategies should San Bernardino County and the region employ to support fueling infrastructure, given the uncertain directions in transportation technology?
- What is the opinion of the public when faced with tradeoffs between the opportunities afforded by growth in the logistics economy versus the associated environmental impacts?
- What are the primary factors holding back higher purchase/lease penetration rates for light duty plug-in electric vehicles in San Bernardino County? How do those factors vary between passenger vehicles and light duty trucks?
- What limitations exist in the utility infrastructure that may stand in the way of rapid penetration of alternative fuel vehicles?
- To what extent are purchase/lease penetration rates for light duty plug-in electric vehicles influenced by price points versus convenience factors (e.g. mileage range, charge times, availability of charging infrastructure) and what role can public agencies and utilities play in influencing more rapid adoption?
- To what extent should public agencies in San Bernardino County and the region be accommodating/partnering with suppliers of other clean fuel types such as hydrogen, CNG/LNG, renewable natural gas, etc.? What barriers should these agencies be aware of that could stand in the way of developing and locally permitting the fueling infrastructure needed for more rapid penetration of clean vehicles?

It is recognized that some of these may be difficult questions to answer at this time. However, it is important that the questions be considered and answered to the extent that information, time, and project budget allows. Proposals should be structured to help the selection panel understand how consultants will go about addressing these and other appropriate questions, keeping in mind that the goal is to improve air quality, reduce GHGs, and promote the economic well-being of the citizens and businesses of San Bernardino County and the SCAG region.

This project should be viewed as an effort that is supplemental to, and not in conflict with, the ongoing activities of the South Coast AQMD and the California Air Resources Board. It will produce analysis that is germane to local implementation in San Bernardino County, identifying the opportunities, alternatives, barriers, costs, benefits, and impacts of implementing the strategies in the 2016 AQMP within the real-world environment of San Bernardino County, a place where all the issues of logistics, air quality, economy, and employment opportunities converge. In other words, if we can make this work in a collaborative fashion in San Bernardino County, it can be made to work anywhere. At the same time, attainment of federal air quality standards is judged on the basis of air basins. This project may need to conduct much of its analysis in the context of the South Coast Air Basin, relying on information in the 2016 AQMP (such as vehicle inventories) at that geographic level, while focusing on San Bernardino County from an implementation perspective.

STUDY OBJECTIVES

Specific objectives the project will accomplish include:

1. **Outreach to stakeholders:** Conduct outreach to public and private stakeholders to define steps that can be taken locally to support technologically feasible and cost-effective paths forward for reduction of GHGs and criteria pollutants.
2. **Define alternative paths to clean vehicle and fuels implementation:** Map out technologically feasible and cost-effective alternative paths to attainment of standards for criteria pollutants and achievement of GHG reduction goals. It is expected that answers to the questions posed in the introduction will provide part of the information necessary to structure these alternative paths and to conduct subsequent analyses.
3. **Identify barriers and costs:** Identify the barriers and costs involved in accelerating the penetration rates of clean passenger and freight vehicles into the local and regional fleet mix.
4. **Identify implementation strategies:** Identify strategies that would be required at the local and regional level to implement the alternative paths to clean vehicle/fuels technology and estimate the associated nature, scale, and timing of investments that would be needed. This would build on the SCAQMD and ARB work on the South Coast AQMP, the Mobile Source Strategy, and the State Implementation Plan (SIP). There are a number of areas where this project could translate the initiatives and control measures in these documents to local implementation, with emphasis on possible structures for clean vehicle incentive funding and ways to optimize the investment to support the economy.
5. **Develop recommendations:** Develop recommendations that can be provided to local, regional, state, and federal agencies, utilities, researchers, manufacturers, fuel providers, and other entities regarding how they can assist public and private sector partners at the local level to advance air quality goals while maintaining vibrant, competitive economies.

Although the focus of this effort will be primarily on clean vehicle and fuels technology penetration into the marketplace, travel efficiency and travel demand management/system management strategies (TDM/TSM) will also be addressed as to their role in achieving criteria pollutant and GHG reduction goals. Consultant may wish to include a baseline scenario, and a scenario where more moderate changes (for instance, aerodynamic vehicles, ITS in vehicle technology) may be proposed as alternative paths. All of these strategies, including clean vehicles/fuels strategies, have implications for the Caltrans-owned and operated transportation system.

There are numerous resources to draw from as a foundation for this proposed project, such as:

- 2016 South Coast Air Quality Management Plan
- SCAG Plug-in Electric Vehicle Readiness Plan, 2012
- California Transportation Plan, 2016, which includes an assessment of GHG reduction strategies
- Caltrans Freight Mobility Plan, 2014
- Caltrans Inter-regional Transportation Strategic Plan, 2015
- ARB's Sustainable Freight Action Plan, 2016
- ARB's Mobile Source Strategy and SIP Strategy, 2016
- ARB Technology and Fuels Assessments, various reports, April-September 2015
- Port of Los Angeles and Long Beach Clean Air Action Plan update, 2017
- San Bernardino County Regional Greenhouse Gas Reduction Plan, 2014

STUDY TASKS

The project tasks have been structured to address the objectives listed earlier. The proposed tasks at a minimum include:

1. **Project initiation, management and existing conditions**
2. **Outreach to stakeholders**
   Gather information from the range of stakeholders identified in the introduction.
3. **Define alternative paths to clean vehicle and fuels implementation.** Map out technologically feasible and cost-effective alternative paths to attainment of standards for criteria pollutants and achievement of GHG reduction goals. Although the focus is primarily on technologically-driven paths, strategies may also include efficiency improvements, and/or TDM/TSM strategies. Alternatives may be structured around criteria pollutant reduction, GHG reduction or some balance of both. It is recommended that Consultant include criteria or examples of how they will determine the scenarios that they will use to develop alternative paths in their submission of this proposal. Costs and expected emissions reductions associated with these strategies will be estimated and the need for supporting infrastructure will be discussed. Alternative paths should demonstrate with more detail how the goals in the 2016 AQMP will be realized.
4. **Identify implementation strategies at the local and regional level.** Identify specific actions by local, regional, and state agencies, utilities, and the private sector that would be required to implement the alternative paths, together with aggressive, but realistic, implementation timelines.
5. **Fiscal management**

Proposed activities under each task are specified below, along with products to be delivered.

1. Project Initiation, Management and Existing Conditions

Task 1.1: Project Kick-off Meeting

- Consultant will meet with SCAG and SBCTA staff to clarify scope of work and discuss project procedures and expectations including invoicing, quarterly reporting, and all other relevant project information. Meeting summary will be documented.
- Responsible party: Consultant/SCAG/SBCTA

Task 1.2: Staff Coordination

- Monthly project team meetings/conference calls to ensure good communication on upcoming tasks and to make sure the project remains on time and within budget. Caltrans staff will be included in the project team meetings, as approved by the SCAG Project Manager. Consultant shall also facilitate meetings of a Technical Advisory Committee (TAC) made up of core stakeholders. Frequency of the TAC meetings will depend on the study progress, though we anticipate bi-monthly meetings.
- Responsible party: Consultant/SCAG/SBCTA

Task 1.3 Existing and Forecast Conditions Technical Memorandum, to include the following:

- Document existing vehicle/fuels technology, and economic conditions/forecasts
- Provide a summary of current air quality standards, regulations, legislation, executive orders, guidelines, reports, and other policy-related material relevant to reducing criteria pollutants and greenhouse gases for mobile sources.
- Document industry related economic goals, forecasts, and strategies at the state, regional, and local level that are related to or could be impacted by initiatives to improve air quality.
- Collect data on vehicle inventory, emission rates (existing and future) by vehicle type, fuel type and other factors germane to estimating emission outputs by pollutant. This will include data on new and emerging technologies that could ultimately become part of a strategy for achieving air quality goals. Much of this data should already be available from the 2016 AQMP, but technology is also advancing rapidly, and the most current information will need to be documented. It is not intended that a separate inventory be developed for San Bernardino County, except where it has implications on plans for implementation in the County. An example might be an inventory of existing alternative fueling stations.
- Prepare a draft technical memorandum documenting existing and forecast conditions
- Consultant will need to update this for the final report to document events that occur during the course of the project.
- Responsible party: Consultant

Deliverables
Kick-off Meeting Notes
Project Team Meetings Notes and TAC meeting notes
Existing and Forecast Conditions Technical Memorandum

2. Outreach to stakeholders

SBCTA and SCAG have contacts with a range of public and private entities related to the subject matter of this project. We envision a working group of entities that have both economic and quality-of-life interests in San Bernardino County, drawn from groups that include: building industry (residential and industrial), air quality agencies, local government (cities and the County), trucking/logistics industry, railroads, energy sector, and health/environmental sector. The consultant will make a more complete inventory of the stakeholders that should be involved and at what level. For example, some of the stakeholders are more directly involved in producing and operating the clean vehicles and systems in response to regional, state, and federal regulations and air quality goals. Others, like local governments, are involved in setting policy and permitting facilities that are needed to support clean vehicles, buildings, and other systems. In addition, a concerted effort will be made to reach out to the county's environmental justice/disadvantaged communities.

Because of the diversity of stakeholders, the outreach will need to be structured to make involvement most efficient and productive. Separate meetings will be needed with certain stakeholders to focus on specific technological or implementation ideas. Their technical expertise and real-world experience is critical to defining realistic paths forward. Other partners will need to be brought in to determine if and how those ideas would actually work.

Outreach will occur at three levels: 1) private sector, 2) public agencies, and 3) public interest/advocacy/Environmental Justice (EJ) communities. Different means such as focus groups, workshops, and individual outreach will be used. Public outreach will also involve collecting existing market research from publications and the trucking sector that quantifies the likely rate of penetration of clean vehicle technology across certain segments of the population and barriers that stand in the way of higher penetration rates (e.g. vehicle range, operating cost, fuel availability, fueling time, etc.).

The subtasks below generally describe how the outreach is currently envisioned to occur. Proposers are free to suggest alternative approaches provided any approach suggest meets the minimum requirements of this Task. Adjustments may be needed as the project gets underway. In all these conversations, we will need to go back to the core question: "How can local and regional agencies and the private sector accelerate the rate of penetration of clean vehicle and fuels technology locally to proactively achieve both air quality and economic goals, and what is a feasible timeline for that progress to occur?" The implementation strategies evaluated will also include efficiency measures that can yield co-benefits for the state's transportation system in terms of mobility, safety, and system preservation.

Task 2.1: Prepare outreach plan and establish core stakeholder group

Task 2.1.1: Prepare an outreach plan that builds on the approach described below. Consultant may make additional recommendations.

Task 2.1.2: A Technical Advisory Committee (TAC) will be established to help provide strategic direction. This will primarily consist of local jurisdictions, air quality agencies, and private sector partners. Each group of stakeholders will have a specific contribution to make. Though additional information may be provided throughout the process, expected areas of expertise at a minimum include:

- Local jurisdictions provide the policy framework for supporting investment in clean vehicle and fuels technology and oversee permitting from a land use standpoint.

  - The private sector partners provide the technical and practical knowledge of how to foster and implement clean vehicle and fuels technology. They understand what is feasible, are directly engaged in technological developments, and are in the best position to understand the most cost-effective approaches. Air quality agencies (regional and state) will need to be consulted regarding data and analyses that are germane to the quantification of both GHG and criteria pollutant emission reductions for the alternative paths.
  - Outreach to EJ communities and Native American tribes will also be conducted in coordination with AQMD and ARB who might offer suggestions based on their existing relationships with these communities.
- Responsible party: Consultant, with SBCTA and SCAG oversight.

Task 2.2: Conduct focus groups and EJ outreach

- The outreach plan will define the specific purpose and scope of focus groups and criteria for selecting participants. The primary intention of the focus groups is to better understand how vehicle owners/drivers and industry may respond to different strategies for increasing the penetration of clean vehicle and fuels technology. This is important as the acceleration of penetration rates will depend on the willingness and financial ability of individuals and businesses to invest in newer transportation technology. Note: some aspects of this may benefit from an on-line or limited-sample opinion polling, which will need to be discussed as part of this task.
- Recruit participants that fit the criteria
- Define focus group facilitation and structure. Example questions for participants could include:
  - What currently prevents you from purchasing or leasing a clean vehicle (may respond to a list of typical vehicle and fuel-type options available)? (Note: may be asked in slightly different ways for personal vehicles vs. commercial vehicles)
  - What would be required for you to purchase or lease a clean vehicle (may respond to a list of typical vehicle and fuel-type options available)? (Note: may be asked in slightly different ways for personal vehicles vs. commercial vehicles)
  - What fueling infrastructure would be needed for you to purchase or lease a clean vehicle?
  - What financial incentives would be needed for you to purchase or lease a clean vehicle?
- Prepare focus group materials and conduct focus groups
- Outreach in the EJ community may occur in a focus group setting, through existing EJ working groups and/or individual outreach. The Consultant, SCAG, Caltrans and SBCTA will discuss the most effective approaches for this outreach.
- Responsible party: Consultant

Task 2.3: Conduct workshops with larger stakeholder group

- Up to three workshops will be held with a broader cross-section of stakeholders and the general public. The timing and geographic location of the workshops will be identified based on the nature of the issues and options identified as the study proceeds. Consultant may propose workshop topics and timing in accordance with the proposed project schedule.

- The focus of at least one of the workshops will be to test stakeholder response to proposed alternative paths to cleaner vehicle and fuels technology and efficiency measures.
- One of the workshops will also focus on the economy and how to leverage initiatives in clean vehicle and fuels technology to keep San Bernardino County competitive in the regional, state, and global economies.

Task 2.4: Document findings and conclusions

- Prepare Tech Memo documenting findings and conclusions from outreach
  Responsible party: Consultant

Task	Deliverable
2.1	*Tech memo with proposed outreach approach and methodologies*
2.2	*Focus group materials and documentation of focus group results*
2.3	*Workshop materials and documentation of workshop results*
2.4	*Technical Memorandum: Outreach Findings and Conclusions*

3. Define alternative paths to clean vehicle and fuels implementation

Responding to the questions cited in the introduction, plus the documentation of existing/forecast data in Task 1 and initial input from the stakeholders in Task 2, will help in the structuring of an initial set of alternative paths. A set of technologically feasible and cost-effective alternative paths will be defined for attainment of standards for criteria pollutants and achievement of GHG reduction goals. Alternative paths will be defined that both adhere to the prescribed federal and state timelines and one or more paths that may not adhere to those timelines, if the stakeholders generally concur that adherence to the timelines is not assured and/or may not be economically practical. Although a primary focus will be on the criteria pollutant goals for 2023 and 2031/32 and the GHG reduction goal for 2030, this must also be done in the context of the longer term GHG reduction goal for 2050.

A reasonable portion of the NOx reduction required to attain ozone standards will need to be "carved out" for the purpose of defining and analyzing these alternatives. Likewise, a portion of the GHG reduction goal will need to be assumed for the mobile source sector. Data are available from the 2016 AQMD to use as a basis for defining San Bernardino's mobile source "share" for purpose of this analysis. The default assumption would be to use the proportion of NOx and GHG emissions for the mobile source sector relative to the whole. These shares would be different for NOx and GHGs.

The approach will be technology neutral; technological advances and the market will ultimately determine optimal paths forward. However, alternative paths may emphasize certain technologies and fuels over others in the short, medium, and long term based on cost-effectiveness criteria or other factors. The project will also identify potential efficiency measures such as routing optimization, equipment modernization and automation, and improved information systems.

Task 3.1: Identify a short-list of alternative paths to clean vehicle and fuels implementation.

- Provide some initial "book-end" alternatives to scale the dimensions of the range of alternatives that can be examined.

- Identify criteria to be used as a basis for screening the alternatives
- Identify a more complete range of alternatives to be considered between the book-ends. The core stakeholder group will need to identify an appropriate number of options, considering factors such as: estimated output of emissions for vehicle/fuel combinations; potential scale of fuel availability by source; technological advances projected in the near, mid, and long-term; vulnerabilities/risks in fuel supply and price; potential regulations/legislation at the federal level that could influence decisions/timing at the state level; and direction of the vehicle manufacturing industry for passenger cars and freight that could impact range and cost of alternative fuel vehicles.
- Screen the range of alternative paths down to a short-list for further consideration.
- Responsible party: Consultant

Task 3.2: Analyze the short-list of alternative paths identified in Task 3.1.

- Identify Criteria for Analysis: Identify criteria to be used as a basis for analyzing the alternative paths to clean vehicle and fuels technology and implementation in the near, mid, and long-term. Example criteria include: emissions trajectory, co-benefits, costs (both public and private), economic benefits/impacts, trajectory of fuel availability and cost, vulnerability to economic cycles, investment risks (due to regulatory uncertainty, price fluctuations, vehicle life-cycles), etc. Consultants will need to propose the level of analytics appropriate for this screening-level analysis and which criteria should be quantitative vs. qualitative.
- Assess relationship to national trends: There are many factors, known and unknown, that may influence the value and predictability of alternative paths. From the standpoint of the economy and competitiveness, industry will want to go down a path that is low cost and predictable, and will be concerned with how the California approach compares with neighboring states and the nation. Federal legislation and regulation will need to be tracked to be able to assess California's relationship to national norms for purposes of economic competitiveness, and this issue will need to be considered as alternative paths are crafted. Federal representatives (e.g. EPA and FHWA) will need to be included in the outreach to properly assess the national perspective and trends in other states.
- Responsible party: Consultant

Task 3.3: Prepare a technical memorandum documenting the analysis of alternative paths

- The tech memo should document the pros and cons of alternative paths and identify the type and magnitude of uncertainties. The tech memo will be reviewed by SBCTA, SCAG, Caltrans, and the TAC and the Consultant shall make any resulting revisions, as approved by the SCAG Project Manager. These comments will be reflected in an updated draft, to be made available to a broader audience and for use in the workshops.
- Responsible party: Consultant

Task	Deliverable
3.1	*Memo documenting criteria and short-list of alternative paths*
3.2	*Draft technical memorandum documenting the analysis of alternative paths*
3.3	*Technical memorandum documenting the analysis of alternative paths, updated with stakeholder comments*

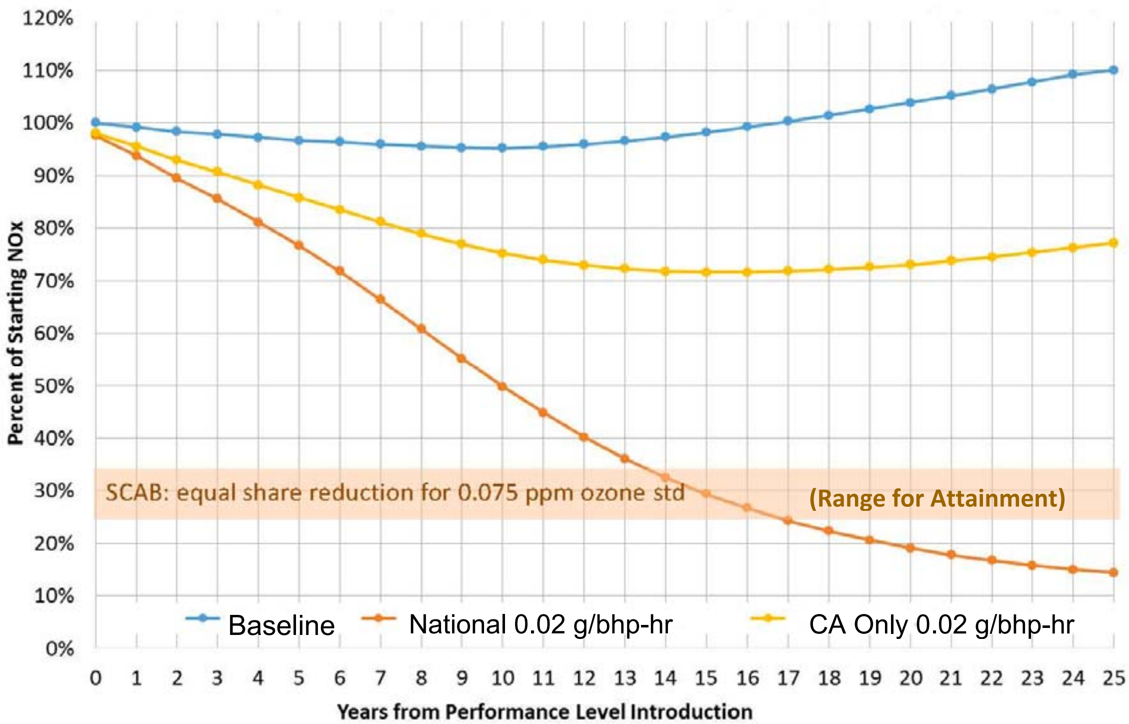
4. Identify implementation strategies at the local and regional level

Task 4.1: Identify challenges or barriers to implementation for each alternative path

- The focus will be on challenges at the local and regional level, but may also identify challenges that can best be addressed (or perhaps only can be addressed) at the state or national level. Figure 3 illustrates the importance of national emission standards as opposed to just state standards. There are many out-of-state trucks that do business in California, and the South Coast Air Basin cannot meet its ozone standards without having cleaner out-of-state trucks.
- As examples, challenges may be related to local policy, permitting, grid capacity, age of infrastructure, etc., or how to deal with non-local trucks.
- Prepare a memo documenting the challenges and barriers for each alternative path
- Responsible party: Consultant

Task 4.2: Develop implementation strategies and possible solutions to the challenges and barriers identified in Task 4.1.

- Identify steps that would be needed for implementation of each alternative path, with a focus on actions that can be taken by agencies and private sector partners in San Bernardino County. However, it may also be appropriate to develop recommendations that can be provided to regional, state, and federal agencies, utilities, researchers, manufacturers, fuel providers, and other entities regarding how they can assist public and private sector partners at the local level to advance air quality goals while maintaining vibrant, competitive economies.
- Develop solutions to the challenges and barriers identified in Task 4.1.
- Identify actions that public and private entities could or should take to accelerate penetration of clean vehicle and fuels technology. Some actions may be common among alternative paths. Others may be unique to certain paths. The objective is not to focus on a single path forward, but to identify those actions that are likely to have a payoff, and permanency, regardless of how vehicle and fuels technology evolve. Solutions should ideally be scalable, enabling adaptation as the technology direction becomes clearer over time.
- Responsible party: Consultant



Source: Presentation by Mr. Cory Pamer, ARB at the Symposium on California's Development of its Phase 2 Greenhouse Gas Emission Standards for On-Road Heavy-Duty Vehicles (April 22, 2015)

Figure 3. Emission Analysis of Statewide vs. National Introduction of New Truck Standards

Task 4.3: Prepare recommendations, and Draft/Final Reports and Action Plan

- Prepare recommendations that can be provided to air districts, state agencies, federal agencies, utilities, researchers, manufacturers, and other entities regarding how they can assist public and private sector partners at the local level to advance air quality goals while maintaining vibrant, competitive economies. It is not expected that any specific alternative paths will be recommended, but that lessons derived from the analysis of alternative paths will become a basis for recommendations to entities that have responsibility for advancements in air quality and economic development. Implementation strategies will be highlighted for specific entities, whether they be local governments, state agencies, federal agencies, vehicle and equipment manufacturers, fuel providers, residential and industrial developers, trucking industry, railroads, etc.
- Prepare an action plan that explains associated implementation strategies at the local and regional level.
- Prepare Final Report. This will include a “Lessons Learned” portion that will have applicability across the state as to how stakeholders may be brought together to focus on practical approaches to accelerating clean vehicle and fuels technology from a local perspective.
- Responsible party: Consultant

Task	Deliverable
4.1	*Memo on challenges and barriers to implementation*
4.2	*Documentation of actions public and private entities can take to accelerate penetration of alternative fuel vehicles*
4.3	*Final Report and Action Plan (including Lessons Learned)*

PROPOSAL AND INTERVIEW EVALUATION FORM (Cost Plus Contracts)

RFP No. 18-032

Consultant Name: ____________________

(a)	(b)	(c)	(d)
Evaluation Criteria	**Max. Possible Points**	**Points Earned**	**Strengths/Weaknesses**
TECHNICAL APPROACH • Tasks & approach clearly described • Creative/innovative approach • Project intent has been met	**25**		Strength(s): Weakness(es):
CONSULTANT FIRMS: Prime Consultant: • Experience with projects of the similar size and scope • Capability to reallocate resources as needed to meet project schedule Sub-Consultant(s): • Each sub provides unique service(s) to the team • Subs are fully capable of performing their tasks	**20**		Strength(s): Weakness(es):
PROJECT MANAGEMENT • Reasonable total number & distribution of hours • Qualifications of key individuals • Time commitment of key individuals	**15**		Strength(s): Weakness(es):
PROJECT COST • Realistic cost for services to be performed • Allocation of cost to tasks & activities	**30**		Strength(s): Weakness(es):
REASONABLENESS OF SCHEDULE • Total time allocated for each task is realistic • Logical & realistic timing of each task • Overall schedule consistent with SCAG's SOW	**10**		
REFERENCES • Similar projects completed on time and within budget	**Pass/ Fail**		
TOTAL:	**100**		

Name of Evaluator (print): ____________________ Agency: ____________________

Signature of Evaluator: ____________________ Date: ____________________

LINE ITEM BUDGET (Cost Proposal) INSTRUCTIONS

1. SCAG uses the Line Item Budget to assess the fairness and reasonableness of a proposer's costs. Once SCAG awards a contract, the negotiated Line Item Budget serves as the basis for reimbursing the proposer (includes Cost Plus as well as Fixed Price contracts).

2. **SCAG shall only award a contract to a offeror who SCAG determines has an adequate financial management and accounting system as required by 48 CFR Part 16.301-3, 49 CFR Part 18, and 48 CFR Part 31 200 or successors thereto.**

3. **All proposers must submit a Line Item Budget using the exact format shown on the following page, or may risk having their proposal disqualified.** Further, a Line Item Budget must be submitted for each subconsultant regardless of dollar value of the subcontract. The Line Item Budget (Attachment 5) template may be downloaded from SCAG's website at: http://www.scag.ca.gov/business/index.htm.

   Disclaimer – Each proposer is responsible for all mathematical calculations and information provided on the Line Item Budget template.

4. Many items that may be normal business costs and tax deductible may not be allowable under Federal and State contract rules (e.g., dues, advertising, contributions, bad debts, interest expense, meals, and entertainment). For a complete listing, see 48 CFR Part 31 and 2 CFR Part 200 or successors thereto.

   All costs must be allowable and consistent with Federal cost principles under 2 CFR Part 200 or successors thereto. Please be aware that the cost-plus-a-percentage-of-cost bid/offer method, where the proposer's profit is a percentage of the reimbursed costs on a project, is not allowed under Federal rules. Also, **contingency fees are not allowed.**

5. Costs shall be structured as follows:

   A. Direct Labor:
      - Direct labor, overhead, and fringe benefits must be shown as separate dollar amounts (United States currency) in the Line Item Budget. Prior to contract award, proposer (awardee) must substantiate the rate (i.e., with payroll register or similar, or U.S. federal tax return…) if SCAG requests it. Only include employees (i.e., staff that you will issue a W-2 to). Do not include sub-consultants in your Direct Labor (or Overhead, Fee and Other Direct Costs). Include all cost for sub-consultants under the Sub-consultants category.
      - Identify Key Personnel by both name and title (e.g., Mary Smith, Sr. Planner). Place an asterisk (*) next to the name(s) of any Key Personnel. Other professional or support/administrative staff may be identified by title only.
      - The labor rate quoted for each position in the Line Item Budget must be the maximum rate that is expected to be paid during the term of the contract, inclusive of any rate increase (e.g. merit, cost-of-living, etc.). If SCAG awards a Cost Plus Fixed Fee contract, **SCAG will only pay the selected consultant the actual rate paid to the person in a position, and all rates must be traceable to and supported by payroll records**.
      - Note: For Firm Fixed Priced (FFP) contracts, SCAG uses the labor and overhead rates quoted in the proposer's Line Item Budget to evaluate the proposed price for each task and cumulatively. Once SCAG has negotiated a final Line Item Budget, during the life of the contract, SCAG intends to pay the selected consultant upon completion of each task (unless otherwise agreed to), regardless of the actual cost to complete the task, provided the cost is allowable and allocable, and complies with federal rules and regulations.

B. Overhead:
   - The overhead rate quoted must be the rate that is expected for each Fiscal Year during the life of the contract. Prior to contract award, proposer (awardee) must substantiate the rate (i.e., with an indirect cost audit or U.S. federal tax return…) if SCAG requests it.

C. Fixed Fee:
   - Fee/Profit is calculated on Direct Labor, Overhead and Fringe Benefits only, not on Subconsultants or Other Direct Costs. Prior to contract award, proposer (awardee) must substantiate the fee if SCAG requests it.

D. Other Direct Costs (ODCs):
   - ODCs must be fully substantiated prior to contract award. If the contract is subject to a pre-award audit (see bullet 6 below), SCAG will review support for ODCs similar to that done for Direct Labor, Overhead, and Fringe Benefits. If SCAG awards a Cost Plus Fixed Fee contract, during the life of the contract, SCAG will require back-up documentation with the monthly invoices to substantiate ODCs.

   - All travel costs must be reasonable**,** and are limited to those rates stated under California's State Department of Personnel Administration rules, (subject to change) posted at: http://www.dot.ca.gov/hq/asc/travel/ch12/1consultant.htm, or successors thereto.

E. Subconsultants:
   - Identify the Direct Labor, Overhead, Fixed Fee and ODCs in the same format as for the Prime.

6. SCAG's Pre-award Audit Requirements are as follows:

   Contracts less than $250,000 may require a pre-award audit; those at $250,000 or more will require a pre-award audit. SCAG's pre-award audit requirements are available at http://www.scag.ca.gov/opportunities/Pages/BusinessWithSCAG.aspx. The selected consultant (awardee) must be prepared to provide an indirect cost audit or U.S. federal tax return, if SCAG requests.

LINE ITEM BUDGET

Consultant: ABC Company
1234 Main Street, Suite 100
Los Angeles, CA 90000
(213) 555-5555

Title of RFP: ____

RFP Number: ____

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)	(x)
Cost Categories	Maximum Hourly Rate	Task 1		Task 2		Task 3		Task 4		Task 5		Task 6		Task 7		Task 8		Task 9		Task 10		Grand Total (All Tasks)	
		TBD		TBD		TBD		TBD		TBD		TBD		TBD		TBD		TBD		TBD			
		Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount
Direct Labor Classification(s):																							$0
A. Person, Sr. Planner	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
Subtotal - Direct Labor		**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**
Overhead & Fringe (inc. G&A):																							$0
			$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0
			$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0
Subtotal - Overhead & Fringe (inc G&A):			**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**
Fixed Fee																							$0
			$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0
Subtotal - Fixed Fee:			**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**
Other Direct Costs (ODCs)																							$0
Travel	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
Printing – Directly Chargeable Only	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
Other	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
Other	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
Subconsultant(s)*																							$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
	$ -		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	0	$0
Subtotal - ODCs:			**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$0**
Grand Total		**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**

** if you anticipate the use of subconsultants, use a copy of this template to identify subconsultant cost detail by task in a similar fashion and input final figures under each subconsultant (Hours & Amount by tasks involved)*

TITLE 49, CODE OF FEDERAL REGULATIONS, PART 29 DEBARMENT AND SUSPENSION CERTIFICATION

RFP No. 18-032

1) All persons or firms, including subconsultants, must complete this certification and certify, under penalty of perjury, that, except as noted below, he/she or any person associated therewith in the capacity of owner, partner, director, officer, or manager:

   a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any federal department or agency;

   b) Have not, within the three (3) year period preceding this certification, been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (federal, state, or local) transaction or contract under a public transaction, violation of Federal or state antitrust statutes, or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

   c) Are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (federal, state, or local) with commission of any of the offenses listed in subparagraph (1)(b) of this certification; and

   d) Have not, within the three (3) year period preceding this certification, had one or more public transactions (Federal, state, and local) terminated for cause or default.

2) If such persons or firms later become aware of any information contradicting the statements of paragraph (1), they will promptly provide that information to SCAG.

If there are any exceptions to this certification, insert the exceptions in the following space.

Exceptions will not necessarily result in denial of award, but will be considered in determining proposer/bidder responsibility. For any exception noted above, indicate below to whom it applies, initiating agency, and dates of actions.

____
Name of Firm

____
Signature (original signature required)

____
Date

SCAG CONFLICT OF INTEREST FORM

RFP No. 18-032

SECTION I: INSTRUCTIONS

All persons or firms seeking contracts must complete and submit a SCAG Conflict of Interest Form along with the proposal. This requirement also applies to any proposed subconsultant(s). Failure to comply with this requirement may cause your proposal to be declared non-responsive.

In order to answer the questions contained in this form, please review SCAG's Conflict of Interest Policy, the list of SCAG employees, and the list of SCAG's Regional Council members. All three documents can be viewed online at **www.scag.ca.gov**. The SCAG Conflict of Interest Policy is located under "OPPORTUNITIES", then "Doing Business with SCAG" and scroll down under the "CONTRACTS" tab; whereas the SCAG staff may be found under "ABOUT" then "Employee Directory"; and Regional Council members can be found under "ABOUT", then scroll down to "ELECTED OFFICIALS" on the left side of the page and click on "See the list of SCAG representative and their Districts."

Any questions regarding the information required to be disclosed in this form should be directed to SCAG's Deputy Legal Counsel, especially if you answer "yes" to any question in this form, as doing so **MAY** also disqualify your firm from submitting an offer on this proposal

Name of Firm: ______________________________

Name of Preparer: ______________________________

Project Title: ______________________________

RFP Number: ______________ **Date Submitted:** ______________

SECTION II: QUESTIONS

1. During the last twelve (12) months, has your firm provided a source of income to employees of SCAG or members of the SCAG Regional Council, or have any employees or Regional Council members held any investment (including real property) in your firm?

   ☐ **YES** ☐ **NO**

   If "yes," please list the names of those SCAG employees and/or SCAG Regional Council members and the nature of the financial interest:

Name	**Nature of Financial Interest**

2. Have you or any members of your firm been an employee of SCAG or served as a member of the SCAG Regional Council within the last twelve (12) months?

☐ **YES** ☐ **NO**

If "yes," please list name, position, and dates of service:

Name	**Position**	**Dates of Service**

3. Are you or any managers, partners, or officers of your firm related by blood or marriage/domestic partnership to an employee of SCAG or member of the SCAG Regional Council that is considering your proposal?

☐ **YES** ☐ **NO**

If "yes," please list name and the nature of the relationship:

Name	**Relationship**

4. Does an employee of SCAG or a member of the SCAG Regional Council hold a position at your firm as a director, officer, partner, trustee, employee, or any position of management?

☐ **YES** ☐ **NO**

If "yes," please list name and the nature of the relationship:

Name	**Relationship**

5. Have you or any managers, partners, or officers of your firm ever given (directly or indirectly), or offered to give on behalf of another or through another person, campaign contributions or gifts to any current employee of SCAG or member of the SCAG Regional Council (including contributions to a political committee created by or on behalf of a member/candidate)?

☐ **YES** ☐ **NO**

If "yes," please list name, date gift or contribution was given/offered, and dollar value:

Name	**Date**	**Dollar Value**
____________________	____________________	____________________
____________________	____________________	____________________
____________________	____________________	____________________
____________________	____________________	____________________

SECTION III: <u>VALIDATION STATEMENT</u>

This Validation Statement must be completed and signed by at least one General Partner, Owner, Principal, or Officer authorized to legally commit the proposer.

DECLARATION

I, (printed full name) ________________________________, hereby declare that I am the (position or title) _____________________________ of (firm name) _____________________________, and that I am duly authorized to execute this Validation Statement on behalf of this entity. I hereby state that this SCAG Conflict of Interest Form dated __________________ is correct and current as submitted. I acknowledge that any false, deceptive, or fraudulent statements on this Validation Statement will result in rejection of my contract proposal.

____ __________________________________

Signature of Person Certifying for Proposer (original signature required) — Date

NOTICE

A material false statement, omission, or fraudulent inducement made in connection with this SCAG Conflict of Interest Form is sufficient cause for rejection of the contract proposal or revocation of a prior contract award.

DISADVANTAGED BUSINESS ENTERPRISE (DBE) INFORMATION

RFP No. 18-032

The requirements of 49 Code of Federal Regulations (CFR) Part 26 applies to this RFP.

DBEs and other small businesses are strongly encouraged to participate in the performance of Agreements financed in whole or in part with federal funds (See 49 CFR 26, "Participation by Disadvantaged Business Enterprises in Department of Transportation Financial Assistance Programs"). The Consultant should ensure that DBEs and other small businesses have the opportunity to participate in the performance of the work that is the subject of this solicitation and should take all necessary and reasonable steps for this assurance. The proposer shall not discriminate on the basis of race, color, national origin, or sex in the award and performance of subcontracts.

DBE DEFINITION

A DBE is a-for-profit "small business concern" that is at least 51 percent owned and controlled by one or more socially and economically disadvantaged individuals. One or more such individuals must also control the management and daily business operations. These individuals must be citizens (or lawfully admitted permanent residents) of the United States and (1) any individual who a recipient finds to be a socially and economically disadvantaged individual on a case-by-case basis, or (2) who are either Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Subcontinent Asian Americans, women, or any other group found to be socially and economically disadvantaged by the Small Business Administration.

DBE PARTICIPATION AND GENERAL INFORMATION

It is the proposer's responsibility to be fully informed regarding their requirements of 49 CFR, Part 26. Particular attention is directed to the following:

A. A DBE must be a small business firm defined pursuant to 13 CFR 121 and be certified through the California Unified Certification Program (CUCP)
B. A certified DBE may participate as a prime consultant, subconsultant, or as a vendor of material or supplies.
C. A DBE must perform a commercially useful function pursuant to 49 CFR 26.55; that is, a DBE firm must be responsible for the execution of a distinct element of the work and must carry out its responsibility by actually performing, managing, and supervising the work.
D. A prime consultant who is a certified DBE is eligible to claim all of the work in the Agreement toward the DBE participation except that portion of the work to be performed by non-DBE subconsultant.

DBE CONTRACT GOAL

SCAG has not established a goal for this contract. However, proposers are encouraged to obtain DBE participation for this contract.

DBE SOURCES

Consultants interested in locating DBE subconsultants may refer to the following source:

Statewide DBE Database of the CUCP (California Unified Certification Program):
http://www.californiaucp.com/
Click on "Directory"

Also, the following agency may be contacted for assistance in locating DBE firms in California:

Caltrans Office of Certification
1-866-810-6346

DBE CERTIFICATION

The DBE firm must hold a current California Unified Certification Program (CUCP) DBE certification at the time of proposal submission. DBE certifications outside of California will not be accepted. Firms that are DBE certified outside of California may apply for a CUCP DBE certification by contacting one of the certifying agencies listed at: http://californiaucp.org/

DISADVANTAGED BUSINESS ENTERPRISE (DBE) INFORMATION

RFP No. 18-032

OBJECTIVE/POLICY STATEMENT

SCAG intends to receive federal financial assistance from the U.S. Department of Transportation (DOT) through the California Department of Transportation (Caltrans), and as a condition of receiving this assistance, SCAG has signed the California Department of Transportation Disadvantaged Business Enterprise Agreement. SCAG agrees to implement the State of California, Department of Transportation Disadvantaged Business Enterprise (DBE) Program Plan (hereinafter referred to as the DBE Program Plan) as it pertains to local agencies. The DBE Program Plan is based on U.S. Department of Transportation (DOT), 49 CFR 26 requirements.

It is the policy of SCAG to ensure that DBEs, as defined in 49 CFR 26, have an equal opportunity to receive and participate in DOT-assisted contracts. It is also SCAG's policy:

- To ensure nondiscrimination in the award and administration of DOT-assisted contracts.
- To create a level playing field on which DBE's can compete fairly for DOT-assisted contracts.
- To ensure that the DBE participation percentage is narrowly tailored, in accordance with applicable law.
- To ensure that only firms that fully meet 49 CFR 26 eligibility standards are permitted to participate as DBEs.
- To help remove barriers to the participation of DBEs in Federal-aid contracts.
- To assist the development of firms that can compete successfully in the market place outside the DBE Program.

SCAG will never exclude any person from participation in, deny any person the benefits of, or otherwise discriminate against anyone in connection with the award and performance of any contract covered by 49 CFR 26 on the basis of race, color, sex, or national origin. In administering the local agency components of the DBE Program Plan, SUB-RECIPIENT will not, directly, or through contractual or other arrangements, use criteria or methods of administration that have the effect of defeating or substantially impairing accomplishment of the objectives of the DBE Program Plan with respect to individuals of a particular race, color, sex, or national origin.

DBE CONTRACT GOAL

A DBE contract goal of **thirteen percent (13%)** has been established for this solicitation. The DBE firm must be certified in California.

A prime consultant who is a certified DBE can meet the contract goal by virtue of the work it performs on the contract with its own forces.

Any proposal submitted without meeting the DBE goal or demonstrating good faith efforts to meet the DBE goal with automatically be disqualified.

LETTER OF INTENT

The bidder/offeror shall submit a Letter of Intent (Attachment 8A) with the proposal to obtain credit for DBE participation in the performance of this contract.

The consultant may not substitute, add, or terminate a subconsultant listed in the original proposal without prior written approval from the Chief Financial Officer of SCAG.

GOOD FAITH EFFORTS

The bidder/offeror must make and document good faith efforts, as defined in Appendix A, 49 CFR Part 26 (Attachment 8B), if the DBE contract goal was not attained or partially attained.

DBE DEFINITION

A for-profit small business concern that is at least 51 percent owned and controlled by one or more socially and economically disadvantaged individuals. One or more such individuals must also control the management and daily business operations. These individuals must be citizens (or lawfully admitted permanent residents) of the United States and (1) any individual who a recipient finds to be a socially and economically disadvantaged individual on a case-by-case basis, or (2) who are either African Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Subcontinent Asian Americans, (persons whose origin are from India, Pakistan, Bangladesh, Bhutan, Maldives Islands, Nepal or Sri Lanka), Women, or any other group found to be socially and economically disadvantaged by the Small Business Administration (See 49 CFR 26).

DBE PARTICIPATION AND GENERAL INFORMATION

It is the proposer's responsibility to be fully informed regarding their requirements of 49 CFR, Part 26. Particular attention is directed to the following:

E. A DBE must be a small business firm defined pursuant to 13 CFR 121 and be certified through the California Unified Certification Program (CUCP)

F. A DBE must perform a commercially useful function pursuant to 49 CFR 26.55; that is, a DBE firm must be responsible for the execution of a distinct element of the work and must carry out its responsibility by actually performing, managing, and supervising the work.

G. If a DBE does not perform or exercise responsibility for at least 30% of the total cost of its contract with its own work force, or the DBE subcontracts a greater portion of the work of a contract than would be expected on the basis of normal industry practice for the type of work involved, one must presume that it is not performing a commercially useful function.

DBE DATABASE

Consultants interested in locating DBE subconsultants may refer to the following source:

Statewide DBE Database of the CUCP (California Unified Certification Program):
http://www.dot.ca.gov/hq/bep/find_certified.htm

DBE CERTIFICATION

The DBE firm **must** hold a current California Unified Certification Program (CUCP) DBE certification at the time of proposal submission. DBE certifications outside of California will **not** be accepted. Firms that are DBE certified outside of California may apply for a CUCP DBE certification by contacting one of the certifying agencies listed at: http://californiaucp.org/

A potential DBE may request certification from Caltrans by requesting an application form at:

Department of Transportation
Office of Business and Economic Opportunity
Certification Unit
1823 14th Street, MS-79
Sacramento, CA 95811
DBE_Certification@dot.ca.gov

The form may also be downloaded from the Internet at: http://www.dot.ca.gov/hq/bep/business_forms.htm

DBE ELIGIBILITY

The CUCP certifies and determines the eligibility of DBE consultant and contractor firms. The CUCP can also remove the eligibility of a firm and issue a written notice of ineligibility. A directory of certified DBE firms is available from the Caltrans Civil Rights, Certification Unit website at:
http://www.dot.ca.gov/hq/bep/find_certified.htm

ADMINISTRATIVE RECONSIDERATION PROCESS

1. As a part of this reconsideration, the bidder/offeror will have the opportunity to provide written documentation or argument concerning this issue of whether it met the goal or made adequate good faith efforts to do so.
2. The reconsideration official will not have played any role in the original determination that the bidder/offeror did not document adequate good faith efforts to do so.
3. The bidder/offeror will have the opportunity to meet in person with SCAG's reconsideration official to discuss the issue of whether it met the goal or made good faith efforts to do so.
4. A written decision on reconsideration will be sent to the bidder/offeror explaining the basis for the finding that the bidder did or did not meet the goal or make adequate good faith efforts to do so.
5. The result of the reconsideration process is not administratively appealable to SCAG's Regional Council or the Department of Transportation.

LETTER OF INTENT

RFP No. 18-032

(Submit this page for each DBE subconsultant)

Name of Prime Consultant: ______________________________

Name of Prime Consultant: ______________________________

City: ____________________ State: ____________ Zip Code: __________

Name of DBE Subconsultant:

Address:

City: State: Zip Code:

Telephone No.: Email

Description of work to be performed by DBE subconsultant:

Task	Description of Work	Dollar Value of Work
	TOTAL	

The bidder/offeror is committed to utilizing the above named DBE firm for the work described.

Affirmation:

The above named DBE firm affirms that it will perform the portion of the contract for the estimated dollar value as stated above.

By: ____________________ ____________________

Signature Title

A copy of the DBE certification must be included in the proposal.

If the bidder/offeror does not receive award of the prime contract, any and all representation in this Letter of Intent and Affirmation shall be null and void.

Appendix A to Part 26—Guidance Concerning Good Faith Efforts

I. When, as a recipient, you establish a contract goal on a DOT-assisted contract for procuring construction, equipment, services, or any other purpose, a bidder must, in order to be responsible and/or responsive, make sufficient good faith efforts to meet the goal. The bidder can meet this requirement in either of two ways. First, the bidder can meet the goal, documenting commitments for participation by DBE firms sufficient for this purpose. Second, even if it doesn't meet the goal, the bidder can document adequate good faith efforts. This means that the bidder must show that it took all necessary and reasonable steps to achieve a DBE goal or other requirement of this part which, by their scope, intensity, and appropriateness to the objective, could reasonably be expected to obtain sufficient DBE participation, even if they were not fully successful.

II. In any situation in which you have established a contract goal, Part 26 requires you to use the good faith efforts mechanism of this part. As a recipient, you have the responsibility to make a fair and reasonable judgment whether a bidder that did not meet the goal made adequate good faith efforts. It is important for you to consider the quality, quantity, and intensity of the different kinds of efforts that the bidder has made, based on the regulations and the guidance in this Appendix.

The efforts employed by the bidder should be those that one could reasonably expect a bidder to take if the bidder were actively and aggressively trying to obtain DBE participation sufficient to meet the DBE contract goal. Mere pro forma efforts are not good faith efforts to meet the DBE contract requirements. We emphasize, however, that your determination concerning the sufficiency of the firm's good faith efforts is a judgment call. Determinations should not be made using quantitative formulas.

III. The Department also strongly cautions you against requiring that a bidder meet a contract goal (i.e., obtain a specified amount of DBE participation) in order to be awarded a contract, even though the bidder makes an adequate good faith efforts showing. This rule specifically prohibits you from ignoring bona fide good faith efforts.

IV. The following is a list of types of actions which you should consider as part of the bidder's good faith efforts to obtain DBE participation. It is not intended to be a mandatory checklist, nor is it intended to be exclusive or exhaustive. Other factors or types of efforts may be relevant in appropriate cases.

A. (1) Conducing market research to identify small business contractors and suppliers and soliciting through all reasonable and available means the interest of all certified DBEs that have the capability to perform the work of the contract. This may include attendance at pre-bid and business matchmaking meetings and events, advertising and/or written notices, posting of Notices of Sources Sought and/or Requests for Proposals, written notices or emails to all DBEs listed in the State's directory of transportation firms that specialize in the areas of work desired (as noted in the DBE directory) and which are located in the area or surrounding areas of the project.

(2) The bidder should solicit this interest as early in the acquisition process as practicable to allow the DBEs to respond to the solicitation and submit a timely offer for the subcontract. The bidder should determine with certainty if the DBEs are interested by taking appropriate steps to follow up initial solicitations.

B. Selecting portions of the work to be performed by DBEs in order to increase the likelihood that the DBE goals will be achieved. This includes, where appropriate, breaking out contract work items into economically feasible units (for example, smaller tasks or quantities) to facilitate DBE participation, even when the prime contractor might otherwise prefer to perform these work items with its own forces. This may include, where possible, establishing flexible timeframes for performance and delivery schedules in a manner that encourages and facilitates DBE participation.

C. Providing interested DBEs with adequate information about the plans, specifications, and requirements of the contract in a timely manner to assist them in responding to a solicitation with their offer for the subcontract.

D. (1) Negotiating in good faith with interested DBEs. It is the bidder's responsibility to make a portion of the work available to DBE subcontractors and suppliers and to select those portions of the work or material needs consistent with the available DBE subcontractors and suppliers, so as to facilitate DBE participation. Evidence of such negotiation includes the names, addresses, and telephone numbers of DBEs that were considered; a description of the information provided regarding the plans and specifications for the work selected for subcontracting; and evidence as to why additional Agreements could not be reached for DBEs to perform the work.

(2) A bidder using good business judgment would consider a number of factors in negotiating with subcontractors, including DBE subcontractors, and would take a firm's price and capabilities as well as contract goals into consideration. However, the fact that there may be some additional costs involved in finding and using DBEs is not in itself sufficient reason for a bidder's failure to meet the contract DBE goal, as long as such costs are reasonable. Also, the ability or desire of a prime contractor to perform the work of a contract with its own organization does not relieve the bidder of the responsibility to make good faith efforts. Prime contractors are not, however, required to accept higher quotes from DBEs if the price difference is excessive or unreasonable.

E. (1) Not rejecting DBEs as being unqualified without sound reasons based on a thorough investigation of their capabilities. The contractor's standing within its industry, membership in specific groups, organizations, or associations and political or social affiliations (for example union vs. non-union status) are not legitimate causes for the rejection or non-solicitation of bids in the contractor's efforts to meet the project goal. Another practice considered an insufficient good faith effort is the rejection of the DBE because its quotation for the work was not the lowest received. However, nothing in this paragraph shall be construed to require the bidder or prime contractor to accept unreasonable quotes in order to satisfy contract goals.

(2) A prime contractor's inability to find a replacement DBE at the original price is not alone sufficient to support a finding that good faith efforts have been made to replace the original DBE. The fact that the contractor has the ability and/or desire to perform the contract work with its own forces does not relieve the contractor of the obligation to make good faith efforts to find a replacement DBE, and it is not a sound basis for rejecting a prospective replacement DBE's reasonable quote.

F. Making efforts to assist interested DBEs in obtaining bonding, lines of credit, or insurance as required by the recipient or contractor.

G. Making efforts to assist interested DBEs in obtaining necessary equipment, supplies, materials, or related assistance or services.

H. Effectively using the services of available minority/women community organizations; minority/women contractors' groups; local, State, and Federal minority/women business assistance offices; and other organizations as allowed on a case-by-case basis to provide assistance in the recruitment and placement of DBEs.

V. In determining whether a bidder has made good faith efforts, it is essential to scrutinize its documented efforts. At a minimum, you must review the performance of other bidders in meeting the contract goal. For example, when the apparent successful bidder fails to meet the contract goal, but others meet it, you may reasonably raise the question of whether, with additional efforts, the apparent successful bidder could have met the goal. If the apparent successful bidder fails to meet the goal, but meets or exceeds the average DBE participation obtained by other bidders, you may view this, in conjunction with other factors, as evidence of the apparent successful bidder having made good faith efforts. As provided in §26.53(b)(2)((vi), you must also require the contractor to submit copies of each DBE and non-DBE subcontractor quote submitted to the bidder when a non-DBE subcontractor was selected over a DBE for work on the contract to review whether DBE prices were substantially higher; and contact the DBEs listed on a contractor's solicitation to inquire as to whether they were contacted by the prime. Pro forma mailings to DBEs requesting bids are not alone sufficient to satisfy good faith efforts under the rule.

VI. A promise to use DBEs after contract award is not considered to be responsive to the contract solicitation or to constitute good faith efforts.

[79 FR 59600, Oct. 2, 2014]

DEMONSTRATION OF GOOD FAITH EFFORTS

When the contract goal was not attained, or when partial goals have been attained, the bidder/offeror shall submit the requested information below for a determination of good faith efforts.

1. Advertisement Documentation

List names and dates of each general circulation newspaper, trade paper/journal and minority focused paper/journal, or other publication in which a request for DBE participation was placed. Attach a copy of the advertisement or proof of publication.

Publication Name	Publication Date(s)

2. DBE Solicitation Documentation

a. List names and dates of written notices sent to certified DBE firm(s) soliciting bids for this project.
b. List the date of follow-up with the DBE firm(s), certifying whether there was interest.
c. Attach a copy of any solicitation package, phone records, email correspondences, fax confirmations, or solicitation follow-up correspondence(s) sent to the DBE firm(s).

DBE Firm		**Contact**	**Phone No. or Email**
Solicitation Information		**Identify the work which was made available to the DBE firm:**	
Date Mailed			
Date Phoned			
Date of Follow-Up			
DBE Responded	DBE Selected	Give reason for non-selection (if applicable):	
☐ Yes ☐ No	☐ Yes ☐ No		

DBE Firm		**Contact**	**Phone No. or Email**
Solicitation Information		**Identify the work which was made available to the DBE firm:**	
Date Mailed			
Date Phoned			
Date of Follow-Up			
DBE Responded	DBE Selected	Give reason for non-selection (if applicable):	
☐ Yes ☐ No	☐ Yes ☐ No		

DBE Firm		Contact	Phone No. or Email
Solicitation Information		**Identify the work which was made available to the DBE firm:**	
Date Mailed			
Date Phoned			
Date of Follow-Up			
DBE Responded	DBE Selected	Give reason for non-selection (if applicable):	
☐ Yes ☐ No	☐ Yes ☐ No		

DBE Firm		Contact	Phone No. or Email
Solicitation Information		**Identify the work which was made available to the DBE firm:**	
Date Mailed			
Date Phoned			
Date of Follow-Up			
DBE Responded	DBE Selected	Give reason for non-selection (if applicable):	
☐ Yes ☐ No	☐ Yes ☐ No		

DBE Firm		Contact	Phone No. or Email
Solicitation Information		**Identify the work which was made available to the DBE firm:**	
Date Mailed			
Date Phoned			
Date of Follow-Up			
DBE Responded	DBE Selected	Give reason for non-selection (if applicable):	
☐ Yes ☐ No	☐ Yes ☐ No		

3. Additional Data

Provide any additional data to support demonstration of good faith efforts, such as contacts with DBE assistance agencies. Attach copies of requests to agencies and any responses received.

FOR SCAG USE ONLY

% of DBE Goal Attained:		**GFE Demonstrated:**	☐ **Yes**	☐ **No**
Name	Signature		Date	

Vendor Information

SECTION 1. GENERAL CONTACT INFORMATION

Primary Contact ______________________

Title ______________________

Telephone No. ______________________ Fax No. ______________________

E-mail Address ______________________

Company Website Address ______________________

SECTION 2. REMITTANCE ADDRESS (IF DIFFERENT FROM FORM W-9)

Company Name ______________________

Address ______________________

City ______________________ State __________ Zip Code __________

Telephone No. ______________________ Fax No. ______________________

SECTION 3 PROPOSER'S/BIDDER'S LIST INFORMATION (REQUIRED)

Is your firm a Disadvantaged Business Enterprise (DBE)? ☐ Yes ☐ No

As defined in Title 49 Part 26.11 of the Code of Federal Regulations, complete the required information below regardless of whether your firm is a DBE or non-DBE:

Age of Firm: ______________________

Annual Gross Receipts (select one):

☐ Less than $1 Million
☐ $1 Million – $ 5 Million
☐ $5 Million – $10 Million
☐ $10 Million – $15 Million
☐ $15 Million – $17.4 Million
☐ $17.4 Million +

A COPY OF THE FIRMS DBE CERTIFICATION MUST BE PROVIDED TO QUALIFY AS A DBE.

For vendors located within the Southern California region, certification must be from one of the agencies listed below.

CALIFORNIA DEPARTMENT OF TRANSPORTATION (CALTRANS)
Civil Rights MS 79, 1823 14th Street ,Sacramento, CA 95814
Phone: (916) 324-1700 or (866) 810-6346, Fax: (916) 324-1862, website: caltrans.ca.gov

CITY OF LOS ANGELES
Office of Contract Compliance, Centralized Certification
1149 S. Broadway Street, Suite 300, Los Angeles, CA 90015
Phone:(213) 847-6480, Fax: (213) 847-5566, website: bca.lacity.org

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY (METRO)
Diversity and Economic Opportunity Department
One Gateway Plaza, Los Angeles, CA 90012
Phone: (213) 922-2600, Fax: (213) 922-7660, website: mta.net

If you believe you qualify as a DBE but are not certified, you may want to contact one of the certifying agencies listed at http://californiaucp.org/ to initiate the certification process.

SECTION 4. COMMODITY CODE

Check all boxes of the commodity codes that apply to your company's particular areas of expertise.

General Goods & Services

✓	NIGP	DESCRIPTION	✓	NIGP	DESCRIPTION	✓	NIGP	DESCRIPTION
☐	60001	Painters	☐	60204	Telecommunications	☐	60720	Paper, Fine
☐	60007	Electrical	☐	60233	Appliances	☐	60730	Trophies & Awards
☐	60008	Plumbing	☐	60400	Audio Visual Equipment	☐	60863	Temporary Staffing
☐	60009	Small General Contractors	☐	60401	Audio Visual Supplies	☐	60875	Registrations (Training/Seminars)
☐	60016	Security Systems	☐	60402	Video Equipment	☐	61000	Office Supplies
☐	60017	H V A C Contractors	☐	60545	Moving & Storage	☐	90640	Graphic Design Services
☐	60030	Sound Systems & Electronics	☐	60637	Lease – Equipment	☐	90640.1	Image Setting
☐	60102	Postage & Courier Services	☐	60637.1	Lease – Building	☐	90640.2	Premium/Promotional Items
☐	60102.1	Postage Machines	☐	60638	Maintenance Agreement	☐	96600	Printing & Related Services
☐	60104	Memberships(Professional)	☐	60640	Copiers/Mimeo/Dupl.	☐	96115	Catering & Concessions
☐	60105	Subscriptions (Periodicals)	☐	60670	Furniture – Office	☐	96115.1	Coffee & Tea Services
☐	60200	Computer Hardware	☐	60700	Typewriters & Supplies	☐	96115.2	Bottled Water
☐	60201	Computer Software	☐	60701	Office Machines	☐	96618	Copying/Reproduction Services
☐	60202	Computer Supplies	☐	60702	Office Machine Supplies	☐	91528	Mailing Services & Electronic Info.
☐	60203	Computer Services	☐	60710	Stationary Supplies	☐		
☐	Other							

Professional/Consulting Services

✓	NIGP	DESCRIPTION	✓	NIGP	DESCRIPTION	✓	NIGP	DESCRIPTION
☐	60012	Architects, Engineer	☐	91840	Employee Benefits Consulting	☐	91892.1	Growth Visioning Planning
☐	90868	Project Management	☐	91843	Environmental Consulting	☐	91893	Security/Safety Consulting
☐	91804	Accounting/Auditing/Budgeting	☐	91846	Feasibility Studies	☐	91894	Traffic Consulting
☐	91804.1	Organizational, Financial, & Performance Audits/Project Management Services	☐	91849	Finance/Economic Consulting	☐	91895	Telecommunications Consulting
			☐	91858	Government Consulting	☐	91896	Transportation Planning Consulting
☐	91806	Administrative Consulting	☐	91858.1	Government Relations	☐	91896.1	Highway Corridor Analysis
☐	91806.1	Administrative Services	☐	91858.2	Institutional Analysis	☐	91896.2	Rail Planning & Analysis
☐	91812	Modeling-Analytical Studies & Surveys	☐	91863	Housing Consulting	☐	91896.3	Transit & Non-motorized Planning & Analysis
☐	91812.1	Survey and Data Collection	☐	91865	Human Relations Consulting			
☐	91812.2	Travel Demand Model Improvement	☐	91866	Human Resources Consulting	☐	91896.4	Transportation Management & Coordination
☐	91812.3	Geographic Information System	☐	91866.1	Executive Search			
☐	91812.4	Software Support for Studies & Surveys	☐	91866.2	Insurance Broker Services	☐	91896.5	Truck Lane Analysis/GoodsMovement
☐	91812.5	Regional Data Systems	☐	91874	Legal Consulting	☐	91896.6	Transportation Financing
☐	91817	Aviation Consulting	☐	91874.1	Legislative Services	☐	91896.7	Transportation & Economic Development
☐	91826	Communications: Public Relations Consulting	☐	91874.2	Alternative Dispute Resolution	☐	91896.8	Transportation Investment Analysis
☐	91828	Computer Hardware Consulting	☐	91875	Management Consulting	☐	91896.9	Transportation Modeling Support
☐	91828.1	Computer Service Center	☐	91875.1	Organization & Staff Development	☐	91897	Gas, Water, Electric Consulting
☐	91829	Computer Software Consulting	☐	91876	Marketing Consulting	☐	91897.1	Air Quality Planning & Modeling
☐	91829.1	Information Systems	☐	91876.1	Social Economic Impact Analysis	☐	91897.2	Water Supply Analysis
☐	91829.2	Unix Systems Support	☐	91876.2	Social Justice/Equity Analysis	☐	96175	Translation Services
☐	91829.3	Macintosh Computer Technical Support	☐	91879	Minority & Small Business Consulting	☐	91892	Urban Planning Consulting
☐	91837	Economy Analysis Consulting	☐	91883	Organizational Development Consulting			
☐	91838	Education & Training Consulting	☐	91885	Personnel/Employment Consulting			
☐	Other							

SECTION 5. F O R M SUBMISSION

Include this form in your proposal

Notice Regarding California Public Records Act

Section ❶ - Summary

A proposal submitted in response to this RFP will be subject to public disclosure pursuant to the California Public Records Act, Cal. Gov. Code section 6250 et. seq., (the "Act"). The Act provides generally that all records relating to a public agency's business are open to public inspection and copying, unless specifically exempt from public disclosure under one of several exemptions set forth in the Act. If you believe that any portion of your proposal is exempt from disclosure under the California Public Records Act, **you must: 1). Mark such portion "TRADE SECRET," "CONFIDENTIAL," or "PROPRIETARY," within you proposal; 2). Complete Section ❷ below, and 3). Include this Attachment 10 in your submittal**, or your proposal will be subject to public disclosure under the Act. Proposals marked "TRADE SECRET," "CONFIDENTIAL," OR "PROPRIETARY" in their entirety will not be honored, and SCAG will not deny public disclosure of proposals so marked. By submitting a proposal with specific material marked "TRADE SECRET," "CONFIDENTIAL," or "PROPRIETARY," you represent you have a good faith belief that the material is exempt from disclosure under the Act; however, such designations will not necessarily be conclusive. You may be required to further justify in writing why such material should not, upon request, be disclosed by SCAG under the Act. Fee and pricing proposals are not considered "TRADE SECRETS", "CONFIDENTIAL", or "PROPRIETARY".

If SCAG denies disclosure, then by submitting your proposal you agree to reimburse SCAG for, and to indemnify, defend, and hold harmless SCAG, its officers, fiduciaries, employees, and agents from and against any and all claims, damages, losses, liabilities, suits, judgments, fines, penalties, costs, and expenses including, without limitation, attorneys' fees, expenses and court costs of any nature whatsoever (collectively, "Claims") arising from, in connection with, or relating to SCAG's non-disclosure. By submitting your proposal, you also agree to defend, indemnify, and hold harmless SCAG from and against any and all Claims arising from, in connection with, or relating to SCAG's public disclosure of any such designated portions of your proposal if SCAG reasonably determines disclosure is deemed required by law, or if disclosure is ordered by a court of competent jurisdiction.

Section ❷ - Exemption Request

Page Number of Proposal	Brief Explanation for the Exemption Under the Act and any Other Comments

Attach additional pages as necessary

☐ Check here if proposer claims no exemption

Signature: ____ Date: ____________________

South Coast
Air Quality Management District
21865 Copley Drive, Diamond Bar, CA 91765
(909) 396-2000, www.aqmd.gov

MOBILE SOURCE COMMITTEE MEETING

Committee Members
Dr. Clark E. Parker, Chair
Dr. Joseph Lyou, Vice Chair
Marion Ashley
Sheila Kuehl
Larry McCallon
Judith Mitchell

October 20, 2017♦ 9:00 AM♦ CC8
21865 Copley Dr., Diamond Bar, CA 91765

TELECONFERENCE LOCATION

11461 West Sunset Boulevard
Brentwood Room 1
Los Angeles, CA 90049

4080 Lemon Street,
5th Floor, Conf. Room D
Riverside, CA 92502

(The public may attend at any locations listed above.)

Call-in for listening purposes only is available by dialing:
Toll Free: [assigned number]
Listen Only Passcode: [assigned passcode]
In addition, a webcast is available for viewing and listening at:
http://www.aqmd.gov/home/library/webcasts

AGENDA

CALL TO ORDER

INFORMATIONAL ITEMS (Items 1-3)

1. **Summary of 2017 Ozone Season and Trend Analysis (No Motion Required)**
   Staff will summarize the 2017 ozone season, including an analysis of recent trends in ozone levels.
   Philip Fine
   Deputy Executive Officer

2. **2016 AQMP Modeling Performance (No Motion Required)**
   The Engine Manufacturers Association (EMA) and their consultant Ramboll-Environ recently submitted a letter raising a concern that the 2016 AQMP modeling may have overestimated the NOx emission reductions needed to attain ozone standards. Staff will present the modeling approach used for the 2016 AQMP, respond to the concerns, and describe the approach for model improvements in subsequent AQMPs.
   Sang-Mi Lee
   Program Supervisor

3. **Facility-Based Mobile Source Measures Progress Report (No Motion Required)**
   Staff will provide an update on progress to implement the Facility-Based Mobile Source Measures adopted in the Final 2016 AQMP. The update will include a summary of the key topics that have been discussed at the ten Working Group meetings that have been held since the last update to the Mobile Source Committee in May 2017, as well as planned activities over the next several months.
   Ian MacMillan
   Planning & Rules Manager

WRITTEN REPORTS (Items 4-5)

4. **Rule 2202 Activity Report: Rule 2202 Summary Status Report**
   The Rule 2202 Summary Status Report summarizes Rule 2202 activities for the period January 1, 2017 to September 30, 2017. The report breaks down the plan submittal activities by option type and lists Air Quality Investment Program funds collected by county.
   Philip Fine

5. **Lead Agency Projects and Environmental Documents Received by SCAQMD**
   This report provides, for the Board's consideration, a listing of CEQA documents received by the SCAQMD between September 1, 2017 and October 31, 2017, and those projects for which the SCAQMD is acting as lead agency pursuant to CEQA.
   Philip Fine

OTHER MATTERS

6. **Other Business**
   Any member of the Committee, or its staff, on his or her own initiative or in response to questions posed by the public, may ask a question for clarification, may make a brief announcement or report on his or her own activities, provide a reference to staff regarding factual information, request staff to report back at a subsequent meeting concerning any matter, or may take action to direct staff to place a matter of business on a future agenda. (Gov't. Code Section 54954.2)

7. **Public Comment Period**
   Members of the public may address this body concerning any agenda item before or during consideration of that item (Gov't. Code Section 54954.3(a)). All agendas for regular meetings are posted at District Headquarters, 21865 Copley Drive, Diamond Bar, California, at least 72 hours in advance of a regular meeting. At the end of the regular meeting agenda, an opportunity is also provided for the public to speak on any subject within the Committee's authority. Speakers may be limited to three (3) minutes each.

   Next Meeting Date: November 17, 2017

ADJOURNMENT

Americans with Disabilities Act

The agenda and documents in the agenda packet will be made available, upon request, in appropriate alternative formats to assist persons with a disability (Gov't. Code Section 54954.2(a)). Disability-related accommodations will also be made available to allow participation in the Mobile Source Committee meeting. Any accommodations must be requested as soon as practicable. Requests will be accommodated to the extent feasible. Please contact Arlene Farol at 909.396.2250 from 7:30 a.m. to 6:00 p.m., Tuesday through Friday, or send the request to afarol@aqmd.gov.

Document Availability

All documents (i) constituting non-exempt public records, (ii) relating to an item on an agenda for a regular meeting, and (iii) having been distributed to at least a majority of the Committee after the agenda is posted, are available prior to the meeting for public review at the South Coast Air Quality Management District, Public Information Center, 21865 Copley Drive, Diamond Bar, CA 91765.

2017 Ozone Season Summary and Trend Analysis

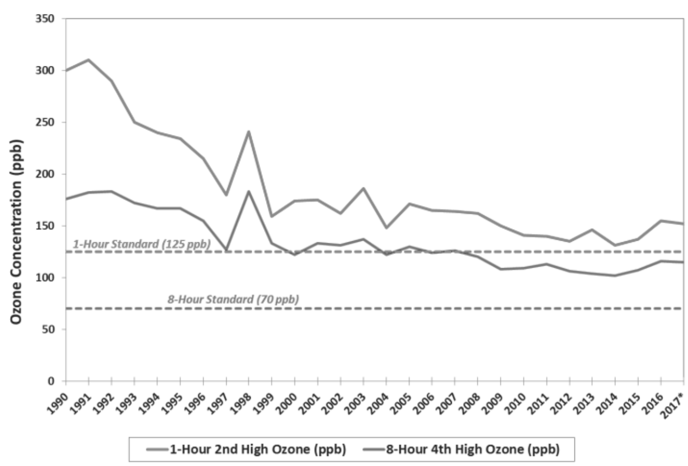
Mobile Source Committee

October 20, 2017

South Coast
Air Quality Management District

Ozone Concentration Trend

4th High 8-Hour and 2nd High 1-Hour, 1990-2017*

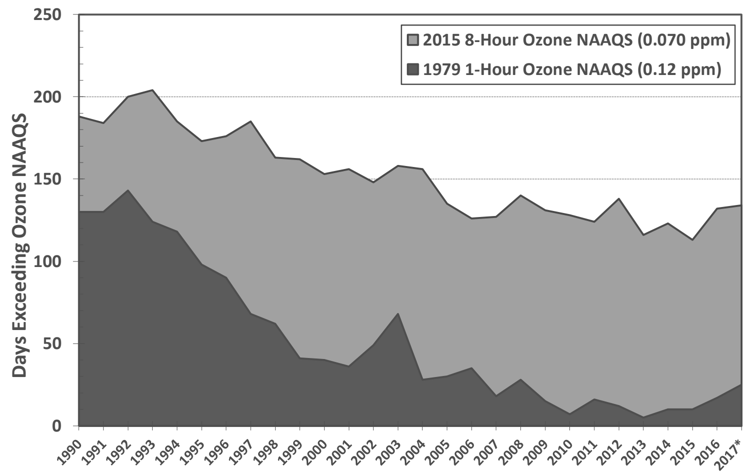


* Based on preliminary 2017 data

South Coast
Air Quality Management District

2

Number of Days Exceeding NAAQS, 1990-2017*



**Based on preliminary 2017 data*

Basin Days Exceeding Ozone NAAQS (70 ppb) by Month and Year

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	0	0	5	11	21	27	30	26	18	7	0	0
2001	0	0	4	9	25	25	28	29	24	10	0	0
2002	0	0	1	11	21	27	30	29	20	7	0	0
2003	0	0	3	3	21	25	30	29	24	16	0	0
2004	0	0	7	11	21	24	29	28	22	6	0	0
2005	0	0	1	10	21	24	31	28	16	5	0	0
2006	0	0	0	3	23	27	27	29	16	1	0	0
2007	0	0	5	5	19	26	28	29	13	1	0	0
2008	0	0	2	11	17	29	31	29	15	5	1	0
2009	0	0	2	6	22	13	29	28	23	6	0	0
2010	0	0	0	8	11	25	31	28	18	2	0	0
2011	0	0	1	7	13	19	26	30	21	5	0	0
2012	0	0	0	9	20	26	26	28	21	8	0	0
2013	0	0	2	7	16	27	28	21	14	1	0	0
2014	0	1	0	7	15	25	25	19	18	13	0	0
2015	0	0	3	11	7	22	18	27	18	6	1	0
2016	0	6	7	8	7	26	30	30	15	3	0	0
2017*	0	0	4	12	16	26	29	29	17	6		

** 2017 based on preliminary data through October 10*

Ongoing Efforts to Understand Increase in Ozone

- Increase in ozone in recent years may be due to the following factors
  - Meteorology
  - Complex chemistry of ozone formation
  - Changes in emissions


Image from Al Pavangkanan https://www.flickr.com/photos/drtran/2186120627

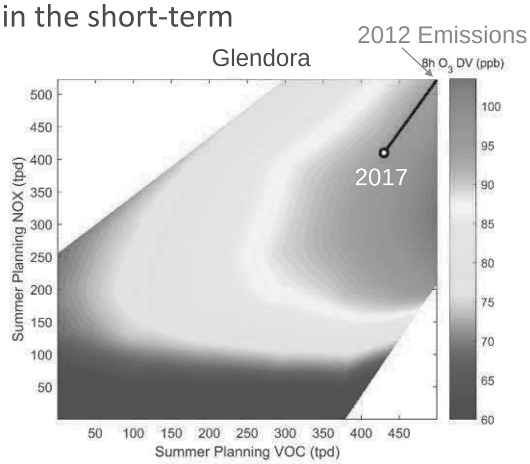
2016 & 2017 Ozone and Meteorology Summary

- Ozone design values and number of days over the federal and state ozone standards increased in 2016 and again in 2017
- The 2016 and 2017 summers were characterized by a very strong, persistent high-pressure ridge aloft and warm temperatures, causing strong temperature inversions and enhanced ozone photochemistry
  - Above average surface temperatures occurred through the summer months in the western third of the U.S.
  - In 2017, California, Oregon, and Washington experienced the warmest month of August on record

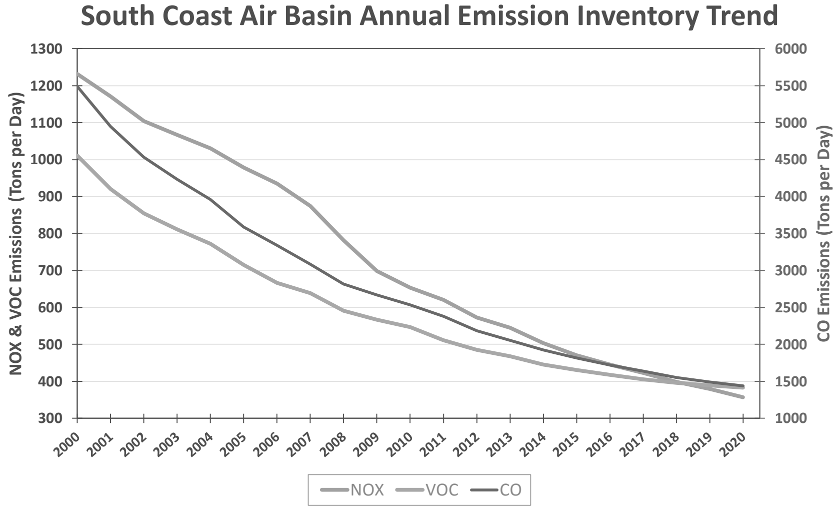
Meteorology in 2016 and 2017 was Conducive to Ozone Formation

Complex Chemistry of Ozone Formation

- A decrease in emissions does not always lead to a decrease in ozone in the short-term



Emission Inventory Projects that NOx and VOC Will Continue to Decrease



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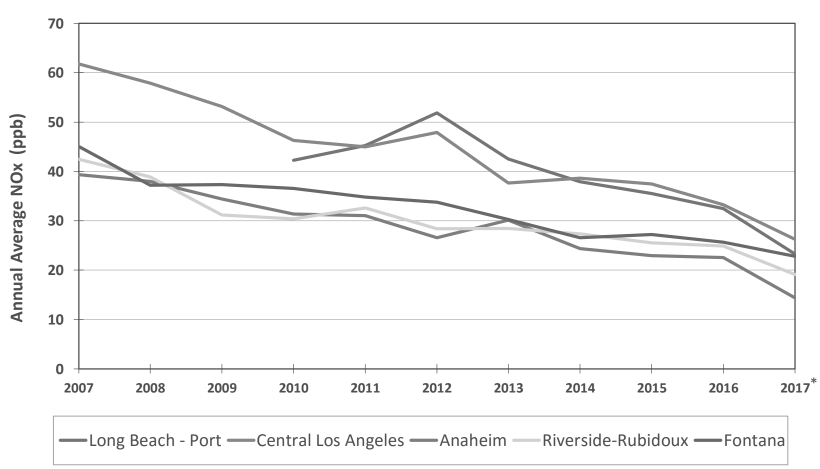
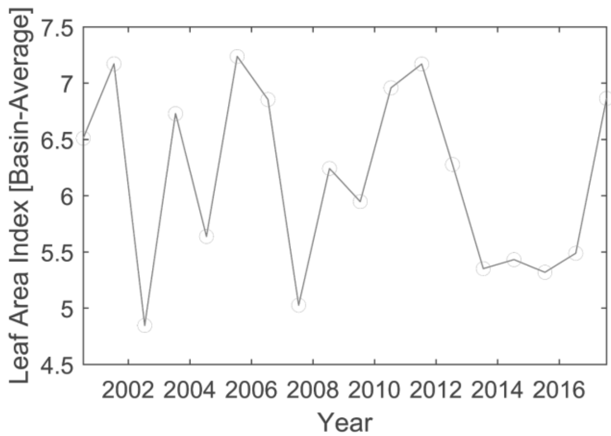
Ambient NOx Trend – Annual Average



* 2017 Data is preliminary, through September

South Coast
Air Quality Management District

Biogenic VOC Emissions Vary Yearly



Large increase in leaf-area in 2017 ozone season

Ongoing Efforts to Improve Emissions Inventory

- Implementation of more accurate biogenic VOC modeling
- Validation with satellite measurements of NO_2
- Increased use of real-time data measurements to spatially and temporally allocate emissions
- Routine updates to inventory

Image from Rennett Stowe: https://www.flickr.com/photos/10393601@N08/5801005238

Summary

- Long-term, ozone shows a downward trend, but with marginal increases in 2016 and 2017
- Year-to-year fluctuations of this magnitude are typical, but needs continual assessment
- Possible reasons for increased ozone include:
  - Meteorology conducive to ozone formation
  - Complex ozone formation chemistry can lead to temporary marginal ozone increases with reduced NOx emissions
  - Unpredicted fluctuations in emissions

April 17, 2018

Trammell Crow Company
3501 Jamboree Road, Suite 230
Newport Beach, California 92660

Attention: Mr. David Drake

Project No.: **16M123-2**

Subject: **Anticipated Grading Operations Discussion**
Buildings D & E
SEC and SWC of Oleander Avenue and Decker Road
Riverside County, California

References: Geotechnical Investigation, Infiltration Study, and Rock Rippability Report for the Proposed Decker Assemblage Industrial Site, Located at the Southeast Corner of Oleander Avenue and Decker Road, Assessor's Parcel Numbers (APN's): 314-040-001, -002, -003, & -008, Western Perris Area, County of Riverside, California, prepared by Matrix Geotechnical Consulting, Inc., dated September 30, 2014.

Geotechnical Investigation and Rock Rippability Report for the Proposed Decker II Assemblage Industrial Site, Located at the Southwest Corner of Oleander Avenue and Decker Road, Assessor's Parcel Numbers (APN's): 314-020-010, -017, -003, and -019, Western Perris Area, County of Riverside, California, prepared by Matrix Geotechnical Consulting, Inc., dated February 19, 2015.

Change of Engineer of Record, Response Report and Plan Review, Building D, SEC Oleander Avenue and Decker Road, Riverside County, California, prepared by Southern California Geotechnical, Inc. (SCG) for Trammell Crow Company (TCC), SCG Project No. 16M123-1, dated June 16, 2016.

Change of Engineer of Record, Response Report and Plan Review, Building E, SWC Oleander Avenue and Decker Road, Riverside County, California, prepared by SCG for TCC, SCG Project No. 16M124-1, dated August 2, 2016.

Geotechnical Report Update and Plan Review, Building E, SWC Oleander Avenue and Decker Road, Riverside County, California, prepared by SCG for TCC, SCG Project No. 16M124-2, dated January 26, 2017.

Gentlemen:

In accordance with the request of the client, we have prepared this letter to address the anticipated grading operations for the subject sites identified as Buildings D and E. Based on information provided to us by the client, these building sites are located southwest and southeast of the intersection of Oleander Road and Decker Road in the County of Riverside, California. Southern California Geotechnical, Inc. (SCG) served as the geotechnical engineer of record for the nearby Nandina Business Center located at 22722 Harley Knox Boulevard, in the County of

Riverside, California. Based on our experience with the geotechnical conditions of the region and on the findings contained in the referenced reports, it is our opinion that the geotechnical conditions beneath the Buildings D and E sites and the Nandina Business Center site are generally similar. Very dense near-surface bedrock requiring blasting operations were encountered at all of these sites. From what SCG observed during our observation and testing for the nearby Nandina Business Center, blasting operations performed without an extensive rock crushing operation were used successfully by the grading contractor to accomplish grading operations. Please note that we have not yet performed a grading plan review to estimate the planned cuts and fills for the project. Also, please note that the means and methods used to accomplish grading operations is the responsibility of the grading contractor. Based on that previous experience and on the generally similar subsurface conditions for the Buildings D and E sites to the Nandina Business Center site, it is considered reasonable to expect that blasting without the need for an extensive rock crushing operation may be utilized to successfully accomplish grading activities at the Building D and E sites.

Closure

We sincerely appreciate the opportunity to be of continued service on this project. We look forward to providing additional consulting services during the course of the project. If we may be of further assistance in any manner, please contact our office.

Respectfully Submitted,

SOUTHERN CALIFORNIA GEOTECHNICAL, INC.

Robert G. Trazo, GE 2655
Principal Engineer

REGISTERED PROFESSIONAL ENGINEER
ROBERT TRAZO
No. 2655
GEOTECHNICAL
STATE OF CALIFORNIA

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April 2, 2018

Mr. Neil Holdridge
Trammell Crow Company
3501 Jamboree Road, Suite 230
Newport Beach, CA 92660

SUBJECT: KNOX BUSINESS PARK BUILDINGS D AND E NOISE BARRIER MEMO

Dear Mr. Neil Holdridge:

Urban Crossroads, Inc. is pleased to submit this Noise Barrier Memo in support of the January 2017 *Knox Business Park Buildings D and E Noise Impact Analysis* ("Noise Study") and the *Final Environmental Impact Report* ("EIR"), which is in unincorporated County of Riverside. This letter has been prepared to provide a comparison of the operational noise barrier attenuation for three different barrier heights:

- The minimum 8-foot high noise barrier identified in the Noise Study;
- The planned 14-foot high Project noise barrier; and
- A 20-foot high noise barrier alternative.

BARRIER ATTENUATION FUNDAMENTALS

Effective noise barriers can reduce noise levels by 10 to 15 dBA which can result in a perceived halving of the loudness of the noise source. A noise barrier is most effective when placed close to the noise source or receiver location, however, they do have limitations. For a noise barrier to be most effective, it must be high enough and long enough to block the path of the noise source and the line-of-sight of the receiver location. Based on the Federal Highway Administration *Highway Traffic Noise Analysis and Abatement Policy and Guidance*, breaking the line-of-sight of the receiver to the noise source provides a minimum of 5 dBA, and every additional increase in height of one meter (roughly 3 feet) results in approximately 1.5 dBA of additional barrier attenuation. Elevation changes and ground conditions can reduce or improve the performance of the noise barrier, and noise barriers are most effective without any openings, gaps, or damage.

PROJECT NOISE BARRIER ATTENUATION

The Noise Study identified a minimum recommended noise barrier height of 8 feet between the Project loading dock areas and the adjacent sensitive receiver locations south of Building D required to satisfy the County of Riverside exterior noise level standards. As shown on Table 1, the 8-foot high noise barrier provides up to 11.0 dBA L_{eq} of noise barrier attenuation based on the geometric relationship between the noise source and receiver locations.

Using the operational noise model and parameters from the Noise Study, this memo calculates the additional barrier attenuation provided by the planned 14-foot high noise barrier and a 20-foot high noise barrier alternative for comparison purposes. Table 1 shows the calculated barrier attenuation provided by each of the three barrier heights, in addition to the increase in barrier attenuation provided by each height increase over the previous, lower barrier height.

TABLE 1: NOISE BARRIER ATTENUATION COMPARISON

Barrier Height	Calculated Noise Barrier Attenuation[1]	Increase in Attenuation[2]
8'	-11.0	n/a
14'	-13.4	-2.4
20'	-15.3	-1.9

[1] See Appendix A for the barrier attenuation calculations.
[2] Increase in barrier attenuation over the previous, lower barrier height.

As shown on Table 1, an increase in the minimum 8-foot high noise barrier to 14-feet results in 2.4 dBA of additional barrier attenuation. Subsequently, the increase to 20 feet results in additional barrier attenuation of 1.9 dBA. The barrier attenuation calculations for each barrier height are provided in Appendix A of this memo. If you have any questions, please contact me directly at (949) 336-5979.

Respectfully submitted,

URBAN CROSSROADS, INC.

Bill Lawson, P.E., INCE
Principal

Alex Wolfe, INCE
Analyst

APPENDIX A:

NOISE BARRIER ATTENUATION CALCULATIONS

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STATIONARY SOURCE NOISE PREDICTION MODEL

3/30/2018

Observer Location:	**R6**	*Project Name:*	Knox Business Park
Source:	Unloading/Docking Activity	*Job Number:*	9349
Condition:	n/a	*Analyst:*	A. Wolfe

NOISE MODEL INPUTS

Noise Distance to Observer	276.0 feet	***Barrier Height:***	**8.0 feet**
Noise Distance to Barrier:	81.0 feet	*Noise Source Height:*	8.0 feet
Barrier Distance to Observer:	195.0 feet	*Observer Height:*	5.0 feet
Observer Elevation:	1,608.0 feet	*Barrier Type (0-Wall, 1-Berm):*	0
Noise Source Elevation:	1,580.0 feet	*Drop Off Coefficient:*	20.0
Barrier Elevation:	1,600.0 feet		

20 = 6 dBA per doubling of distance
15 = 4.5 dBA per doubling of distance

NOISE MODEL PROJECTIONS

Noise Level	*Distance (feet)*	*Leq*	*L50*	*L25*	*L8*	*L2*	*Lmax*
Reference (Sample)	30.0	67.2	0.0	0.0	0.0	0.0	0.0
Distance Attenuation	276.0	-19.3	-19.3	-19.3	-19.3	-19.3	-19.3
Shielding (Barrier Attenuation)	81.0	-11.0	-11.0	-11.0	-11.0	-11.0	-11.0
Raw (Distance + Barrier)		36.9	-30.3	-30.3	-30.3	-30.3	-30.3
60 Minute Hourly Adjustment		**36.9**	**-30.3**	**-30.3**	**-30.3**	**-30.3**	**-30.3**

STATIONARY SOURCE NOISE PREDICTION MODEL

3/30/2018

Observer Location:	**R6**	*Project Name:*	Knox Business Park
Source:	Unloading/Docking Activity	*Job Number:*	9349
Condition:	n/a	*Analyst:*	A. Wolfe

NOISE MODEL INPUTS

Noise Distance to Observer	276.0 feet	***Barrier Height:***	**14.0 feet**
Noise Distance to Barrier:	81.0 feet	*Noise Source Height:*	8.0 feet
Barrier Distance to Observer:	195.0 feet	*Observer Height:*	5.0 feet
Observer Elevation:	1,608.0 feet	*Barrier Type (0-Wall, 1-Berm):*	0
Noise Source Elevation:	1,580.0 feet	*Drop Off Coefficient:*	20.0
Barrier Elevation:	1,600.0 feet		

20 = 6 dBA per doubling of distance
15 = 4.5 dBA per doubling of distance

NOISE MODEL PROJECTIONS

Noise Level	*Distance (feet)*	*Leq*	*L50*	*L25*	*L8*	*L2*	*Lmax*
Reference (Sample)	30.0	67.2	0.0	0.0	0.0	0.0	0.0
Distance Attenuation	276.0	-19.3	-19.3	-19.3	-19.3	-19.3	-19.3
Shielding (Barrier Attenuation)	81.0	-13.4	-13.4	-13.4	-13.4	-13.4	-13.4
Raw (Distance + Barrier)		34.5	-32.7	-32.7	-32.7	-32.7	-32.7
60 Minute Hourly Adjustment		**34.5**	**-32.7**	**-32.7**	**-32.7**	**-32.7**	**-32.7**

STATIONARY SOURCE NOISE PREDICTION MODEL

3/30/2018

***Observer Location:* R6**
Source: Unloading/Docking Activity
Condition: n/a

Project Name: Knox Business Park
Job Number: 9349
Analyst: A. Wolfe

NOISE MODEL INPUTS

Noise Distance to Observer 276.0 feet
Noise Distance to Barrier: 81.0 feet
Barrier Distance to Observer: 195.0 feet

Observer Elevation: 1,608.0 feet
Noise Source Elevation: 1,580.0 feet
Barrier Elevation: 1,600.0 feet

Barrier Height: **20.0 feet**
Noise Source Height: 8.0 feet
Observer Height: 5.0 feet

Barrier Type (0-Wall, 1-Berm): 0
Drop Off Coefficient: 20.0

20 = 6 dBA per doubling of distance
15 = 4.5 dBA per doubling of distance

NOISE MODEL PROJECTIONS

Noise Level	*Distance (feet)*	*Leq*	*L50*	*L25*	*L8*	*L2*	*Lmax*
Reference (Sample)	30.0	67.2	0.0	0.0	0.0	0.0	0.0
Distance Attenuation	276.0	-19.3	-19.3	-19.3	-19.3	-19.3	-19.3
Shielding (Barrier Attenuation)	81.0	-15.3	-15.3	-15.3	-15.3	-15.3	-15.3
Raw (Distance + Barrier)		32.6	-34.6	-34.6	-34.6	-34.6	-34.6
60 Minute Hourly Adjustment		**32.6**	**-34.6**	**-34.6**	**-34.6**	**-34.6**	**-34.6**

WHITE PAPER

SEPTEMBER 2017

TRANSITIONING TO ZERO-EMISSION HEAVY-DUTY FREIGHT VEHICLES

Marissa Moultak, Nic Lutsey, Dale Hall

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ACKNOWLEDGMENTS

This work was conducted for the International Zero-Emission Vehicle (ZEV) Alliance and is supported by its members (British Columbia, California, Connecticut, Germany, Maryland, Massachusetts, the Netherlands, New York, Norway, Oregon, Québec, Rhode Island, the United Kingdom, and Vermont). Members of the ZEV Alliance provided key input on activities, demonstrations, and policy in each of their jurisdictions. Josh Miller provided key data inputs to evaluate truck emissions. Members of the ZEV Alliance provided critical reviews on an earlier version of the report. Their review does not imply an endorsement, and any errors are the authors' own.

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EXECUTIVE SUMMARY

A clear path toward decarbonization of the heavy-duty freight sector has been elusive. Barriers to the growth of electric and hydrogen fuel cell heavy-duty commercial freight trucks include limited technology availability, limited economies of scale, long-distance travel requirements, payload mass and volume constraints, and a lack of refueling and recharging infrastructure. Many governments and companies are seeking to break down such barriers to help decarbonize heavy-duty freight trucks.

In this report, we assess zero-emission heavy-duty vehicle technology to support decarbonization of the freight sector. We compare the evolution of heavy-duty diesel, diesel hybrid, natural gas, fuel cell, and battery electric technologies in the 2025–2030 timeframe. We synthesize data from the research literature, demonstrations, and low-volume commercial trucks regarding their potential to deliver freight with zero tailpipe emissions. We analyze the emerging technologies by their cost of ownership and life-cycle greenhouse gas emissions for the three vehicle markets of China, Europe, and the United States.

Based on this work, we assess the relative advantages and disadvantages among the various emerging electric-drive technologies. Table ES-1 summarizes our findings regarding the zero-emission heavy-duty vehicle technology benefits and barriers to widespread adoption. The table shows results for the three main zero-emission technology areas: plug-in electric, catenary or in-road charging electric, and hydrogen fuel cell vehicles. Each technology offers the prospect of lower carbon emissions, no tailpipe emissions, and greater renewable energy use. Matching specific electric and hydrogen technologies to particular truck segments can help overcome barriers such as traveling range, infrastructure, and recharging time.

Table ES-1. Summary of promising segments, benefits, and barriers for zero-emission heavy-duty freight vehicle technologies.

Technology	Benefits	Prevailing barriers to widespread viability	Promising segments for widespread commercialization
Electric (plug-in)	• Reduce greenhouse gas emissions • Eliminate local air pollution • Reduce fueling costs • Reduce maintenance costs • Increase energy efficiency • Increase renewable energy use	• Limited electric range • Vehicle cost (battery) • Charging time (unless battery swapping is utilized) • Cargo weight and size	• Light commercial urban delivery vans • Medium-duty regional delivery trucks • Refuse trucks
Electric (catenary or in-road charging)	• Reduce greenhouse gas emissions • Eliminate local air pollution • Reduce fueling costs • Reduce maintenance costs • Increase energy efficiency • Increase renewable energy use • Enable regional travel	• Infrastructure cost • Standardization across regions • Complete infrastructure network before vehicle deployment • Visual obstruction (catenary)	• Medium-duty trucks and heavy-duty tractor-trailers on medium-distance routes with high freight use • Drayage trucks around ports
Hydrogen fuel cell	• Reduce greenhouse gas emissions • Eliminate local air pollution • Increase energy efficiency • Enable quick refueling time • Increase renewable energy use	• Refueling infrastructure cost • Renewable hydrogen cost • Vehicle costs (fuel cell)	• Heavy-duty tractor-trailers in long-haul operation • Drayage trucks around ports

We also assess and discuss these factors to better understand the prospects for widespread commercialization over the 2025 and beyond timeframe. Based on the research findings, we draw the following three conclusions regarding emerging vehicle zero-emission technologies for heavy-duty vehicles.

Electric-drive heavy-duty vehicle technologies are essential to fully decarbonize the transport sector. Heavy-duty freight trucks are disproportionate contributors to pollution, representing less than one tenth of all vehicles but roughly 40% of their carbon emissions, and their activity keeps growing. Electric-drive technologies, similar to those being commercialized in cars, will be essential to decarbonize the heavy-duty sector and help meet climate stabilization goals. Whereas the more efficient potential diesel technologies can reduce carbon emissions by about 40%, electric-drive technologies powered by renewable sources can achieve over an 80% reduction in fuel life-cycle emissions.

By 2030, electric-drive heavy-duty vehicle technologies could offer cost-effective opportunities for deep emission reductions. Major projects involving heavy-duty electric and hydrogen fuel cell vehicle technologies show great potential due to their much greater efficiency and use of available low-carbon fuel sources. We find that overhead catenary electric heavy-duty vehicles would cost approximately 25%–30% less, and hydrogen fuel cells at least 5%–30% less, than diesel vehicles to own, operate, and fuel in the 2030 timeframe. Key drivers for cost-effectiveness are battery pack costs dropping to below $150 per kilowatt-hour, hydrogen fuel costs dropping to below the per-energy-unit cost of diesel, and the cost of the associated infrastructure decreasing over time.

Different electric-drive technologies are suitable for different heavy-duty vehicle segments, but massive infrastructure investments would be needed. Advances in battery packs and other electrical components will enable shorter distance urban commercial vans to become plug-in electric, similar to cars. Battery electric vehicles with overhead catenary or in-road charging can enable electric zero-emission goods transport on and around heavily traveled freight corridors. Hydrogen fuel cell technology might be especially key for longer-distance duty cycles. These technologies each have formidable barriers and will require sustained and extensive infrastructure investments by government and industry (e.g., overhead transmission, in-road charging, hydrogen refueling stations).

I. INTRODUCTION

The transition to electric-drive vehicles is widely regarded as critical for the transportation sector. Electric-drive vehicles, including battery electric, plug-in hybrid, and hydrogen fuel cell vehicles, offer the potential for a vehicle fleet to shift away from petroleum fuels and bring dramatic emission reductions that are needed to achieve long-term air quality and climate change goals. The transition to electric drive is already beginning for passenger automobiles, with millions of electric cars on roads around the world as of early 2017, and the same technology is now available for light commercial vans. In addition, hundreds of thousands of electric buses have been put into local service. Progress with heavy-duty commercial freight vehicles has been more limited, with dozens of demonstrations and prototypes, but few commercial offerings around the world.

There is growing interest in deploying advanced technologies in heavy-duty freight vehicles for a number of reasons, including climate change, energy diversification, and local air quality. The challenge of climate change provides a major overarching motivation for most major national and local governments, and the breakdown of truck activity helps underscore the imperative to focus not just on cars, but on heavy-duty freight vehicles as well.

Figure 1 summarizes the breakdown of the world vehicle population, travel activity, and greenhouse gas emissions. Freight trucks, which primarily operate on diesel (and sometimes gasoline or natural gas), account for a large and growing share of local pollutant and greenhouse gas emissions. Despite representing merely 9% of the global vehicle stock and 17% of the total vehicle miles driven, freight trucks accounted for approximately 39% of the life-cycle road vehicle greenhouse gas emissions, with the share being even higher for other pollutants (ICCT, 2017; Miller and Façanha, 2014).

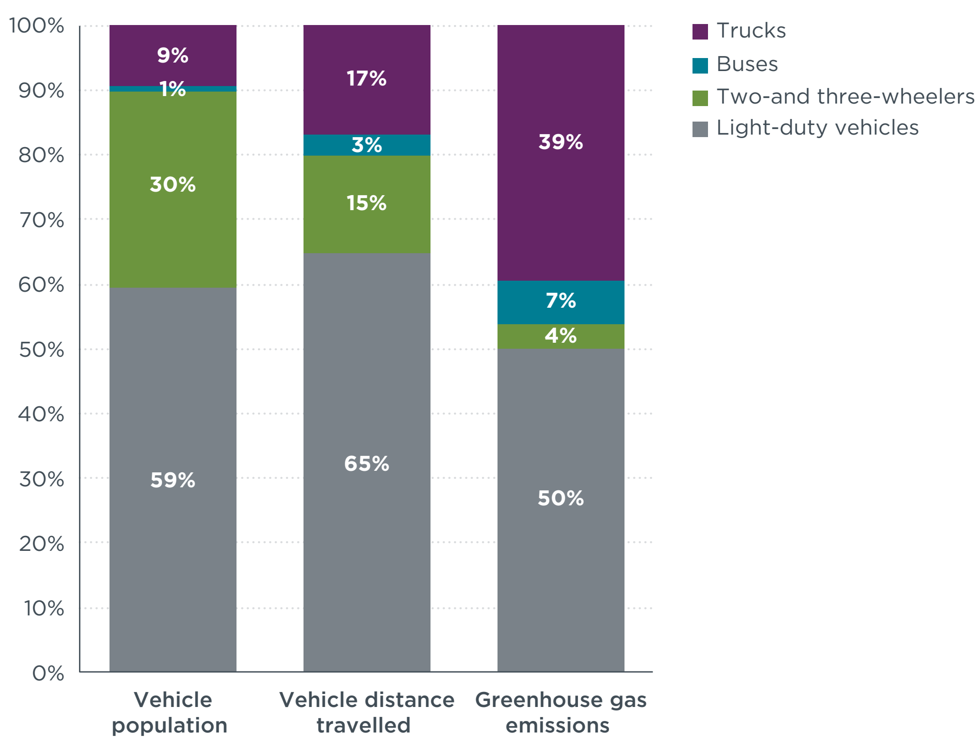

Figure 1. Global vehicle stock, distance traveled, and life-cycle road transport greenhouse gas emissions by vehicle type in 2015.

Heavy-duty vehicles' disproportionate contribution to global greenhouse gas emissions is expected to increase for decades to come due to a substantial increase in road freight activity. Figure 2 illustrates the global freight activity and the life-cycle greenhouse gas emissions in carbon dioxide equivalent (CO_2e) from 2015 projected through 2050 (ICCT, 2017; Miller and Façanha, 2014). The figure shows freight activity for light, medium, and heavy trucks in trillions of freight payload multiplied by distance traveled (corresponding to the left axis). The figure also, with the grey line, illustrates the associated life-cycle greenhouse gas emissions, including vehicle exhaust and upstream emissions to produce the trucks' fuels, based on business-as-usual vehicle efficiency trends (right axis). As shown, from 2015 to 2050, global truck freight activity and truck life-cycle greenhouse gas emissions are estimated to at least double under the business-as-usual scenario. The figure also illustrates how much of the heavy-duty freight activity is from the heaviest trucks—typically these are combination tractor-trailers with the tractors classified as Class 8 in the North America, or trucks with greater than 15-ton weight capacity in Europe. These heaviest vehicles represent over 60% of the freight truck metric ton-kilometer activity and over 75% of the freight truck carbon dioxide (CO_2) emissions and are the primary focus of this report.

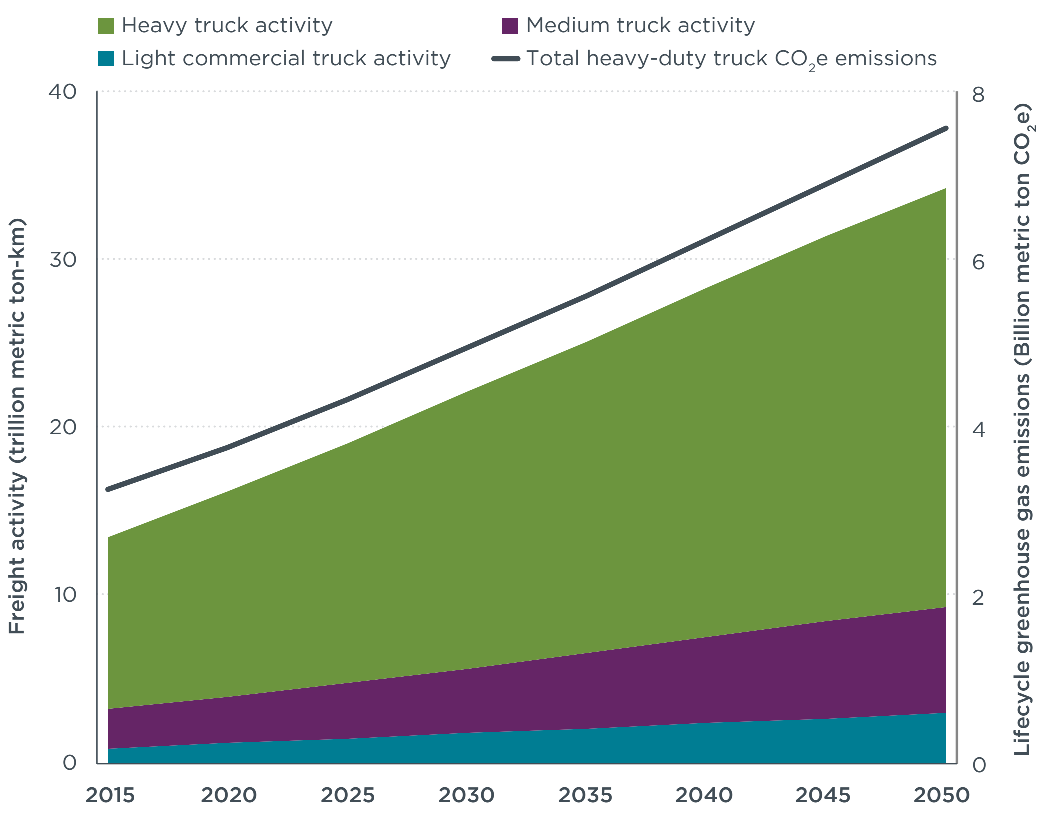

Figure 2. Projected global freight activity and life-cycle greenhouse gas emissions from 2015 to 2050.

In addition to the climate issues associated with the greenhouse gas emissions from freight transport, the associated local air pollution, particularly of oxides of nitrogen and particulate matter emissions, negatively impacts health and quality of life, particularly in areas near concentrated freight activity. These burdens are disproportionally experienced by the communities that live closest to freight hubs and corridors, most typically populated by low-income residents.

Although increased vehicle efficiency and modern aftertreatment technology to reduce tailpipe emissions offer the lowest-cost emissions reductions, there are a number of more advanced emerging zero-emission vehicle technologies that could bring much deeper reductions. The increasing scale of electric car production, with cumulative global electric cars sales surpassing 2 million in the beginning of 2017, brings forth major cost reductions in batteries. New longer range models are paving the way for mainstream adoption. Furthermore, charging infrastructure to support such vehicles continues to grow (Hall & Lutsey, 2017). Feeding the progress, governments around the world are setting ever-ambitious targets to phase out combustion in favor of electric cars and reinforcing efforts with supporting policy, incentives, and infrastructure (e.g., see Lutsey, 2015; Lutsey, 2017; Slowik & Lutsey, 2016).

Many governments seek to break down barriers to help decarbonize heavy-duty freight trucks by leveraging their ongoing progress on electric cars. The activity and emissions trends introduced above increasingly indicate that long-term climate and air quality goals require that all major transport modes, including those for commercial freight, move toward much lower emissions, including with the broad application of plug-in electric and hydrogen fuel cell technology. Many of these technologies, in greater use in light-duty vehicles, are also being explored for deployment in heavy-duty freight vehicles.

Zero-emission buses are being deployed in growing numbers, and this could also help pave the way for zero-emission freight. Through 2016, this market development has been dominated by China; the country had over 280,000 electric buses, or over 95% of the world electric bus market (EV sales, 2017a, 2017b). Deployments of all-electric, plug-in hybrid, and fuel cell buses in Europe and the U.S. are increasing (e.g., Eudy, Post, & Jeffers, 2016; European Alternative Fuels Observatory, 2017). These bus deployments increase the production volume of batteries, fuel cell stacks, on-vehicle power electronics, electric motors, and charging and refueling equipment. This increasing component volume helps the development of a supplier base that is also likely to support heavy-duty freight technology. Likewise, the growing experience of charging and refueling providers on these bus deployments puts them in stronger position for installations for similar zero-emission freight applications in the future.

To inform such government activities on zero-emission heavy-duty vehicles, it is important to gain a clearer understanding of the potential viability for the various zero-emission heavy-duty vehicle technologies. Especially for the heaviest long-haul tractor-trailers, the activity and emissions appear to be the most problematic, and there appears to be a number of potential technology paths. Which technologies are most appropriate for which applications? What are the potential climate benefits of these vehicles considering their various fuel sources? What are the associated vehicle technology costs? This paper seeks to address these questions and discuss the potential for an electric drive heavy-duty fleet.

To help address these questions about the potential for deep emission cuts for heavy-duty vehicles, we focus on electric and hydrogen fuel cell vehicle technologies. Various forms of these technologies would leverage electric and fuel cell developments in cars, light-commercial vans, and buses. Beyond simply plugging in to the electric grid, electric heavy-duty vehicles could use battery swapping stations or “e-roads” with inductive dynamic charging embedded in roadways or via overhead catenary electricity transmission. E-roads provide a continuous source of power to vehicles, directly transmitting electricity to the electric motor and charging an on-board battery.

When these catenary systems are deployed on various highway segments, they allow for greater range and significantly smaller batteries. The vehicles used on e-roads are equipped with either full electric drivetrains, where the pantograph or inductive coils and power electronics are combined with a battery pack, or a hybrid drivetrain, with a combustion engine. The hybrid drivetrain or additional battery capacity allow the vehicle to travel greater range from the e-roads. Fuel cells use on-board hydrogen storage and electrochemically convert hydrogen to electricity to power the vehicle to enable long-range and quick fuel times. Each of these options provides the potential for much greater on-vehicle efficiency and renewable energy sources.

In Section II, we review heavy-duty vehicle technology developments to compile data from the research literature, demonstration fleets, and low-volume commercial truck models and provide context for analysis of zero-emission technologies that follows. Then, in Section III, we assess the major vehicle technologies, comparing the evolution of diesel, diesel hybrid, natural gas, fuel cell, battery electric, dynamic induction grid, and overhead catenary in the 2025–2030 timeframe in a vehicle-related cost-of-ownership framework. In Section IV, we analyze these technologies by their life-cycle greenhouse gas emissions, including upstream fuel cycle emissions, based on the three vehicle markets of China, Europe, and the U.S. Finally, in Section V, we summarize and discuss the results.

II. REVIEW OF HEAVY-DUTY VEHICLE TECHNOLOGY DEVELOPMENTS

To provide context and additional background for the analysis below, this section first introduces existing heavy-duty vehicle policy. In the subsequent subsections, we summarize the associated research literature, physical truck demonstrations, and announced commercial truck offerings regarding zero-emission heavy-duty vehicle technologies.

HEAVY-DUTY VEHICLE POLICY BACKGROUND

Because of the projected increase in heavy-duty activity, and with more stringent efficiency standards implemented for light-duty vehicles compared to heavy-duty-vehicles, the portion of greenhouse gas emissions from heavy-duty vehicles is expected to continue to increase under business-as-usual conditions. A primary driver for this trend is that freight vehicle efficiency will tend to remain relatively constant without regulations that require available efficiency technologies be deployed (Davis, Williams, & Boundy, 2016; Muncrief & Sharpe, 2015). To date, only a handful of countries—Canada, China, Japan, and the U.S.—have implemented efficiency and greenhouse gas emissions standards. The European Union is widely expected to propose heavy-duty CO_2 regulations in the near future. Standards in the EU will likely open the doors for other countries in Asia and Latin America that pattern their standards on the European Commission's vehicle regulations. Less than half of heavy-duty new vehicle sales globally are regulated for efficiency or CO_2, compared to over 80% of the world's passenger vehicles (Miller and Façanha, 2014).

By improving engine efficiency, aerodynamics, and aftertreatment technology, there is the potential for substantial, highly cost-effective improvements in heavy-duty vehicle efficiency and emissions. In the U.S., the efficiency and CO_2 regulations will cut business-as-usual heavy-duty vehicle fuel use by over one third by 2050 (Sharpe et al., 2016). Although the necessary technology improvements to meet those standards have an associated increase in technology costs, the fuel efficiency improvements lead to expected payback periods ranging from 2 to 4 years for the various vehicle types. The efficiency regulations include special provisions for electric trucks (e.g., disregarding upstream emissions and providing multipliers to count them multiple times), but they are not expected to play significantly in regulatory compliance (Lutsey, 2017; U.S. EPA and U.S. DOT, 2016). Electric-drive truck technology is similarly not needed to comply with near-term conventional pollutant emission regulations, where technologies such as exhaust gas recirculation systems and diesel particulate filters can greatly reduce negative health impacts associated with heavy-duty diesel engines. For manageable costs of approximately $7,000 per vehicle, nitrogen oxide (NO_x) and particulate matter (PM) emissions could be reduced by over 95% (Posada, Chambliss, & Blumberg, 2016) for vehicles that can typically cost well over $100,000.

These technologies are attractive for near-term progress, but this incremental approach is more limited in the long-term, when much deeper emission cuts are necessary to meet government environmental goals and global climate protection commitments. In the 2030–2045 timeframe, advanced efficiency technologies are expected to offer a potential fuel consumption reduction of 40%–52% in combination tractor-trailers, and up to 30%–36% for rigid delivery trucks (Delgado, Miller, Sharpe, & Muncrief, 2016). Looking beyond truck efficiency improvements, freight transport efficiency gains through further optimization of routes and sharing trucks and warehouses between companies could reduce CO_2 emissions by one third (OECD/ITF, 2017). In addition, biofuels can be a partial solution, if and when broader sustainability and indirect land use change impacts are more fully addressed. However, with the anticipated increase in heavy-duty vehicle freight shipping and with their slow fleet turnover, even widespread adoption of these approaches would still not result in a net improvement in CO_2 emissions and fuel consumption in 2050 compared to 2015. To meet international climate stabilization goals, more ambitious emissions-reduction approaches, including zero-emission heavy-duty vehicles using low-carbon upstream energy sources, will be necessary.

REVIEW OF RESEARCH LITERATURE

Although few zero-emission heavy-duty commercial freight vehicles are on the road today, a variety of studies over the past 5 years have considered the feasibility of a number of technologies and their potential to reduce emissions. Table 1 lists the associated technical research studies and identifies the vehicle types, technologies, and analytical estimates in each report. Because of the uncertain and quickly changing technologies involved, cost estimates and conclusions vary greatly between the reports. In addition, the scope of each report varies greatly, including which region, truck types, duty cycles, and fuel cost assumptions were considered.

Table 1. Quantitative studies of medium- and heavy-duty electric-drive vehicles.

			Vehicle Types			Technology			Analysis		
Study	Region	Timeframe	LCV	MDV	HDV	Battery electric	Fuel Cell	Catenary	Cost	CO_2	Fleet
den Boer, Aarnink, Kleiner, & Pagenkopf, 2013	Europe	2030		X	X	X	X	X	X	X	
Fulton & Miller, 2015	California	2050			X	X	X		X	X	X
Gladstein, Neandross & Associates, 2012	California	2020			X	X	X	X	X		X
Wood, Wang, Gonder, & Ulsh, 2013	United States	Present	X	X		X	X		X		
Silver & Brotherton, 2013	California	2050		X	X	X				X	X
Kleiner et al, 2015	Europe, South Korea, Turkey	Present	X			X	X		X		X
CARB, 2015a	California	2030		X	X	X			X		X
CARB, 2015b	California	2025		X	X		X		X		X
Zhao, Burke, & Zhu, 2013	United States	Present			X	X	X		X	X	
Connolly, 2016	Denmark	2050			X	X		X	X	X	
Löfstrand et al., 2013	Sweden	2025		X	X	X			X		
Sen, Ercan, & Tatari, 2016	United States	2040			X	X			X	X	
Lee & Thomas, 2016	United States	Present		X		X			X	X	

LCV = light commercial vehicle; MDV = medium-duty vehicle; HDV = heavy-duty vehicle

Based on the research literature, plug-in electric vehicles are being considered for a number of applications in the medium- and heavy-duty sectors. Electric vehicles' high efficiency, generally 3 to 4 times more efficient than diesel and natural gas engines, results in a reduction in primary energy use and greenhouse gas emissions (e.g., Chandler, Espino, & O'Dea, 2016). These vehicles are most suited for applications with short ranges and duty cycles that can take advantage of regenerative braking and where required electric battery packs sizes are lower (CARB, 2015b). An analysis of duty cycles suggests urban delivery vans and delivery trucks, refuse trucks, and drayage trucks as targets for electrification (Kelly, 2016).

The potential for electric-drive medium-duty delivery trucks was analyzed in several different studies. Löfstrand et al. (2013) estimate that battery electric trucks will have the lowest total cost of ownership of any powertrain option by 2025 for scenarios with short routes and high utilization. Similarly, the California Hybrid, Efficient and Advanced Truck Research Center expects electrified delivery trucks to be ready for widespread commercial implementation, with a 3- to 5-year return-on-investment, around 2020 (Silver & Brotherton, 2013). Other assessments are even more optimistic, with one showing that battery electric delivery vehicles are already cheaper in total cost of ownership than diesel vehicles in several countries when considering tax policies (Kleiner et al., 2015).

Battery-powered drivetrains could also be used in other types of heavy-duty vehicles, including various types of vocational vehicles. Drayage trucks, which operate over shorter distances (less than 60 miles) around ports, could be an early market for heavy-duty truck electrification (Chandler et al., 2016). Refuse trucks, which have similar duty cycles to urban buses and are based out of a central location each day, are potentially well suited to be powered by batteries, reducing noise and pollution in urban environments (CARB, 2015a).

To overcome the charging time barrier of plug-in battery electric medium- and heavy-duty vehicles, battery-swapping technology could be used. Such an approach would require that truck or tractor designs accommodate multiple daily battery pack swaps, battery-swapping stations are deployed on key routes, and a larger stock of battery packs is managed as a system. The time to replace the battery would then become competitive with refueling time, but they would still require more stops daily than conventional diesel if used on long-haul operation (see den Boer et al., 2013). Because of the infrastructure and system level complexities, only a few projects have been become operational. Since 2013, a fleet of electric buses in Qingdao, China, have extensively utilized battery swapping, and testing is expected on electric trucks in Québec starting in 2018 (La Presse, 2016; Phoenix Contact, 2013). The India-based partnership between Ashok Leyland and Sun Mobility also began investigating options in 2017 for a battery-swapping system, starting with bus and delivery van applications (Mohile, 2017).

Fuel cells are also receiving significant attention as an option for medium- and heavy-duty applications. Using hydrogen as their fuel source, fuel cell electric vehicles offer longer ranges with shorter refuel times, compared to battery-electric vehicle recharging. Fuel cell stacks, capable of greater than 50% efficiency, are much more efficient than diesel systems, which typically have maximum engine efficiencies of 37%–39% (Chandler et al., 2016; Thiruvengadam et al., 2014). Several studies have identified fuel cells as a potential solution to applications like suburban delivery trucks, drayage trucks, and shuttle buses where flexibility and long range is needed. One estimate suggests that hydrogen fuel-cell range-extending motors become competitive with plug-in electric vehicles at ranges over

60 miles, although falling battery prices may affect this trade-off (Wood et al., 2013). Nonetheless, hydrogen-powered vehicles face challenges, including high hydrogen costs and a lack of refueling infrastructure, which government interventions are seeking to overcome (CARB, 2015b). Because of the high costs of fuel cells and hydrogen, Kleiner et al. (2015) calculate that fuel cell delivery vehicles have higher total cost of ownership compared to conventional, hybrid, or battery electric vehicles.

E-roads and catenary electric-drive technologies have also been proposed as a long-term solution for the heavy-duty sector. Such projects have higher infrastructure costs and are therefore primarily considered for heavily used freight corridors (e.g., near ports or highways between major cities). Despite these high up-front investments, catenary-hybrid trucks offer low fuel and maintenance costs, and one study found them to be competitive with conventional heavy-duty Class 8 vehicles (i.e., those over 15-ton weight capacity) for near-dock drayage applications (Gladstein, Neandross & Associates, 2012). This technology, whether combined with an internal combustion engine or a limited battery system, results in lower vehicle prices compared to full electric or fuel cell heavy-duty trucks, but the primary obstacle is the construction of a catenary system (den Boer et al., 2013). Other types of "e-roads" are also under consideration, including inductive charging and conductive on-road strips. These systems could potentially lower infrastructure costs and enable use by a wider variety of vehicles and be relatively cost-effective in the future, although these technologies are generally less mature than overhead catenary systems (Connolly, 2016).

DEMONSTRATIONS AND EXAMPLES

Electric vehicles are starting to enter the medium- and heavy-duty vehicle markets through fleets and demonstration projects. Electric transit buses, school buses, shuttle buses, and medium-duty vehicles (primarily for delivery purposes) are becoming increasingly commercially available, but the transition to zero-emission heavy-duty long-haul tractor-trailers is particularly challenging and is currently only in the prototype phase. The various zero-emission vehicle technologies face cost barriers, and in some cases real-world performance barriers as well, but the demonstration projects help resolve such issues while costs are decreasing.

Tables 2 through 5 summarize available information on such zero-emission truck projects across vehicle technology types and vehicle classes. The demonstration projects are categorized according to medium-duty electric (Table 2), heavy-duty electric (Table 3), in-road and catenary electric charging (Table 4), and hydrogen fuel cell trucks (Table 5). We apply the approximate designation of "medium-duty" as U.S. weight Classes 3 through 6 (below 12-metric ton gross curb weight in Europe) and typically straight trucks, and "heavy-duty" as U.S. weight Classes 7 and 8 (above 12 metric tons in Europe) that are normally combination tractor-trailers. However, there is some ambiguity in that the demonstration truck projects do not all have clear weight specifications, and some of the projects span vehicle types. As shown, the wide-ranging zero-emission truck initiatives cover a spectrum of technologies, locations, fleet applications, manufacturer and other stakeholders, and truck fleet sizes.

Table 2. Medium-duty electric vehicle demonstration projects.

Technology	Organization	Location	Time frame	Description	Source
Class 6 electric delivery trucks	Frito Lay	United States	2013	More than 250 Smith Newton electric delivery trucks. Project evaluates 10 of these delivery trucks to better understand the effectiveness of electric trucks in real-world applications.	Frito Lay, (2016); Prohaska, Ragatz, Simpson, & Kelly (2016)
Fuso Canter E-Cell/ Fuso eCanter	Daimler Trucks	Portugal	2014–2015	Eight vehicles used in trials for short-range delivery and inner-city transport.	FUSO (2015)
		Stuttgart, Germany	2016	Testing of five Fuso Carter E-Cell trucks by the parcel service provider Hermes.	Daimler (2016a,b)
Electric delivery vehicles for urban distribution	CWS, Boco, UPS, Smith Electric Vehicles, EFA-S, TCDi, Busch-Jaegen	North Rhine-Westphalia, Germany	2011–2015	A 2-year demonstration project that took data of 107,402 km driven by battery-powered electric trucks for urban distribution.	Stütz (2015)
Electric delivery trucks	Renault Trucks	Paris, France	2015	Testing of the all-electric D-range on delivery rounds of over 200 km with multiple battery recharge times during a 24-hour operating cycle.	Volvo Group (2015)
E-trucks—all electric trucks with refrigerated body	Renault Trucks	Switzerland	2016	Renault Trucks is testing two concept trucks that combined Renault's all-electric Midlum with an electric powered refrigerated body capable of carrying 3 metric tons of refrigerated products.	Volvo Group (2015)
Electric parcel and letter delivery trucks	German Post AG, StreetScooter GmbH, Langmatz GmbH, RWTH Aachen University, BMUB	Bonn, Germany	2012–2016	CO_2 GoGreen aimed to improve the vehicle technology, infrastructure technology, energy supply, and process design for using electric vehicles in parcel and letter delivery.	Appel (2013); BMUB (2016c)
Maxity electric delivery truck	Renault Trucks	France	2010	Pilot customers operated between 10 and 30 pre-production all electric trucks for deliveries.	Renault Trucks (2010)
Electric parcel delivery trucks	CalHEAT, California Energy Commission, Navistar, FCCC, Smith	Southern California	2012	Comprehensive performance evaluation of 3 E-Truck models using in-use data collection, on-road-testing, and chassis dynamometer testing.	Gallo & Tomić (2013)
Electric delivery truck	UPS, EVI	California	2013	UPS deployed 100 electric medium-duty delivery trucks to their California fleet, offsetting 126,000 gallons of conventional motor fuel per year.	EVI (2011); UPS (2017)
Electric delivery trucks	BAAQMD, CARB, San Francisco Goodwill, the Center for Transp. and Environment, BYD Corp.	Bay Area, California	2017	Goodwill is introducing 11 all-electric trucks to its truck fleet in 3 Californian counties, a $4.4 million project funded through California's cap-and-trade program, BAAQMD, and Goodwill.	CARB (2016a, 2016b)
Electric delivery trucks	SJVUAPCD, Motiv Power Systems, AmeriPride Services, CALSTART, First Priority Bus Sales	Central Valley, California	2016	Deployment of 20 zero-emission electric walk-in-vans and the necessary charging infrastructure for deliveries in the Central Valley, focused on disadvantaged communities. Funded through $7.1M grant from CARB, $5.8M from partners.	CARB (2016a, 2016b); SJVUAPCD (2016)
Electric parcel delivery truck	SJVAPCD, USPS, EDI, Motiv Power Systems, Morgan Olson, CALSTART, SunEdison	Stockton & Fresno, California	2016	Deployment of 15 all electric USPS "step vans" and the necessary charging infrastructure to form the basis of a USPS Advanced Vehicle Cluster. The project received $4.5M in California funds.	CARB (2016a, 2016b)
Electric delivery truck	UPS, H-GAC, CTE, US DOE, Workhorse Group	Houston-Galveston area, Texas	2015	Deployment of 18 all electric delivery trucks, estimated to avoid the consumption of 1.1 million gallons of diesel fuel over 20 years.	UPS (2015)
Electric delivery truck	UPS Limited	Feltham, UK	2017	Implementation of a smart charging system with energy storage to increase the number of vehicles that can be charged at a depot.	UK (2017)
Electric delivery vehicles	Gnewt Cargo	Southwark, UK	2017	Lease of 33 electric vehicles for last-mile logistics.	UK (2017)
Electric delivery truck	Nordresa, Purolator	Québec, Canada	2017	Purolator is testing of an all-electric delivery truck developed by Nordresa. The trials show electric trucks saving an average of 0.60 $CAN per kilometer resulting in profitable operation within 2 years.	AVEQ (2017)
Electric delivery truck	UPS, FREVUE	Rotterdam, Netherlands; London, UK	2014–2015	Deployed and tested 16 7.5-ton electrically retrofitted P80E Mercedes T2 in London and 4 in Rotterdam with charging infrastructure.	FREVUE (2017b, 2017c)
Electric logistics truck	FREVUE, Arup, Smith Newton, The Crown Estate, Clipper Logistics	London, UK	2014	Deployment of a 10-ton and 12-ton all electric Smith Newton to accommodate increased delivery volume from a depot to a consolidation center.	FREVUE (2017e)
Electric delivery trucks	UPS	Amsterdam, Netherlands	2013	UPS deployed 6 electric parcel delivery trucks in Amsterdam.	Netherlands Enterprise Agency (2016)

Table 3. Heavy-duty electric vehicle demonstration projects.

Technology	Organization	Location	Time frame	Description	Source
Zero-emission drayage trucks	SCAQMD, the State of California, BYD, Kenworth, Peterbilt, and Volvo	California	2016	Statewide demonstration project of 43 zero-emission battery electric and plug-in hybrid drayage trucks used to transport goods over short distances from ports to distribution centers and rail yards.	SCAQMD (2016a)
Electric Class 8 truck	TransPower	California	2015	Demonstration of 4 Class 8 fully battery electric trucks from San Diego County 110 miles to the Los Angeles-Long Beach port region.	TransPower (2015)
Electric Class 8 yard trucks & Class 5 medium-duty service trucks	BYD, San Bernardino Associated Governments (SANBAG), & BNSF Railway	San Bernardino, Commerce, & Fontana, California	2016–2018	Two-year demonstration project of 23 battery-electric Class 8 yard trucks and 4 Class 5 medium-duty service trucks for use in rail yards and large-scale freight distribution centers, replacing diesel-powered heavy-duty tractors. The State of California awarded $9 million, through the California Climate Investments (CCI) program.	BYD (2016); CARB (2017)
Electric heavy-duty refuse truck	Motiv Power Systems & the City of Chicago	Chicago, Illinois	2014	The City of Chicago uses an all-electric refuse truck in different refuse and recycling routes up to 60 miles long.	Motiv (2014)
Zero-emission distribution trucks	EMOSS B.V., Hytruck	Netherlands	2013–2014	Zero-emission city distribution project- 8 hybrid and electric trucks with 2 fully electric 19-ton trucks (largest electric trucks of their kind in Europe)	EMOSS (2016)
Battery electric waste disposal	FAUN Umwelttechnik GmbH & Co. KG, DFKI, BEG, BMUB	Germany	2017–2019	Battery electric waste disposal with robot support (BEAR) is a project that develops and implements a fully electric refuse pilot truck to be tested by the Bremerhaven waste disposal company for 12 months.	BMUB (2016a)
Electric heavy-duty refuse truck	Waste Management NZ & EMOSS	Auckland & Christchurch, New Zealand	2016–2017	One electric body waste collection truck and two side-loader waste collection trucks for late 2016/ early 2017. Electricity will come from the gas emissions for a local landfill. First step in Waste Management transition to all electric.	Bradley (2016); Waste Management NZ (2016)
Electric heavy-duty logistic trucks	INTERREG, EU, LIOF, FIER Automotive, Köppen, Samskip, CTV, KLG Europe, Meulenberg Transport, Limburg	North Limburg, Netherlands & Duisburg, Germany	2017	Green Electric Last Mile (eGLM)—A project implementing 9 40- to 50-ton electric heavy-duty trucks in the cross-border logistics region of North Limburg-Duisburg	eGLM (2017); Weken & Kroon (2017)
Electric heavy-duty trucks for beverage distribution	FREVUE, Heineken, Simon Loos,	Amsterdam & Rotterdam, Netherlands	2017	Testing of 6 12-ton and 1 19-ton electric freight trucks in Heineken's delivery truck fleet.	FREVUE (2017a)
Electric freight trucks	Autobus Lion, TM4, AddÉnergie Technologies, Solution Adetel, Alcoa Canada	Québec, Canada	2017	Designing and manufacturing four prototypes (two freight trucks and two passenger buses). The project is valued at 17.2 million CAN with 8.6 million $CAN funding from the government.	Government of Québec (2016)
Electric refuse truck	Phoenix Danmark, Norsk Gjenvinning	Sparsborg, Norway	2017	Two refurbished electric refuse trucks, each truck is expected to save 60 metric tons of CO_2 per year	Norsk elbilforening (2017)
Electric delivery truck	ASKO	Oslo, Norway	2016	Norway's first electric distribution truck in operation, used to deliver food to city-center shops. 18-ton refrigeration truck with 240-kWh battery capacity, 200 km range, and cost ~$4 million NOK (~$470,000), twice that of diesel truck.	Dalløkken (2016)
Electric refuse truck	Motiv Power Systems, Crane Carrier, Loadmaster, and the City of Sacramento	Sacramento, California	2017	State's first all-electric garbage truck deployed in the city of Sacramento. It is expected to save 6,000 gallons of fuel per year.	PR Newswire (2017)
Electric delivery truck	EMOSS, FREVUE, BREYTNER	Rotterdam, Netherlands		Testing of one 19-ton EMOSS truck in Rotterdam by BREYTNER Transportation.	FREVUE (2017d)
Electric truck	BMW Group, SCHERM Group, Terberg	Munich, Germany	2015	40-ton electric truck for material transport from a logistic center, charged with renewable electricity	BMW Group (2015)
Electric commercial vehicles	Fraunhofer IML, TU Berlin, Hochschule Fulda, Florida Eis, Meyer Logistik, Meyer&Meyer, BMUB	Germany	2017–2019	"EN-WIN" is 18-month field trial of electric vehicles in the food, textile, and distribution logistics. Data to develop forecasting tool on e-commercial vehicles. Part two of project is to construct a 26 t electric vehicle for urban traffic use.	BMUB (2017a)
Freight electric vehicles	Emons Spedition, BMUB	Dresden, Germany	2016–2018	CitE-Truck project: Emons to deploy three electric heavy-duty vehicles (12t and 18t)	BMUB (2016b)
Electric terminal truck	Terex MHPS, Hamburger Hafen und Logisitik, Hermann Paus, Neuss Trimodal, Maschinenfabrik	Neuss & Hamburg, Germany	2012–2017	Terminal truck project to develop and test battery-powered terminal trucks for container handling.	BMUB (2016g)

Table 4. In-road and catenary charging heavy-duty electric vehicle demonstration projects.

Technology	Organization	Location	Time frame	Description	Source
Conductive rail to charge all vehicles	Elonroad and Lund University	Outside Lund, Sweden	2017	Developing a 200-meter test tract to demonstrate "Elonraod" (a conductive rail that is laid on top of the road to charge all vehicle types).	Elonroad (2016)
Wireless power road	INTIS	Lathen, Germany		Currently testing a 25-meter track with contactless inductive charging of all vehicles.	INTIS, 2016
Conductive rail to charge all vehicles	Elväg AB, NCC, KTH University, Swedish Energy Agency, & Arlandastad Holding AB	Sweden		Demonstrated conductive underneath charging for all vehicles on a test track and currently a 2 km pilot is under construction.	Connolly, D. (2016)
Conductive in-road charging for heavy-duty vehicles	Volvo and Alstom	Hällered, Sweden	2012	400-meter test track with two power lines built into the surface of the road and a current collector on the truck that connects to the road.	Volvo Trucks (2013)
Catenary electric trucks	Siemens, Volvo, SCAQMD	Los Angeles & Long Beach, California	2017	One-mile of highway equipped with a catenary system in both direction for freight transport near ports.	Siemens (2014, 2016b)
Catenary electric system—heavy commercial	Siemens, BASt, TU Dresden, EDAG, DLR, LBST, NOW, IFEU	Germany	2016–2019	ELANO project is a research and development project for catenary electric system powered by renewable energy for heavy-duty commercial vehicles.	BMUB (2016d)
Catenary heavy commercial vehicles	Siemens	Outside of Berlin, Germany	2010–2011	ENUBA – a study and demonstration on a private road that examined the electrification of heavy-duty commercial vehicles in conurbations with a catenary system.	BMUB (2016e)
Catenary electric trucks, eHighway	DLR, Siemens, TU Dresden, BMUB, Scania	Gross Dölln, Germany	4/2012–12/2015	ENUBA 2 – a 2km overhead catenary system for heavy-duty vehicles and an extension for bus applications. The project researched vehicle technology, the relevant traffic, energy, ecological, economic, and legal aspects and tested the functionality and reliability of such vehicles.	BMUB (2016f), Scania (2014)
eHighway field trial—overhead catenary electric trucks	LBV-SH, Forschungs-und Entwicklungszentrum Fachhochschule Kiel GmbH	Hamburg – Lübeck, Schleswig Holstein, Germany	1/1/2017–12/31/2018	FESH I – Planning and construction phase of 6 km of overhead catenary infrastructure in both directions, supported by a €14 million subsidy from BMUB.	BMUB (2017b)
	LBV-SH, TU Dresden, FH Keil, Spedition Bode, Stadtwerke Lübeck, Lübecker Hafengesellschaft, Scania, Siemens		mid 2018–2021	FESH II – Field testing of the system supported by a €3-4 million subsidy from BMUB. The goal of the system is to have trucks powered purely electrically the 25 km from the Lübeck harbor to the logistics center – 12 km (6 km each direction) through a catenary system and the remaining 38 km through an onboard battery pack. Initially diesel hybrid trucks will be included in the study to ensure reliability.	BMUB (2017b)
eHighway field trial—overhead catenary electric trucks	Hessen Mobil Strassen – und Verkehrsmanagement, TU Darmstadt	Frankfurt – Darmstadt, Hesse, Germany	1/1/2017–12/31/2018	ELISA I – Planning and construction of about 6 km of overhead catenary lines in both directions to allow for trucks to travel over 15 km electrically powered. The project is funded by a €14.6 million subsidy from BMUB.	BMUB (2017b)
	Power Supplier, Vehicle Manufacture (possibly Scania), Siemens		mid 2018–2021	ELISA II – Field testing of the system supported by a €3-4 million subsidy from BMUB. The goal is to allow for emission-free delivery of goods in the Frankfurt urban area and to provide a guide and basis for future system expansion.	BMUB (2017b)
eHighway	Siemens and Scania	Sweden	June 2016–2018	World's first eHighway system on public roads. Operating two adapted diesel hybrid vehicles under a catenary system spanning two kilometers on the highway.	Siemens (2016a)

Table 5. Medium- and heavy-duty hydrogen fuel cell vehicle demonstration projects.

Technology	Organization	Location	Time frame	Description	Source
Hydrogen fuel cell medium-duty parcel delivery truck	FedEx, US Department of Energy, Plug Power, Workhorse Group	Memphis, Tennessee & California	May 2016–October 2019	Demonstration of 20 hydrogen fuel cell extended-range battery electric parcel delivery trucks operating one 10-hour shift for 260 days annually for approximately 1.92 years (~5,000 hours per truck). Project received $3.0 million in funding from the DOE and $3.367 million from partners.	Griffin (2016)
Maxity Electric Truck with fuel cell range extender	Renault Trucks and French Post Office	France	2015	A year field test by the French Post Office of Renault's Maxity Electric Truck equipped with a hydrogen-powered fuel cell.	Renault Trucks (2015)
Hydrogen fuel cell hybrid electric parcel delivery truck	CTE, UPS, Univeristy of Texas, EVI, Hydrogenics USA, Valance Technology	California	2014–	The project will retrofit 17 delivery vans with fuel cell hybrid technology and test them at distribution facilities in California.	CTE (2016); Satyapal (2014)
Hydrogen fuel cell drayage truck	Environmental Defense Fund, US DOE, (H-GAC), Gas Technology Institute, US Hybrid, Richardson Trucking, University of Texas	Port of Houston, Texas	2015–	Three-year demonstration project of three zero-emission heavy-duty Class 8 drayage trucks powered by a hydrogen fuel cell – electric hybrid power system at the Port of Houston. The project received $3.4 M in federal funding and the project partners committed to funding $3.0 M.	Wolfe (2015)
Fuel cell drayage truck	Hydrogenics, Siemens, Total Transportation Services (TTSI)	Alameda Corridor, Port of Los Angeles & Long Beach, California	2015–	The "Advanced Fuel Cell Vehicle Technology Demonstration for Drayage Truck" is a project demonstrating a hydrogen fuel cell powered Class 8 drayage truck.	Hydrogenics (2015)
Hydrogen fuel cell hybrid battery electric drayage trucks	SCAQMD, CTE, TransPower, U.S. Hybrid, Hydrogenics USA	Port of Los Angeles & Long Beach, California	June 2015–September 2018	Development and demonstration of 6 battery electric trucks with hydrogen fuel cell range extenders for drayage applications.	SCAQMD (2014, 2016b)
Hydrogen fuel cell distribution trucks	Scania and Asko	Norway	2016	3 three-axle electric distribution trucks powered by hydrogen fuel cells used for distribution services of almost 500 km. The hydrogen gas will be locally produced from solar cells.	Scania (2016)
Fuel cell drayage truck	Toyota	Ports of LA & Long Beach, California	Summer 2017	Toyota will test fuel cell trucks system, Project Portal, to determine the feasibility of using fuel cell trucks for port drayage applications.	Toyota (2017)

As seen in Tables 2 through 5, many of the truck demonstration projects to date have been concentrated in California, Germany, and the Netherlands, with several of the electric road charging projects being carried out in Sweden. The Californian, German, and Swedish governments have spurred demonstration projects in their respective regions with government support, both financially and through direct government involvement. For the 2014–2015 and 2015–2016 fiscal years alone, the California Air Resources Board allocated $84 million in grants for zero-emission truck and bus pilot commercial deployment projects (CARB, 2015c, 2015d). Governments have also shown support through direct involvement in carrying out research and development projects. For example, in 2016, the government of Québec supported a project for all-electric heavy-duty vehicles that included the manufacturing of four prototypes, including two passenger buses and two freight trucks. In 2017, as part of their partnership for innovation, the German and Swedish governments have been conducting a joint study on the electrification of roads to explore the various technical options and business models, as well as how to overcome cross-border interoperability questions and gain European level support (Die Bundesregierung & Government of Sweden, 2017).

Drayage applications around ports in the United States, particularly the ports of Los Angeles and Long Beach, have become a focal point for innovative heavy-duty fuel cell and catenary truck zero-emission demonstration projects. This is driven in large part by the area being a hot spot for increased pollution and public health impacts, resulting in heightened demand for greater emission reductions there. The duty cycle, short distance traveled, and heavily traveled routes of drayage trucks around ports makes them particularly suited for zero-emission technologies, as limited infrastructure (either catenary wires or hydrogen fueling stations) is required to supplied a large number of trucks. In addition, plug-in battery electric trucks have made great strides in the medium-duty delivery sector, with companies—especially those located across the United States and Europe—incorporating thousands of delivery trucks into their fleets. In terms of companies, Siemens has been at the forefront of heavy-duty catenary demonstration projects, partnering with various companies, universities, and government agencies to carry out three projects in California, Germany, and Sweden. Data collection and results from demonstration projects are crucial in leading the way to commercialization of zero-emission vehicles by helping to improve technology, drive down costs, familiarize truck owners and operators with the new technology, and determine and demonstrate best suited applications for the various technologies.

COMMERCIAL ZERO-EMISSION TRUCKS

Many vehicle manufacturers, both those long established in the industry and new start-up companies, are developing zero emission medium- and heavy-duty vehicles, and some are already producing vehicles at low volume. Among the larger automotive companies, Daimler has announced that it expects to begin production on a fully electric heavy-duty truck in 2020 (Daimler, 2016a). Tesla has revealed that heavy-duty trucks are in the early development phase with a reveal of a prototype electric semi-tractor slated to occur in September 2017 (Musk, 2016). Toyota announced that it is exploring hydrogen fuel cells for heavy-duty drayage truck applications through a California-based feasibility study beginning in summer 2017 (Toyota, 2017). BYD is currently producing Class 5, 6, and 8 electric trucks (BYD, 2016). Renault has also released electric and fuel cell trucks (Renault Trucks, 2015). Among the start-ups that have entered the zero-emission truck market are Nikola Motor Company (a U.S.-based company developing a hydrogen fuel cell powered semi-truck), Charge (a U.K.-based company developing electric trucks), and E-Force (a Switzerland-based company producing fully electric Class 8 trucks). See the Annex for details on the various commercial zero-emission commercial vehicles in development or production.

Among the key specifications for these companies is the available range of vehicle and what vehicle segment the companies envision for these electric and fuel cell vehicles. Figure 3 shows the range of commercial electric and hydrogen fuel cell trucks that are under development, have been announced, or are being produced, according to their respective truck classes. As shown in the figure, plug-in battery electric vehicles encompass the majority of the commercial medium- and heavy-duty trucks with ranges that are generally between 100 to 200 km. Fuel cell electric vehicles allow for significantly higher range across all truck classes. The Nikola One fuel cell announcement indicated a range of over 1,200 km for a Class 8 tractor-trailer application (Nikola, 2016). Further details, including the manufacturer, technology, range, current status, and detailed technology specifications, on these medium- and heavy-duty zero-emission commercial vehicles can be found in the Annex.

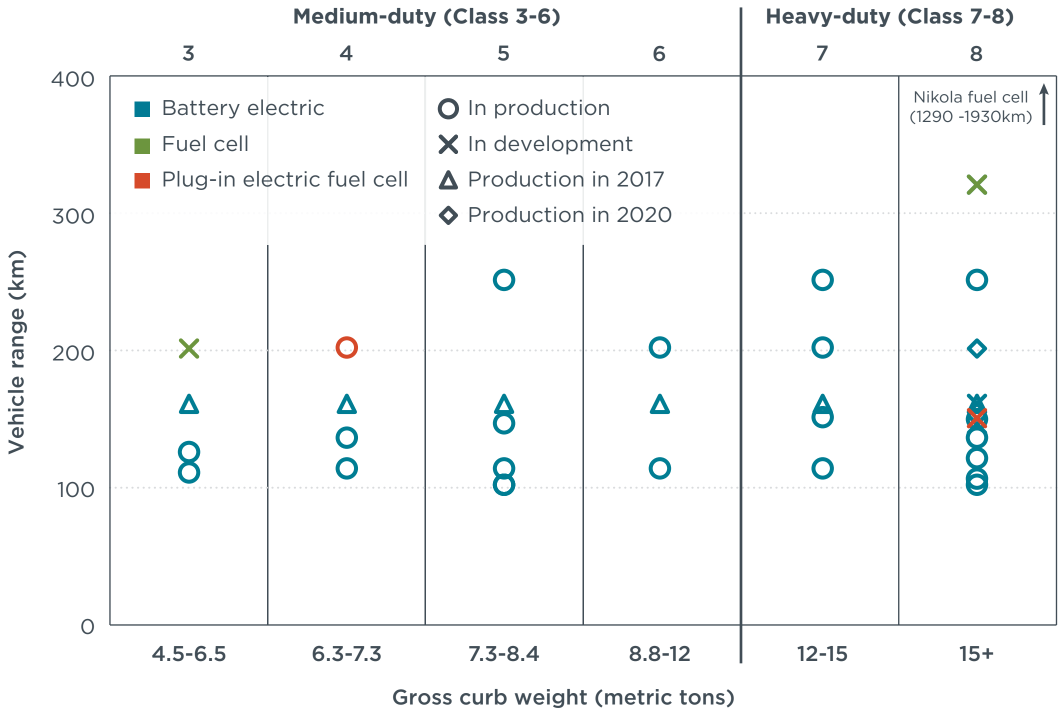

Figure 3. Ranges of zero-emission medium- and heavy-duty trucks currently in development or production broken down by truck class.

III. TECHNOLOGY COST ANALYSIS

To assess zero-emission vehicle technology costs, in this section we develop a cost-of-ownership evaluation of the various vehicle technology alternatives and discuss broader infrastructure costs.

VEHICLE COST OF OWNERSHIP

To gain an understanding of the viability of various zero-emission heavy-duty technologies for long-haul heavy-duty tractor-trailer applications, we analyzed the technologies under a vehicle-related cost of ownership framework. We base the analysis on the research and available data on vehicle technology costs, efficiency, and emissions from the projects outlined above. We report on results for 2015 through 2030 to show our best estimates of the progression of the costs over time.

The objective of the cost analysis is to illustrate the cost differences of various tractor-trailer technologies over different periods of time. The cost of ownership analysis includes capital costs (tractor-trailer purchase price), maintenance costs, and fuel costs experienced by the owner over the vehicle lifetime. The fuels and technologies considered in the analysis are diesel, diesel hybrid, compressed natural gas, liquefied natural gas, overhead catenary electric, dynamic induction electric, and hydrogen fuel cell. Due to uncertainties related to potential battery-swapping systems, including how many extra battery packs would be needed, we do not include an electric battery-swapping scenario in the analysis. All costs in the analysis are in 2015 U.S. dollars. The analysis is constrained to vehicle and fuel costs. Motor vehicle taxes, insurance costs, driver wages, tolls, and road fees are excluded. The analysis is for vehicle costs; infrastructure costs are discussed further below. We make a series of assumptions on average annual vehicle use, efficiency technology, cost, and fuel cost to develop bottom-up cost models for the various tractor-trailer technologies.

Vehicle use. We analyze the costs for tractor-trailers over 10 years of long-haul freight activity. The more uncertain and varied use of the vehicle after its more intensive long-haul use (perhaps repurposed for less-mileage-intensive applications) in regional or drayage operation is excluded from the analysis, although of course there would still be fuel-saving benefits in that later stage. The vehicle miles traveled with vehicle age over the 10-year period are based on the U.S. EPA's regulatory analysis (U.S. EPA and DOT, 2011), with China and Europe adjusted downward to account for 27% and 40% lower average annual driving distances, respectively. For consistency, the alternative vehicle technologies are assumed to have comparable functionality and reliability as diesel powertrains. The catenary and dynamic inductive grid-operated trucks are assumed to run on 100% electricity and are capable of traveling approximately 80 km powered by the onboard battery pack, assuming an 80% depth of discharge (den Boer et al., 2013). The baseline tractor-trailer is assumed to have three trailers per common industry practice to account for there being three long-haul trailers, on average, in operation for every tractor (Meszler, Lutsey, & Delgado, 2015). The average annual distance traveled for each region over the lifetime of the vehicle along with additional data sources and assumptions are provided in the Annex.

Efficiency. The average tractor-trailer fuel consumption for China, Europe, and U.S. diesel tractor-trailers are taken from various regulatory and research studies. The 2015 fuel economy is assumed to be 5.4 mpg (44 L/100km) in China, 6.9 mpg (34 L/100km) in Europe, and 5.9 mpg (40 L/100km) in the U.S. (based on Delgado, 2016; Muncrief & Sharpe, 2015). The fuel efficiency for the new U.S. tractor-trailers is assumed to improve, following the Phase 2 U.S. greenhouse gas emissions and fuel efficiency standards, which result in a 2027 fuel economy of 9.1 mpg (26 L/100km) (Sharpe et al., 2016). Europe tractor-trailer fuel efficiency is based on the 2015 real-world testing of tractor-trailers of 6.9 mpg (34 L/100km) (Muncrief & Sharpe, 2015). When considering improved technology in Europe from 2021 on, we assume a 2.5% per year annual fuel consumption reduction. This is based on the average between incremental and moderate improvements analyzed in Delgado et al. (2016) and assumes that CO_2-reduction standards will be implemented in Europe. For China, the fuel efficiency is assumed to follow the Stage 3 China fuel consumption standards, achieving 6.3 mpg (37 L/100km) in 2020 (Delgado, 2016). After 2020, the China tractor-trailer fuel consumption is assumed to improve by 2.5% annually, similar to Europe, assuming new standards will be implemented there.

For diesel hybrid tractor-trailers, we assume a reduction in fuel consumption of 5% in the U.S. and China and 7% in Europe relative to the conventional diesel average (Rodriguez, Muncrief, Delgado, & Baldino, 2017). Natural gas engines are assumed to follow the same fuel efficiency improvements as diesel engines at a 10% and 15% efficiency loss for compression ignition (CI) and spark ignition (SI) engines, respectively (Delgado & Muncrief, 2015; Kasten et al., 2016). The energy consumption for fuel cell, catenary electric, and dynamic induction electric tractor-trailers are taken to be 9.5 megajoule per kilometer (MJ/km), 5.7 MJ/km, and 9.0 MJ/km, based on a variety of sources, and are assumed improve by 1% annually for catenary electric and 2% for fuel cell and dynamic induction electric (based on Akerman, 2016; den Boer, 2013; Kasten et al., 2016; Schmied, Wüthrich, Zah, Althaus, & Friedl, 2015. The energy consumption assumptions for these vehicle technologies are provided in the Annex.

Technology cost. The base diesel tractor-trailer in the U.S. is assumed to cost $210,000, including a tractor at $135,000 with three trailers at $25,000 each (Meszler et al., 2015). The comparable base tractor-trailer cost for Europe is estimated to be approximately the same, before future efficiency technology is considered. Based on data on comparable tractor and trailer costs, the heavy-duty tractor-trailer is approximated at $90,000 for China. Battery and fuel cell system costs vary widely in the literature, depending on innovation, supplier competition, and economies of scale that are underway largely as a result of light-duty vehicle developments. We base our electric-drive vehicle costs on Slowik et al. (2016) and Wolfram & Lutsey (2016). Slowik et al. (2016) summarized a range of lithium ion battery pack costs from 2015 to 2023 for medium- and high-volume scenarios, and found costs ranging from approximately $230/kWh to $420/kWh in 2015 and $150/kWh to $225/kWh in 2023. The battery costs applied here are within that study's medium- and high-volume projections. The expected reduction in lithium-ion battery costs is attributed to the replacement of high-cost materials, economies of scale, improvements to battery design and production methods, manufacturing improvements, and competition among suppliers.

Table 6 shows our key component cost assumptions for 2015–2030. We apply estimates from Wolfram & Lutsey (2016) to estimate fuel cell system costs. Based on annual production of 1,000, fuel cell system costs are estimated at $240 per kilowatt (kW) in 2015; with increasing production to 10,000 in 2025, the cost drops to $89/kW, then to production of 50,000 in 2030 to $59/kW. Both battery pack and fuel cell systems are assumed to use similar technology in heavy-duty applications as in light-duty, and therefore these component prices are assumed to follow price projections for light-duty vehicles. This allows greater economies of scale in heavy-duty applications. The assumption is in line with Tesla's statement that the upcoming Tesla Semi will share parts with its electric car production and Toyota's announcement that its Class 8 fuel cell tractor will use its Mirai passenger car fuel cell stacks (Lambert, 2017; Toyota, 2017). Cost of the additional required fuel cell and battery electric systems are the electric systems (power electronics, battery management systems, etc.) necessary to control the power transfer. These additional costs are anticipated to decrease over time as the technology increases in volume and continues to improve.

Table 6. Estimated vehicle component costs for vehicles purchased in 2015–2030.

Component Costs	2015	2020	2025	2030
Battery ($/kWh)	326	228	168	120
Electric motor fixed cost ($)	120	94	85	75
Electric motor ($/kW)	22	18	16	14
Fuel cell system ($/kW)	240	166	89	59
Additional fuel cell systems ($/kW)	38	34	31	28
Overhead catenary vehicle grid connection ($)	71,700	49,600	21,200	21,200
Dynamic induction vehicle grid connection ($)	16,700	11,800	11,500	10,800
Additional electric vehicle systems ($/kW)	55	52	46	41

Based on den Boer et al., 2013; Slowik et al., 2016; Wolfram & Lutsey, 2016

Internal combustion engine costs are forecasted to increase over time as additional improvements and new technologies will be required to meet tightening efficiency and exhaust after-treatment regulations (den Boer et al., 2013). The baseline cost for internal combustion engines is assumed, based a study done by CE Delft (2013), to be $118/kW. The forecasted costs associated with engine improvements and vehicle efficiencies are based on a study conducted by Meszler et al. (2015). That study estimated a wide range of technology packages that are applicable for meeting global heavy-duty vehicle efficiency standards; therefore, we apply technology costs from that study for the projected costs of advanced efficiency technologies for heavy-duty vehicles to meet the expected incremental efficiency improvements (as mentioned above) in the 2020–2030 timeframe.

Based on the above assumptions, Table 7 summarizes the tractor-trailer capital costs for 2015–2030. The total tractor-trailer capital cost is amortized over 10 years at a 10% interest rate. The analysis excludes analysis of the residual value of the tractor-trailer because previous studies have found that the residual value is insignificant to the overall outcome of the cost analysis (see Lee & Thomas, 2016). As shown, the total vehicle costs for all alternative vehicles are more expensive than diesel vehicles initially. Over time, the total costs for alternative vehicle types are forecasted to be less than diesel as the costs of new technologies decrease greatly as a result of anticipated increases in production. The alternative vehicles and their components benefit from economies of scale, technology improvements, and production optimizations, greatly reducing their overall costs. The total initial vehicle purchase cost, rounded to the nearest thousand, is shown in Table 7, and the total breakdown of costs for the components of each vehicle is shown in the Annex.

Table 7. Total estimated tractor-trailer capital costs (in thousands of 2015 U.S. dollars).

		2015	2020	2025	2030
	Diesel	90	91	95	100
	Hybrid electric	101	101	103	108
	Liquefied natural gas (compression ignition)	118	116	115	116
	Liquefied natural gas (spark ignition)	153	147	143	141
China	Compressed natural gas (spark ignition)	113	110	108	109
	Hydrogen fuel cell	256	196	164	150
	Electric overhead catenary	220	178	138	131
	Electric dynamic induction	251	140	128	121
	Diesel	204	204	208	218
	Hybrid electric	229	226	227	236
	Liquefied natural gas (compression ignition)	267	260	255	255
	Liquefied natural gas (spark ignition)	239	232	228	228
Europe	Compressed natural gas (spark ignition)	256	246	239	237
	Hydrogen fuel cell	342	281	249	236
	Electric overhead catenary	306	262	222	218
	Electric dynamic induction	251	225	213	208
	Diesel	210	220	223	250
	Hybrid electric	234	242	242	268
	Liquefied natural gas (compression ignition)	270	270	260	273
	Liquefied natural gas (spark ignition)	242	242	233	246
United States	Compressed natural gas (spark ignition)	259	256	255	255
	Hydrogen fuel cell	345	281	253	255
	Electric overhead catenary	309	272	227	236
	Electric dynamic induction	254	234	218	226

Values rounded to nearest 1,000

Maintenance costs. Baseline maintenance and repair costs are based on those from Argonne National Laboratory's GREET model. The model assumes similar incremental maintenance and repair costs across various vehicle types but considers the reduced costs for hybrid and electric drive heavy-duty vehicles (Burnham, 2016). The costs are provided on a per-kilometer basis and are assumed to remain constant for vehicles produced in 2015 through 2030. The maintenance and repair costs are assumed to be $0.12 per kilometer for diesel and natural gas tractor-trailers and $0.11 per kilometer for diesel hybrid, electric powered, and fuel cell tractor-trailers. As tractor-trailers become more efficient over time in the analysis, the maintenance costs become a higher percentage of the total vehicle operating costs.

Fuel cost. We base our forecasted diesel fuel price on the International Energy Agency (IEA) World Energy Outlook (WEO) 2015 and the natural gas prices from U.S. EIA (IEA, 2015; U.S. EIA, 2017a). The differences between fuel prices in China, Europe, and the U.S. are assumed to be the same as their historical differences. The historical natural gas prices are from the Eurostat database for Europe and from a study done by the Oxford Institute for Energy Studies for China (Eurostat, 2017a; Li, 2015). Historical diesel fuel prices are based on World Bank data (World Bank, 2017). The IEA WEO projects crude oil prices from $50 per barrel in 2015, increasing to $128 per barrel through 2040. Electricity price projections for the U.S. follow the U.S. EIA's Annual Energy Outlook 2017 transportation electricity price projections (U.S. EIA, 2017b), and prices in China and Europe are based on Eurostat and Lawrence Berkeley National Laboratory data (Eurostat, 2017b; LBNL, 2014). Our estimated hydrogen fuel price decreases from $12 per kilogram in 2017 to $4 in 2030 for natural gas-based hydrogen (based on Fulton & Miller, 2015). In addition, we assume the that the cost of hydrogen drops to $5 per kilogram for hydrogen produced from renewable energy electrolysis (Fulton & Miller, 2015). The future fuel costs are discounted using a 4% discount rate to determine the net present value for each vehicle purchase.

Vehicle-related cost of ownership. Figure 4 shows the vehicle-related cost of ownership for trucks in China, Europe, and the U.S. for long-haul heavy-duty tractor-trailers for 2015 through 2030. The graphs show the breakdown of the tractor-trailer capital cost, maintenance cost, and fuel cost over 10 years of operation. The cost analysis excludes infrastructure cost for the dynamic inductive grid and overhead catenary technologies, which are discussed further below. By analyzing the 10-year operating cycle, we intend to cover at least the first phase of the tractor life while it is in long-haul operation. With uncertainties about total electricity throughput, charging–discharging cycles, and any degradation over time for catenary and in-road charging electric tractors, we do not include battery replacements. The results are summarized for the various vehicle technologies as compared to conventional diesel (which increases in efficiency over time), diesel hybrid (which retains an efficiency advantage over conventional diesel), and three natural gas technologies (liquefied compression ignition, liquefied spark ignition, and compressed spark ignition). Two fuel cell technology pathways are shown, first for natural gas-derived hydrogen and second for renewable source-derived hydrogen.

Figure 4. Cost of ownership in China, Europe, and the United States for each long-haul heavy-duty truck technology for a vehicle purchased in 2015–2030 broken down by capital cost, maintenance cost, and fuel cost.

Figure 4 illustrates the results on the various technologies' associated costs. The figure shows how conventional diesel vehicle costs increase incrementally, but are relatively consistent in future years, as compared to the alternative fuel technologies. Essentially all the other technologies see reduced cost of ownership over time, primarily because their capital technology costs decrease from 2015 through 2030. Natural gas, especially the liquefied natural gas with compression ignition, consistently offers among the lowest cost of ownership.

The zero-emission vehicle technologies show the greatest cost reductions from 2015 to 2030. Fuel cell technology shows the largest reduction in cost over time, due to both the expected drops in fuel cell costs and hydrogen costs. Excluding infrastructure costs, the two electric vehicle scenarios, induction and overhead catenary, ultimately arrive at among the lowest total vehicle cost in the 2025–2030 timeframe, similar to natural gas. Compared with diesel vehicles in 2030, overhead catenary results in 25%–30% lower costs, in-road induction results in 15%–25% lower costs, and hydrogen fuel cells result in 5%–30% lower costs to own, operate, and fuel. The reduced vehicle costs for electric tractor-trailers result in upfront costs that are similar to conventional diesel trailers in the 2025–2030 timeframe—aided, of course, by the distributed electric power, which allows smaller battery packs than would otherwise be needed. The gap in costs between conventional diesel and electric technology further widens across regions, as diesel tractor-trailers become incrementally more advanced and as compliance with future efficiency regulations becomes more expensive. Overall, when comparing the costs across the three major regions, the technologies show similar relative technology comparisons, although in absolute terms the costs are higher in the U.S., as a result of the U.S. having the largest annual distance traveled per truck.

SUPPORTING INFRASTRUCTURE COSTS, VIABILITY, AND IMPLEMENTATION

Beyond the cost of ownership, the cost, availability, and implementation of the required infrastructure is also of great importance in determining the viability of zero-emission technologies in the heavy-duty sector. The required infrastructure is particularly important for the long-haul heavy-duty applications analyzed above, as these trucks cover large distances and would need extensive charging (overhead catenary wires, or in-road inductive or conductive charging) or natural gas or hydrogen refueling infrastructure. On the other hand, the required infrastructure to support regional heavy-duty, waste, and drayage trucks tends to be easier to implement and less costly as these trucks tend to follow set routes, have greater downtime, and cover much shorter distances. Required infrastructure for regional heavy-duty vehicles could be quite similar to the charging and hydrogen infrastructure for battery electric and hydrogen fuel cell buses, which have been implemented in some regions, especially in China (and also increasingly in some cities in Europe and the U.S.).

Although there is considerable uncertainty, approximate first estimates are available for the applicable charging infrastructure costs. Overhead catenary wires provide a continuous supply of power to trucks, requiring an extensive and continuous network of energy infrastructure along roadways. In addition to the catenary wires, infrastructure to support the necessary supply of electricity (substations, connection to the grid, transformer, and rectifiers) need to be added to motorways (den Boer et al., 2013). Catenary wires are estimated to cost between $0.8 million and $3.8 million per kilometer, with annual operation and maintenance costs of 1%–2.5% of the initial capital cost of the catenary and energy infrastructure (based on den Boer et al., 2013; Gladstein, Neandross & Associates, 2012; Siemens, 2016b). Once completed in various regions, these electric charging systems would enable high utilization, which would allow for the overall system costs to be spread over many heavy-duty vehicles over time.

Similar to catenary wires, dynamic grid inductive or conductive charging requires expensive energy support infrastructure in addition to the necessary charging on top of, or under, the roadway. The installation of underground infrastructure could be more costly and invasive than overhead catenary wires, but it could have lower maintenance requirements, because there is no wear and tear on the components. Dynamic grid in-road infrastructure is estimated to cost between $2.5 million and $4 million per kilometer, with annual operation and maintenance costs of 1% of the initial installation cost of the charging infrastructure (Connolly, 2016; den Boer et al., 2013). These road charging systems would enable high utilization.

Hydrogen fueling station cost estimates have ranged from $350,000 to $5.3 million (Wolfram & Lutsey, 2016). Hydrogen refueling times are comparable to conventional diesel and gasoline vehicles. Quick refueling times allow for the possibility of high utilization of fueling stations and therefore distributes the investment costs over the use of many vehicles. Estimating the cost of hydrogen fueling stations on a per-vehicle basis is difficult because it is dependent upon the station's utilization and hydrogen throughput, which are uncertain. In the hydrogen case, how quickly the shift toward high station utilization happens could be partially dependent upon whether both passenger and heavy-duty freight vehicle approaches grow and co-evolve. Other key considerations with hydrogen cost implications are the exact production, transport, and distribution system (e.g., compressed or liquefied hydrogen, pipeline or truck distribution) involved with supplying the fuel to stations.

To help inform on infrastructure and system-level costs, we summarize results from a directly applicable study by the Öko Institut. Kasten et al. (2016) conducted a comprehensive study comparing the cost of energy supply, energy supply infrastructure (investment, maintenance and operation, and connection costs for gas stations or charging infrastructure), and vehicle purchase cost for alternative vehicle technologies to conventional fossil fuel–powered vehicles. The study compared four alternative scenarios to decarbonize and reduce air pollution from the German fleet of trucks in the long-haul freight sector. These scenarios were (a) internal combustion, with power-to-liquid fuels with very low lifecycle carbon emissions; (b) overhead catenary line electricity for hybrid diesel-electric powertrain; (c) liquefied natural gas from low-carbon power-to-gas methane; and (d) fuel cell with liquefied power-to-gas hydrogen. The study estimated the additional cost for each of the scenarios from 2010 to 2050 compared to the reference case, where the whole long-haul heavy-duty fleet would otherwise be powered by conventional diesel fuel.

The results from Kasten et al. (2016) on the energy supply, infrastructure, and vehicle costs for long-haul freight road transport are shown in Figure 5. As shown, the costs range from $100 billion to $400 billion dollars from 2010 to 2050, so any of these approaches would amount to a major transportation overhaul to help decarbonize the freight sector. Because the scenarios were set to have comparable emission-reduction benefits, the scenario with the lowest total cost (i.e., overhead catenary electric system) provides the most cost-effective long-term greenhouse gas reduction. The analysis does not consider the relative practical feasibility of implementing the different alternative technologies. The figure shows that even though the overhead electric option is infrastructure intensive, it compares very favorably against the options to use renewable power to develop liquid combustion diesel replacements, natural gas, and hydrogen—each of which has significant energy supply, infrastructure, and vehicle costs.

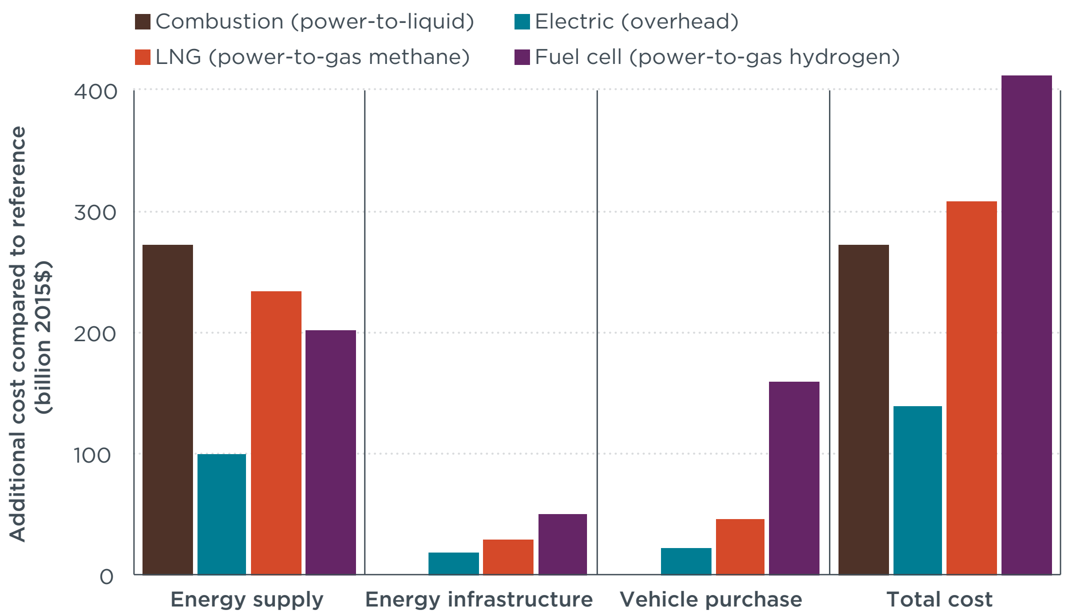

Figure 5. Additional cost for four different greenhouse gas reduction scenarios compared to the reference case (all fossil fuel use) for the long-haul heavy-duty freight transport sector in Germany (based on Kasten et al., 2016).

For further information on the Kasten et al. (2016) study summarized in the figure, the trucks powered by the overhead catenary system are assumed to be hybrids, powered by electric energy 75% of the time through the catenary wires or the small on-board battery and the remaining 25% of the time by an internal combustion engine powered by power-to-liquid fuel. For this case, it is assumed that 4,000 km (approximately 30%) of the German federal motorways are electrified. The market introduction of the overhead catenary trucks is assumed to begin in 2025 and ramp up to 90% of new registrations by 2050. For the power-to-gas natural gas scenario, trucks will enter the market in 2015 and reach full penetration by 2035. In the power-to-gas hydrogen case, fuel cell trucks would be introduced to the market in 2020 and reach full penetration by 2035. In the combustion scenario, the trucks would be fully powered by low-carbon power-to-liquid fuels by 2050.

Although road electrification has high upfront costs from the required energy infrastructure, these costs are dwarfed in the long term by cheaper energy supply costs compared to alternative liquid fuels. The study indicates that the cost of energy infrastructure is relatively small compared to the high cost of energy supply and vehicle costs over the long-term, leading to the result that electrification is the most cost-effective technology for freight transport in the long-term. A similar effect can be seen for the power-to-gas hydrogen case, for which the costs of the market introduction of fuel cell heavy-duty trucks drives the high costs of vehicle purchase. In this case, the cheap energy supply costs and the low system costs (both compared to the power-to-liquid and the power-to-methane option) would become effective after the transformation process and in a longer timeframe than 2050.

Although it is the most cost-effective option, road electrification would require sustained political support to offset the upfront cost and the initially unprofitable operation of charging infrastructure. It would also need public support, high fleet participation and utilization, and international coordination. All scenarios require broad support but could be implemented, to some degree, in a modular and incremental way, focusing on one region, with one or several fuel production facilities and refueling stations and several nearby routes at a time.

IV. ANALYSIS OF EMISSIONS IMPACTS

VEHICLE TECHNOLOGY GREENHOUSE GAS EMISSIONS

To gain an understanding of the emissions impacts of the various tractor-trailer technologies, we analyze the lifecycle greenhouse gas emissions for each technology for a truck purchased in 2015 through 2030. In addition to the assumptions used above in the cost ownership analysis, we include the upstream fuel cycle emission impacts associated with the production of the various fuel. We apply the carbon intensities of diesel, natural gas, and hydrogen for 2015 from California's Low Carbon Fuel Standard (LCFS) across all regions.

Table 8 shows the assumed fuel carbon intensities that we apply to our lifecycle analysis. Carbon intensities for diesel and natural gas are assumed to remain constant from 2015 through 2030, whereas the carbon intensity of hydrogen is expected to decrease significantly as hydrogen transitions from being produced mainly from fossil fuels through steam-methane reformation to being produced from renewable energy sources. For hydrogen's carbon intensity, we assume a 5% annual reduction based on continued policy to ensure that fuel supply was low carbon. The carbon intensity of electricity is based on the IEA WEO 2015 electricity assumptions for each of the respective regions and similarly assumes sustained efforts to decarbonize (i.e., their 2°C climate stabilization scenario). We note that there are many regions (e.g., Norway and Québec) where the electricity carbon intensity is already near zero, as a result of electricity generation predominantly coming from renewable energy sources. In such cases, electric vehicle applications offer over a 95% reduction in carbon emissions.

Table 8. Fuel carbon intensities (gCO_2e/MJ) for 2015 and 2030 and the percent reduction in emissions from 2015 to 2030.

Fuel	Region	Fuel carbon intensity (gCO_2e/MJ)		Greenhouse gas emission reduction in 2030*
		2015	2030	
Diesel	All	102	102	-
Compressed natural gas	All	81	81	-
Liquefied natural gas	All	86	86	-
Hydrogen	All	151	70	54%
Electricity	United States	144	49	66%
	Europe	101	44	57%
	China	202	82	60%

**Greenhouse gas emission reduction includes on-vehicle efficiency improvement (i.e., relative MJ per kilometer)*

The total lifecycle wheel-to-well greenhouse gas emissions in carbon dioxide equivalents (CO_2e) for each long-haul heavy-duty freight truck technology for tractor-trailers purchased in 2015 through 2030 are shown in Figure 6. The three panes represent the unique assumptions and characteristics (e.g., vehicle efficiency, annual vehicle travel activity over vehicle life) for the trucks purchased and operated in China, Europe, and the U.S.

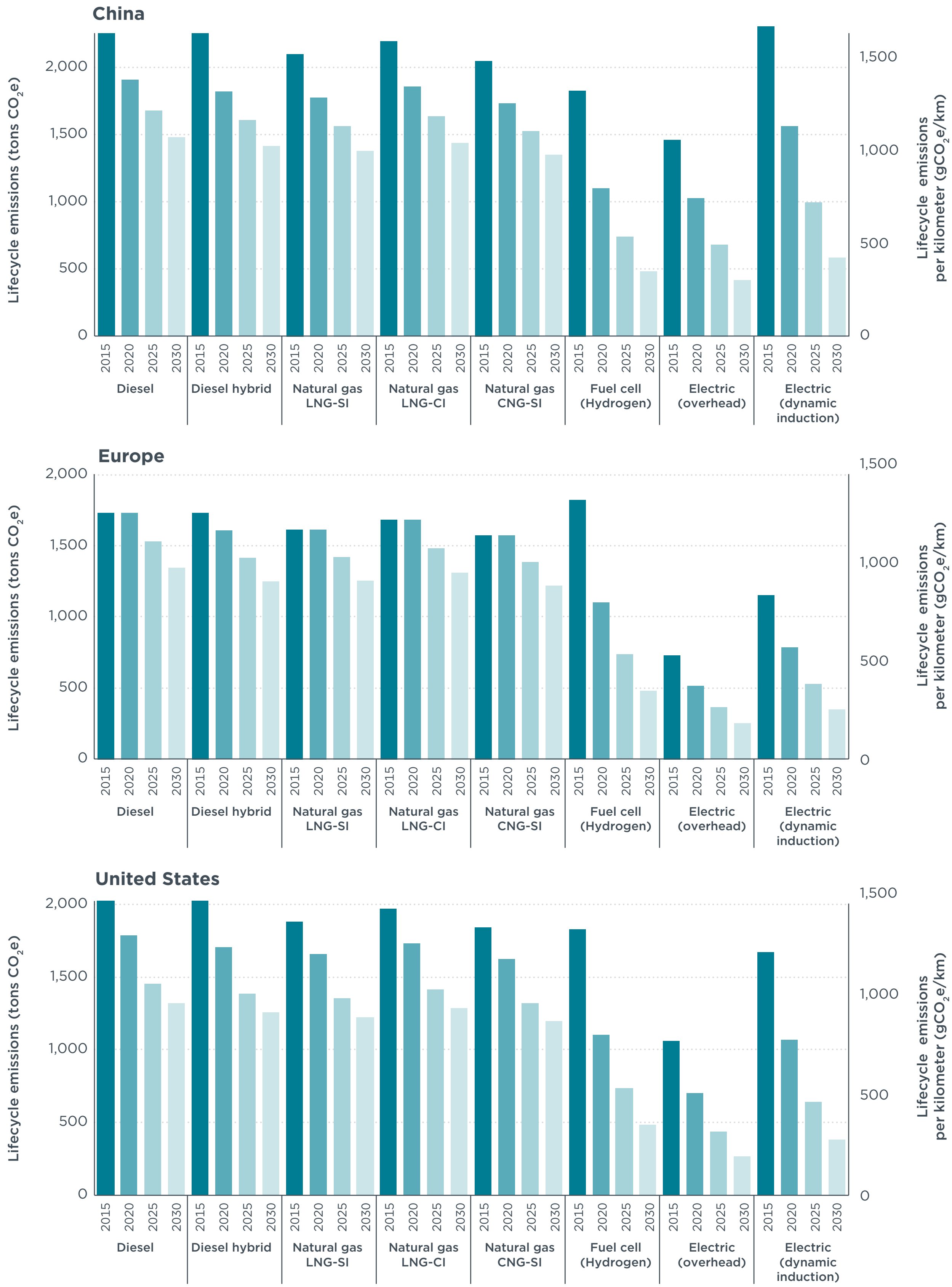

Figure 6. China, Europe, and U.S. lifecycle CO_2 emissions over vehicle lifetime (left axis) and per kilometer (right axis) by vehicle technology type.

Major emission differences across the technologies and over time are apparent from the figure. For 2015, catenary electric vehicles have 35%, 58%, and 48% lower lifetime CO_2e emissions than conventional diesel vehicles in China, Europe, and the U.S., respectively, while fuel cell vehicles have 19%, 5%, and 10% lower emissions. We note that in the case of China, dynamic induction electric vehicles have comparable CO_2e emissions to diesel in 2015 as a result of high grid emissions and reduced efficiency of dynamic grid electric vehicle in comparison to catenary electric, but the emissions significantly decrease over time as the grid decarbonizes. The diesel and natural gas technologies are relatively similar in their CO_2 emission levels. As shown in Figure 6, there is the potential for major reductions in all the vehicle technology types in the 2025–2030 timeframe. In the case of the diesel and natural gas technologies, the emission reductions are driven by efficiency technology on the vehicle. On the electric and fuel cell technologies, the emission reductions are driven primarily by the reduced fuel carbon intensity. The diesel tractor-trailer is shown with greatly reduced carbon intensity, with a 22%–35% reduction from 2015 to 2030. The fuel cell technology results in a 73% reduction in carbon emissions from 2015 to 2030. The catenary and dynamic induction electric vehicle technology show a reduction of 66%–76% and 61%–77%, respectively, by 2030 across the three regions.

Overhead catenary electric heavy-duty trucks have the lowest lifetime emissions in each region. In China, catenary electric trucks deliver a 72% reduction from the 2030 high-efficiency diesel emission level (an 82% reduction from the 2015 diesel baseline). In Europe, the catenary electric truck provides an 81% reduction in emissions as compared with the high-efficiency 2030 diesel truck (an 87% reduction from the 2015 baseline). In the U.S., catenary electric trucks deliver an 80% reduction over the high-efficiency 2030 diesel (an 88% reduction from the 2015 baseline). The emission benefits from the hydrogen fuel cell technology cases were also very substantial: The CO_2 reductions were 62%–67% as compared with the 2030 high-efficiency diesel (73%–78% reduction from the 2015 baseline diesel).

FLEET LEVEL IMPACTS OF ZERO-EMISSION TRUCK PENETRATION

To further inform the question about how zero-emission trucks could contribute toward climate change goals, we conducted a narrower analysis of the penetration of zero-emission trucks in one particular market—Europe. As indicated earlier, many of the details of the above vehicle cost analysis are uncertain, and the analysis is driven by a series of assumptions without firm real-world data. Beyond questions about the cost and necessary infrastructure and energy supply deployment, the future penetration of the technologies is even more uncertain because it is dependent on many industry, government, and market factors. Yet, we provide an illustrative, first-order analysis of fleet emissions to assess the potential impact of greater deployment electric-drive heavy-duty vehicle technologies if the prevailing technology and institutional barriers are overcome.

The broader context for long-term climate scenarios is the Paris climate agreement, signed by nearly every nation, which establishes the goal of limiting the increase in global average temperatures to below 2°C above the pre-industrial temperature. The leaders of the European Union adopted the 2030 climate and energy framework in 2014. The framework sets a binding target for the EU to reduce total greenhouse gas emissions by at least 40% below 1990 levels in 2030 and reduce emissions from transportation by 30% relative to 2005 levels by 2030 (European Commission, 2017a). The European Commission created the Energy Roadmap 2050 to explore the options of transitioning the energy system to meet the long-term goals of cutting emissions 80%–95% from 1990 levels by 2050 in the most competitive manner while achieving maximum energy security (European Commission, 2017a, 2017b). The transport sector is required to reduce emissions at least 60% below 1990 levels by 2050 while allowing for increased mobility and a competitive transport sector (European Commission, 2011a, 2011b).

We analyze the impact of the penetration of zero-emission heavy-duty vehicle technologies in the European fleet from 2015 to 2050 to estimate the CO_2 emission impact. Our analysis is focused on the tractor-trailer portion of the heavy-duty fleet. The analysis applies the International Council on Clean Transportation (ICCT) Roadmap vehicle stock-turnover model (see ICCT, 2017). This model simulates advanced technologies being phased into the fleet beginning in 2020 as new vehicles increasingly take over larger fractions of freight activity through 2050, whereas older vehicles' activity decreases over time until they are eventually retired from the fleet. The vehicle stock-turnover model provides greater perspective on how quickly the climate benefits accrue from transitioning to zero-emission technologies over time.

Figure 7 shows four scenarios for lifecycle CO_2 emissions of tractor-trailers in Europe, reflecting varying technology penetrating the new vehicle fleet from 2020 through 2050. The first scenario is the base case, which assumes the entire European tractor-trailer fleet remains completely composed of internal combustion engine vehicles powered by diesel fuel without adopting additional efficiency standards that promote greater efficiency. The second scenario assumes that efficiency standards are implemented, leading to advanced diesel efficiency improvements based on the best available technology. We include two zero-emission vehicle scenarios, with each reflecting the possibility that one technology becomes the leading technology over time, while the other remains in more niche applications in the fleet. The two zero-emission vehicle scenarios build upon the diesel efficiency improvements (i.e., all the scenarios other than the base case include the diesel improvements). The fuel cell–intensive scenario has initial fuel cell tractor-trailer sales starting in 2020 and ramping up to reach 50% of the sales share in 2050, and overhead catenary electric tractor-trailer sales starting in 2020 and reaching 15% of the sales share in 2050. The final electric-intensive scenario has electric sales starting in 2020 and ramping up to 50% of the sales share in 2050, and fuel cells starting in 2020 and reaching 15% in 2050.

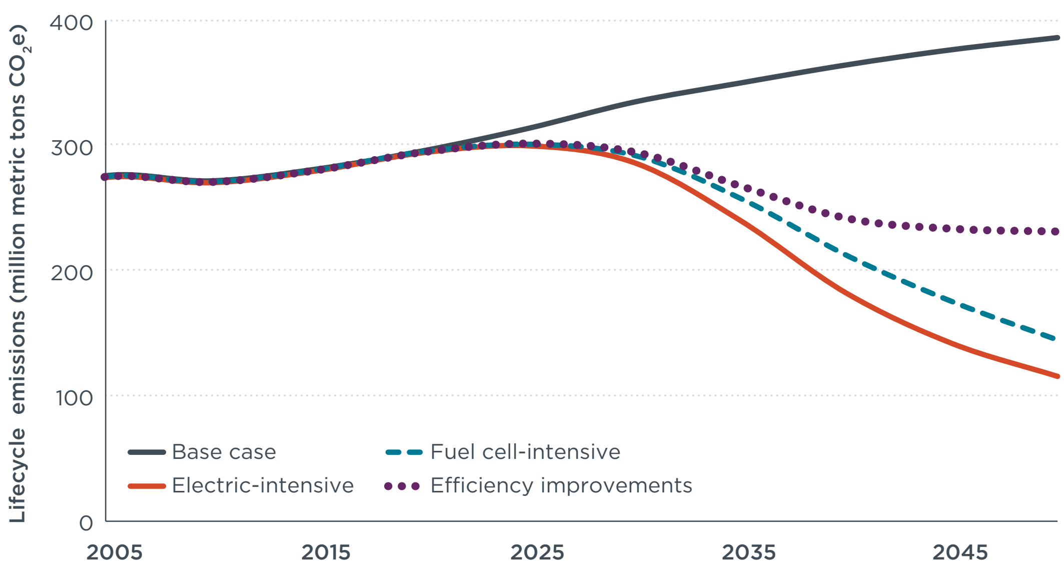

Figure 7. Lifecycle CO_2e emissions from Europe heavy-duty tractor-trailer fleet from 2015–2050, with base case, efficiency improvements, fuel cell-intensive, and electric-intensive scenarios.

Table 9 summarizes several key greenhouse gas emission results from the vehicle deployment scenarios shown in Figure 7. Under the base case, the lifecycle emissions are estimated to increase approximately 38% from 2015 to 2050, from 281 to 386 million metric tons of CO_2e. With incremental diesel efficiency technology improvements linked to efficiency standards (but without any zero emission vehicles) in the fleet from 2015 to 2050, CO_2 emissions in the 2050 fleet would decrease by 156 million tons—a 40% reduction from the base case in 2050. As shown in the efficiency scenario, CO_2 emissions begin to flatline after 2035, as the incremental efficiency gains slow and freight activity continues to increase. For the fuel cell–intensive scenario, emissions are estimated to peak around 2025 at 300 million metric tons of CO_2e and proceed to decrease through 2050, resulting in a 63% reduction in emissions relative to the base case in 2050. Finally, for the electric-intensive scenario, emissions are expected to peak around 2025 at 300 million metric tons of CO_2e and proceed to decrease through 2050, resulting in a 70% reduction in emissions relative to the base case in 2050.

Table 9. GHG emissions from EU tractor-trailers for baseline, fuel cell vehicle–intensive, and electric vehicle–intensive scenarios for 2050, with associated change in emissions

Scenario	Emissions by year (million ton CO_2e)			Change in emissions	
	2005	2015	2050	2015 to 2050	From 2050 base case
Base case	275	280	386		
Increased efficiency	275	280	230	-18%	-40%
Fuel cell intensive	275	280	145	-48%	-63%
Electric intensive	275	280	115	-59%	-70%

Both scenarios with substantial penetration of zero-emission vehicle technologies show substantial reduction in emissions relative to the base scenario and their overall CO_2 emissions in absolute terms. The fuel cell–intensive case results in 47% lower emissions in 2050 than in 2005. The electric-intensive case would cut emissions by 58%. Therefore, these scenarios underscore the great challenge at hand to decarbonize heavy-duty freight emissions. Advanced diesel efficiency technology and greatly accelerated penetration of zero emission vehicles will be required to achieve the 30% CO_2 emission reduction from the heavy-duty vehicle sector in 2030 and 60% reduction by 2050 relative to 2005 levels, as targeted by the European Commission.

Several recent analyses also help to estimate the potential and the implications for greater penetration of advanced heavy-duty vehicle electric drive technologies. A European Union analysis indicates that nearly 40% of highways could be electrified with overhead electric lines, up to 90% of new long-haul tractor-trailers could be electric, and up to 34% of heavy-goods vehicle activity could be powered by electric vehicles by 2050 (Ministry of the Environment, Energy, and Sea, 2016; Transport & Environment, 2016). A Germany-focused study on the increasing role of transport electrification includes a scenario for up to 80% tractor-trailer activity being powered by overhead catenary systems by 2050 (Renewbility, 2016). The IEA assesses technologies and freight-system improvements to decarbonize freight trucks and illustrates the importance of electrification to achieve deep carbon cuts (IEA, 2017). Essentially all of these studies agree with our findings that developing electric-drive pathways is key to being able to substantially decarbonize heavy-duty vehicles.

V. FINDINGS AND CONCLUSIONS

Decarbonizing heavy-duty vehicle activity by transitioning to zero-emission vehicle technologies, including electricity and hydrogen technologies, presents an immense challenge. Yet, there are many promising technologies that have been demonstrated and announced that prove the technical viability and suggest how these technologies could eventually be deployed on a large scale. Mass deployment of zero-emission vehicles can enable greater impact on reducing emissions and energy use, while helping to enable more renewable energy use. The ongoing zero-emission truck projects around the world in 2017 inform the vision forward on where the sector can go if motivated governments and companies act to deploy the technology beginning in 2020.

Table 10 summarizes our findings regarding the potential benefits, prevailing barriers to widespread adoption, and the relatively promising market segments for various zero-emission technologies for heavy-duty freight vehicles. The table summarizes findings for the three main technology areas that were analyzed: plug-in battery electric, dynamic electric charging (catenary or in-road), and hydrogen fuel cell vehicles. Each technology offers the prospect of lower climate emissions, no tailpipe pollutant emissions, lower fueling cost, greater renewable energy use, and higher on-vehicle energy efficiency.

Table 10. Summary of promising segments, benefits, and barriers for zero-emission heavy-duty freight vehicle technologies

Technology	Benefits	Prevailing barriers to widespread viability	Promising segments for widespread commercialization
Electric (plug-in)	• Reduce greenhouse gas emissions • Eliminate local air pollution • Reduce fueling costs • Reduce maintenance costs • Increase energy efficiency • Increase renewable energy use	• Limited electric range • Vehicle cost (battery) • Charging time (unless battery swapping is utilized) • Cargo weight and size	• Light commercial urban delivery vans • Medium-duty regional delivery trucks • Refuse trucks
Electric (catenary or in-road charging)	• Reduce greenhouse gas emissions • Eliminate local air pollution • Reduce fueling costs • Reduce maintenance costs • Increase energy efficiency • Increase renewable energy use • Enable regional travel	• Infrastructure cost • Standardization across regions • Complete infrastructure network before vehicle deployment • Visual obstruction (catenary)	• Medium-duty trucks and heavy-duty tractor-trailers on medium-distance routes with high freight use • Drayage trucks around ports
Hydrogen fuel cell	• Reduce greenhouse gas emissions • Eliminate local air pollution • Increase energy efficiency • Enable quick refueling time • Increase renewable energy use	• Refueling infrastructure cost • Renewable hydrogen cost • Vehicle costs (fuel cell)	• Heavy-duty tractor-trailers in long-haul operation • Drayage trucks around ports

The zero-emission vehicle technologies do present considerable challenges. They have a combination of near- and long-term barriers, issues, and questions that will have to be addressed before they can become widespread replacements for conventional trucks and tractor-trailers that are typically diesel fueled. These challenges are somewhat different for the three different zero-emission vehicle technologies. As a result, the three technologies have different truck segments for which they offer the most promise for widespread commercialization, based on our assessment in 2017. We emphasize the high uncertainty in how these technologies could evolve over the long-term for 2030 and beyond. With sustained government and private industry investment, each of these various electric-drive technologies has the potential to overcome the various barriers faster than the others. Considering the vast scale of the problem of decarbonizing freight transport, it appears likely that many of the battery and fuel cell technologies will need to grow in parallel to meet medium- and long-distance freight demands as soon as they prove themselves.

The key barriers for plug-in battery electric vehicles include meeting the various freight vehicle specifications for daily travel range, initial vehicle cost, charging time, and maintaining vehicle cargo weight and volume capacity. The applications of light commercial urban vans, medium-duty regional vans, and other local vocational trucks (e.g., refuse trucks) offer higher potential for battery electric vehicles because they are more likely to have local usage and fleet operations that downplay or minimize the near-term technology limitations. Battery-swapping technology, although now only used in a couple isolated applications, has the potential to largely eliminate the charging time issue; however, it was not analyzed here due to lack of available information. Vehicles in urban delivery operation that offer a shorter radius from their base location, lower daily distances, less volume and mass constraints for cargo, and recharge in just one or two locations are suited for plug-in electric trucks. Many such vehicles are in local city government operations, short-distance urban cargo delivery, electric power utility service vehicles, and other applications in every major city. Several major automakers are adapting their electric car technology for light-commercial vans. The Deutsche Post StreetScooter is a recent example of the commercialization of electric truck technology for urban settings. Tesla's announced battery electric semi-tractor prototype is the only battery electric project we found in our assessment targeting long-haul heavy-duty applications without dynamic charging.

Electric vehicles that are dynamically charged—via overhead catenary transmission, on-road conductive tracks, or in-road inductive wireless charging—could play an important role in unlocking more potential advantages and market options for electric trucks. Dynamically charged trucks on dedicated e-roads could be implemented on a regional basis in a way that greatly reduces the battery electric truck barriers of battery cost, weight, size, and range. However, the dynamic electric truck charging systems have high infrastructure costs, for which only very early cost estimates are available. They also present an issue of needing some standardization of truck technology and infrastructure systems across regions (e.g., multiple countries in Europe) to be able to span long distance routes. Based on these technologies' relative advantages and barriers, promising applications include medium-duty trucks and heavy-duty tractor-trailers on short- and medium-distance routes with high freight use. This approach would require major infrastructure investments and could be rolled out initially on high-freight-traffic corridors, for examples for drayage trucks around shipping ports with key distribution to cities within several hundred miles. Examples of this technology already exist. Trolleybuses powered by overhead catenary wires are deployed in hundreds of cities worldwide, and prominent research projects in Germany and Sweden are demonstrating the technology for freight applications.

Hydrogen fuel cell heavy-duty vehicles could play a key role for low-carbon freight transport in several applications. As noted by the limitations above, an especially important opportunity for fuel cells is in applications for which plug-in and dynamic charging is difficult practically or from a cost perspective. Hydrogen fuel cell technology offers much faster refueling times compared with electric charging times, and this is of great importance to many truck fleets that cannot accommodate additional downtime within their freight activity patterns. The technology also offers the potential for much greater range from hydrogen than battery electric trucks with similar specifications. Especially strong potential is in urban fleets, where governments have prioritized hydrogen infrastructure deployment, and for long-haul tractor-trailer fleets with routes around and between those cities. A key challenge for fuel cells is in their fuel supply, specifically moving toward renewable hydrogen fuel supply, which is simultaneously lower carbon and lower cost. Perhaps the most prominent such projects in 2017 are the in-development Nikola and Toyota fuel cell hydrogen tractor-trailer demonstrations.

Based on the research analytical results and qualitative assessment of projects around the world, we close with several summary conclusions regarding emerging zero-emission technologies for heavy-duty vehicles.

First, we find that electric-drive technologies for heavy-duty vehicles will be essential to decarbonize the transport sector. Heavy-duty freight trucks are disproportionate contributors to pollution, with less than one tenth of all vehicles but roughly 40% of their carbon emissions, and their activity keeps growing. Electric-drive technologies, similar to those being commercialized in passenger cars, will be essential to decarbonize the heavy-duty sector and help meet climate stabilization goals. While the more efficient diesel technologies can reduce carbon emissions by about 40%, electric-drive technologies powered by renewable sources can achieve over an 80% reduction in lifecycle emissions. These technologies can be phased into the fleet through 2050. However, our analysis indicates that these technologies will be insufficient to achieve decarbonization of heavy-duty vehicles by 2050. This is largely a result of how long it takes the fleet to turn over as high-emission trucks are slowly retired over time. Decarbonization will also likely require broader freight sector strategies, including modal shift, logistics improvements, and demand management approaches.

Second, even though these electric-drive heavy-duty truck technologies are in their relative infancy in 2017, by 2030 these technologies are likely to offer cost-effective opportunities for deep emission reductions. Major projects involving heavy-duty electric and hydrogen fuel cell technologies show great potential as a result of their much greater efficiency and available low-carbon fuel sources. Compared with diesel heavy-duty vehicles in the approximate 2030 timeframe, when infrastructure costs are excluded, we find that overhead catenary results in 25%–30% lower costs, in-road induction results in 15%–25% lower costs, and hydrogen fuel cells result in 5%–30% lower costs to own, operate, and fuel. Key drivers for cost-effectiveness are battery pack costs dropping to below $150 per kilowatt-hour and hydrogen fuel costs dropping to below the per-energy-unit cost of diesel (i.e., below $4 per kilogram), as well as the deployment of supporting infrastructure. Beyond these cost-effectiveness considerations, any low-emission technology will have to prove that it meets the same utility, reliability, and safety demands as conventional combustion technologies.

Third, we find that different electric-drive technologies are suitable for different heavy-duty vehicle segments, but simultaneous massive infrastructure investments will be needed for each of them. Advances in battery packs and other electrical components will enable shorter distance urban commercial vans to become plug-in electric, similar to passenger cars. By eliminating battery weight and volume constraints, overhead catenary or dynamic inductive grid technologies can enable electric zero-emission goods transport on and around heavily traveled freight corridors. Hydrogen fuel cell technology might be especially key for longer distance duty cycles. Both of these technologies will require sustained investments by government and industry. Electric highways will require extensive charging (at central stations, with overhead transmission, or inductive road charging). Investments in low-carbon and low-cost hydrogen pathways and refueling infrastructure will have to be made in parallel with vehicle technology advances.

Beyond this report's scope, there is the larger question about how to strategically develop a balanced freight system that includes the right mix of many technologies, including battery electric and fuel cells, in a system that develops over time. Eventually, in the 2020–2030 timeframe, governments and industry leaders will have to make more discrete decisions about infrastructure to serve various technologies of particular vehicle types (medium- and heavy-duty) and freight applications (medium- and long-distance). As technology solutions emerge, questions about how best to sequence the rollout of infrastructure in advance of vehicle deployment, and avoid technology lock-in or stranded assets, will become more important. For the next 5 years, there is minimal such risk, because the technologies analyzed here are all in research, exploratory, and early demonstration phases. Analyzing the expanding and evolving infrastructure systems from a longer term strategic perspective remains a rich area for future research. Studies like this and others (see IEA [2017] and Transport & Environment [2016]) will continue to help inform strategic policy development as technologies evolve.

Based on these conclusions, the challenge for decarbonizing freight transport is becoming clear. To stabilize global temperatures, many developed countries have set the goal of reducing greenhouse gas emissions 80% from 1990 levels by 2050. Efficiency improvements will be of great importance but transitioning to zero-emission vehicles and fuels will be required to achieve greenhouse gas emission reduction targets. To achieve such a transition, a large variety of policy actions will be needed to increase heavy-duty sector efficiency and advance the low-carbon fuel options. Government policies, incentives, and investments will be needed to help offset the increased technology costs until the costs are competitive with conventional vehicle technologies, as well as to set clear expectations for industry investments.

For the near term, the continued and strengthened promotion for drayage, bus, and urban delivery truck applications are important to identify the most appealing business cases for electric-drive trucks. The lessons learned from the uptake of zero emission vehicles in these heavy-duty applications and the resulting reduction in overall technology costs will help to ease the transition in the more demanding long-haul applications. While we are learning from these early projects, government-backed investments in infrastructure give fleets and manufacturers the confidence to more heavily invest in the development, production, and deployment of zero-emission heavy-duty vehicle technologies. The case of California's continued support for zero-emission buses is instructive. The state and local bus agencies continued to feed both hydrogen and electric buses with sustained infrastructure and incentives over the past decade, and now electric buses are demonstrating success and the potential become self-sustaining.

Governments have been acting in key ways to help spur this progress. Simultaneously exploring the bigger, bolder, and infrastructure-intensive options like hydrogen fuel cells and dynamic electric charging in major freight regions is necessary to better understand the costs, benefits, and viability of these technology options for widespread applications. Using available resources, for example from the Volkswagen settlement mitigation funding, for such infrastructure or demonstration projects would certainly be warranted. Key roles for governments are in setting a clear vision, making initial investments in the key technologies, and encouraging further industry development of the ultimate solutions (e.g., Brown, 2016). Because of the complexity of the freight sector, it seems highly likely that a mix of many technologies, likely including plug-in, charging systems, and fuel cells, will ultimately be needed for long-term decarbonization.

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ANNEX

Table A1. Commercial medium-duty zero emission vehicles in development or production.

Company	Name	Technology	Current Status	Technology Specifications									Source
				Range (km)	Battery Chemistry	Max Speed (km/hr)	Recharge Time/ Refuel Time	Torque (Nm)	Power output (kW)	Battery kWh (or Hydrogen Storage kg)	Vehicle Gross Weight (ton)	Load Capacity (ton)	
BYD	T5	Electric Class 5 truck	Production	250	FePO4	97	1.5 h	550	150	145	7.3	3.8	BYD (2016b)
BYD	T7	Electric Class 6 truck	Production	200	FePO4	90	1.75 h	550	150	175	11	5.9	BYD (2016c)
Daimler	eCanter	All-electric light-duty truck	Small-scale production	>100	Li-Ion		7 h (1 h = 80%)	380	185	70	7.5	4.6	Daimler (2016c)
Daimler Trucks	Canter E-CELL	All-electric light-duty truck	Replaced by the eCanter	>100	Li-Ion	90	7 h (1 h)	650	110	48.5	6	3	FUSO (2014)
Deutsche Post DHL Group	StreetScooter Work	Battery electric delivery truck	Production	50–80	Li-ion	120			48	20.4	2.1		Deutsche Post DHL Group (2016)
EFA-S	P80-E	Electric medium-duty delivery truck	Production	80–130	LI-FeYPO4	80	8–10 h	300	91	62	7.5	3.5	EFA-S (2010)
EMOSS	DYNA EV200	Battery electric	Production	160	LI-FeYPO4	85	8 h	700	120	62	7.5	4.6	EMOSS (2016)
EVI	EVI-MD	Battery electric medium-duty truck	Production	145	LiFeMgPO4	105	6–12 h	900	200	99	7.3–10		GreenFleet (2016)
Iveco	Electric Daily 5t	Battery electric delivery truck	Production	90–130	ZEBRA (NaNi/Cl2)	70		300	80	63.6	5	2	Deutsche Post DHL Group (2013)
Motiv Power Systems & Rockport		Electric delivery truck	Production	109–161		97	8 h (2–3 h 50%)	1,200	150	85/106/127	6.6	3.6	Motiv (2016a)
ORTEN & EFA-S	ORTEN E 75 AT	Electric medium-duty truck	Production	100	LiFePO4	80	4 h (22 kW)	1,150	90	72.5	7.5	3.6	ORTEN (2016)
Paneltex		Electric delivery truck	Production	200	LiFePO4					80–120	7.5–11		Paneltex (2017)
Renault	Maxity	Electric with hydrogen-powered fuel cell	Field test 2015	200		90		270	47/ 20	42/ 45	3.5	1	Renault Trucks (2015)
Smith	Edison	Battery electric (chassis cab)	Production (except U.S.)	90–160	Li-ion	80	6–8 h (4 h fast)		90	40	3.5–4.6	1.2–2.1	Smith (2011a)
Smith	Newton	Battery electric (chassis cab)	Production	65–160	Li-ion	80	8 h	600	120	40–120	6.4–12	2.8-7.6	Smith, (2011b, 2011c)
Spijkstaal	Ecotruck 7500	Electric garbage truck		70–100	Li-ion	40	6–8 h		20		7.5	3.7	Spijkstaal (2016)
US Hybrid	eCargo	Battery electric cargo truck	Production	120	Li-ion (18650)	104			120	36	4.5		US Hybrid (2016a)
US Hybrid	H2 Cargo	Fuel cell plug-in cargo truck	Production	200	Li-ion	97	<5 min		120	28 (9.8 kg)	6.4		US Hybrid (2016c)
Workhorse	E-Gen	Electric delivery with range extender		96 (145)		108		2,200	200	60	8.8		Workhorse (2016)

Table A2. Commercial heavy-duty zero emission vehicles in development or production.

Company	Name	Technology	Current Status	Technology Specifications									Source
				Range (km)	Battery Chemistry	Max Speed (km/ hr)	Recharge Time / Refuel Time	Torque (Nm)	Power output (kW)	Battery kWh (or Hydrogen Storage kg)	Vehicle Gross Weight (ton)	Load Capacity (ton)	
Artisan		Battery electric Class 8 drayage		129–161						250			Artisan (2016)
BYD	Q1M	Electric terminal tractor (yard truck)	Production	15	FePO4	53	1–2 h	1,500	180	209	46	9	BYD (2016a)
BYD	T9	Electric Class 8 truck	Production	148	FePO4	90	2.5 h	2,999	359	188	54	11	BYD (2016d)
Charge		Electric truck	2017	160							3.5-26		Charge (2016)
Daimler	Urban eTruck	Fully electric heavy-duty truck	Production 2020	200	Li-Ion			2 × 500	2 × 125	212	26		Daimler (2016a,2016b)
Dennis Eagle, PVI, Phoenix		Electric refuse truck	Production	>150	Li-ion	90	6–8 h			170/255	26.8	9.7	Norsk elbilforening (2017)
E-Force		Electric Class 8 truck	Production	300 (city) 200 (highway)	LiFePO4	87	6 h (44 kW)	630	300	240	18	10	E-Force (2015)
EMOSS	CM 1212	Battery electric truck	Production	150	LiFePO4		2.8/5,5 h	950	150	120	12	6.6	EMOSS (2016)
EMOSS	CM 1216	Battery electric truck	Production	200	LiFePO4		3.6/7.3 h	950	150	160	12	6	EMOSS (2016)
EMOSS	CM 1220	Battery electric truck	Production	250	LiFePO4		4.5/9 h	950	150	200	12	5.4	EMOSS (2016)
ESORO		Class 8 fuel cell truck	Production	375–400	LiFePO4		10 mins		250	120 (35 kg)	34 t		ESORO (2017)
Ginaf	E 2114	Electric delivery truck	Production	105	LiFePO4			1,400 (3,400)	155 (280)	120	13.5 t	7.7	Ginaf (2017)
Ginaf	E 2115	Electric delivery truck	Production	135	LiFePO5			1,400 (3,400)	155 (280)	156	13.5	7.7	Ginaf (2017)
Ginaf	E 2116	Electric delivery truck	Production	150	LiFePO6			1,400 (3,400)	155 (280)	180	13.5	7.7	Ginaf (2017)
Motiv Power. Cumberland		Electric Class 8 refuse truck		80–130		80	8 h (2.5 50%)	3,000	280	170/212	30	20	Motiv (2016b)
Nikola Motor Company	NikolaOne	Hydrogen fuel cell electric semi-truck	Production 2020	1290–1930	Li-Ion		–	2,700	746	320	37-39	29	Nikola (2016)
Renault	Midlum Truck	All-electric refrigerated truck		100	Li-Ion		8 h		103	150	16	5.5	Renault Trucks (2011)
Renault	Trucks D	All-electric truck		120	Li-Ion		7 h		103	170	16.3	6	Kane (2014)
Symbio FCell	Electric Dennis Eagle	Plug-in electric hydrogen waste truck		150	Li-Ion	80			40	85	26	17	Symbio FCell (2016)
Toyota		Class 8 fuel cell drayage truck	Demonstration 2017	>320				1800	500	12	36		Toyota (2017)
TransPower	Elec Truck	Electric drayage truck		110–160	Li-Ion (LFP)				300	215-270	36	26	TransPower (2015)
US Hybrid	H2 Truck	Fuel cell electric drayage truck	Development	320	Li-ion	97	<9 min		320	30 (25 kg)	36		US Hybrid (2016d)
US Hybrid	ETruck	Battery electric Class 8 truck	Development	161 (@27t)	Li-ion	97			320	240	36		US Hybrid (2016b)

Table A3. Long-haul heavy-duty freight truck vehicle component cost breakdown for the different vehicle technologies. The values used are the best estimates from a variety of literature sources.

Vehicle component costs	2015	2020	2025	2030
U.S. base diesel tractor cost ($)	135,000	135,000	135,000	135,000
EU base diesel tractor cost ($)	135,000	135,000	135,000	135,000
China base diesel tractor cost ($)	60,000	60,000	60,000	60,000
U.S. baseline trailer costs ($)	25,000	25,000	25,000	25,000
EU baseline trailer costs ($)	25,000	25,000	25,000	25,000
China baseline trailer costs ($)	10,000	10,000	10,000	10,000
Number of trailers	3	3	3	3
U.S. base truck, "Glider" costs ($)	78,300	78,300	78,300	78,300
EU base truck, "Glider" costs ($)	78,300	78,300	78,300	78,300
China base truck, "Glider" costs ($)	37,400	37,400	37,400	37,400
U.S. other efficiency improvements ($)	2,790	9,580	7,140	26,500
EU other efficiency improvements ($)	-	-	2,240	8,260
China other efficiency improvements ($)	-	1,110	3,170	7,440
Diesel				
Engine power (kW)	350	350	350	350
Fuel tank ($)	2,120	2,120	2,120	2,120
Battery ($)	531	531	531	531
Aftertreatment ($)	6,940	6,940	6,940	6,940
U.S. engine efficiency improvements ($)	2,980	6,280	11,900	18,800
EU engine efficiency improvements ($)	-	-	1,800	5,530
China engine efficiency improvements ($)	-	883	4,270	5,330
U.S. total diesel/ICE vehicle cost ($)	210,000	220,000	223,000	250,000
EU total diesel/ICE vehicle cost ($)	204,000	204,000	208,000	218,000
China total diesel/ICE vehicle cost ($)	90,000	91,500	95,100	99,800
Hybrid Battery Electric				
U.S. additional costs for hybrids ($)	24,700	21,800	18,600	18,100
EU additional costs for hybrids ($)	24,700	21,800	18,600	18,100
China additional costs for hybrids ($)	11,000	9,680	8,270	8,050
U.S. total hybrid electric vehicle cost ($)	235,000	242,000	242,000	268,000
EU total hybrid electric vehicle cost ($)	229,000	226,000	227,000	236,000
China total hybrid electric vehicle cost ($)	101,000	101,000	103,000	108,000
Natural Gas				
LNG SI tank ($/DGE)	246	226	207	187
LNG SI tank capacity (DGE)	173	156	140	123
LNG SI tank cost ($)	42,500	35,300	28,800	23,000
LNG CI tank ($/DGE)	295	272	248	225
LNG CI tank capacity (DGE)	150	136	121	107
LNG CI tank cost ($)	44,300	36,900	30,200	24,100
CNG SI tank ($/DGE)	345	317	290	262
CNG SI tank capacity (DGE)	173	156	140	123
CNG SI tank cost ($)	59,500	49,500	40,400	32,200
Battery cost ($)	531	531	531	531
CI engine ($)	68,900	68,900	68,900	68,900
SI engine ($)	42,900	42,900	42,900	42,900
U.S. total LNG SI vehicle cost ($)	242,000	242,000	233,000	246,000
EU total LNG SI vehicle cost ($)	239,000	232,000	228,000	228,000
China total LNG SI vehicle cost ($)	153,000	147,000	143,000	141,000

Vehicle component costs	2015	2020	2025	2030
U.S. total LNG CI vehicle cost ($)	270,000	269,000	260,000	273,000
EU total LNG CI vehicle cost ($)	267,000	260,000	255,000	255,000
China total LNG CI vehicle cost ($)	118,000	116,000	115,000	117,000
U.S. total CNG SI vehicle cost ($)	259,000	256,000	244,000	255,000
EU total CNG SI vehicle cost ($)	256,000	246,000	239,000	237,000
China total CNG SI vehicle cost ($)	113,000	110,000	108,000	109,000
Dynamic Induction Grid				
Battery (kWh)	165	155	143	133
Battery cost ($)	53,800	35,300	24,000	15,900
Additional required BEV systems ($)	19,300	18,100	16,000	14,300
Electric motor (kW)	350	350	350	350
Electric motor ($)	7,960	6,370	5,720	5,080
Dynamic induction grid connection ($)	16,700	11,800	11,500	10,800
U.S. total dynamic induction vehicle cost ($)	254,000	234,000	218,000	226,000
EU total dynamic induction vehicle cost ($)	251,000	225,000	213,000	208,000
China total dynamic induction vehicle cost ($)	165,000	140,000	128,000	121,000
Overhead Catenary				
Battery (kWh)	165	155	143	133
Battery cost ($)	53,800	35,300	24,000	15,900
Additional required BEV systems ($)	19,300	18,100	16,000	14,300
Electric motor (kW)	350	350	350	350
Electric motor ($)	7,960	6,370	5,720	5,080
Overhead catenary grid connection ($)	71,700	49,600	21,200	21,200
U.S. total overhead catenary vehicle cost ($)	309,000	272,000	227,000	236,000
EU total overhead catenary vehicle cost ($)	306,000	263,000	222,000	218,000
China total overhead catenary vehicle cost ($)	220,000	178,000	138,000	131,000
Fuel Cell				
Power (kW)	350	350	350	350
Fuel cell system ($)	84,000	58,300	31,000	20,500
Compressed gaseous H2 tank ($/kWh)	33	23	21	19
Compressed gaseous H2 tank capacity (kWh)	2,790	2,570	2,570	2,480
Compressed gaseous H2 tank price ($)	92,000	59,100	54,000	47,200
Electric motor (kW)	400	400	400	400
Electric motor ($)	9,080	7,270	6,530	5,800
Battery capacity (kWh)	12	12	12	12
Battery cost ($)	3,910	2,740	2,020	1,430
Additional required FCHEV systems ($)	13,300	11,900	10,800	9,670
U.S. total fuel cell cost—gaseous hydrogen ($)	345,000	290,000	254,000	255,000
EU total fuel cell cost—gaseous hydrogen ($)	342,000	281,000	249,000	236,000
China total fuel cell cost—gaseous hydrogen ($)	256,000	196,000	164,000	150,000

Based on den Boer et al. (2013); Fulton & Miller (2015); Meszler et al. (2015); Posada et al. (2016); Sen et al. (2016)

Table A4. Annual vehicle distance traveled (in kilometers) for U.S., EU-28, and China long-haul heavy-duty vehicles.

Age	U.S.[a]	EU-28	China
1	130,832	126,332	153,175
2	119,001	114,908	139,324
3	108,164	104,444	126,636
4	97,441	94,090	114,082
5	87,476	84,467	102,415
6	78,930	76,215	92,409
7	70,940	68,500	83,055
8	63,474	61,291	74,314
9	56,865	54,909	66,576
10	50,887	49,137	59,577
10-Year Total	1,390,490	834,294	1,011,563

[a] U.S. EPA & NHTSA, 2011

Table A5. Energy consumption (MJ/km) of each vehicle technology for vehicles purchased in 2015, 2020, 2025, and 2030.

	Region	2015	2020	2025	2030
Diesel	United States	14	13	10	9.3
	China	16	13	12	10
	EU-28	12	12	11	9
Diesel hybrid	United States	14	12	10	8.9
	China	15	13	11	10
	EU-28	11	11	10	8.8
Liquefied natural gas (compression ignition)	United States	16	14	11	10
	China	17	15	13	11
	EU-28	13	13	12	10
Liquefied natural gas (spark ignition)	United States	16	14	12	11
	China	18	15	14	12
	EU-28	14	14	12	11
Compressed natural gas (spark ignition)	United States	16	14	12	11
	China	18	15	14	12
	EU-28	14	14	12	11
Hydrogen fuel cell	United States	9.5	8.8	8.2	7.6
	China	9.5	8.8	8.2	7.6
	EU-28	9.5	8.8	8.2	7.6
Electric overhead catenary	United States	5.7	5.3	4.9	4.5
	China	5.7	5.3	4.9	4.5
	EU-28	5.7	5.3	4.9	4.5
Electric dynamic induction	United States	9.0	8.2	7.5	6.9
	China	9.0	8.2	7.5	6.9
	EU-28	9.0	8.2	7.5	6.9

Diesel conversion: 36.66 MJ/l

Table A6. Fuel cost projections from 2015 to 2040

Vehicle	Region	Fuel Prices					
		2015	2020	2025	2030	2035	2040
Diesel ($/gallon)	United States	2.14	3.42	4.27	4.83	5.15	5.47
	China	2.53	4.00	5.00	5.73	6.03	6.40
	EU-28	3.72	5.94	7.43	8.40	8.95	9.51
CNG ($/MMBTU)	United States	15.08	17.12	16.28	15.71	15.18	14.94
	China	7.22	7.59	7.22	6.97	6.73	6.63
	EU-28	13.92	14.65	13.94	13.44	12.99	12.79
LNG ($/MMBTU)	United States	17.62	18.54	17.64	17.01	16.44	16.19
	China	7.82	8.23	7.83	7.55	7.30	7.18
	EU-28	15.06	15.87	15.10	14.57	14.08	13.86
Hydrogen from Natural Gas ($/dge)	United States	6.00	5.46	4.93	4.39	3.85	3.32
	China	6.00	5.46	4.93	4.39	3.85	3.32
	EU-28	6.00	5.46	4.93	4.39	3.85	3.32
Hydrogen from Renewable Pathways ($/dge)	United States	11.00	9.66	8.31	6.97	5.63	4.28
	China	11.00	9.66	8.31	6.97	5.63	4.28
	EU-28	11.00	9.66	8.31	6.97	5.63	4.28
Electricity ($/kWh)	United States	0.10	0.12	0.13	0.14	0.13	0.13
	China	0.09	0.10	0.11	0.12	0.13	0.14
	EU-28	0.14	0.19	0.21	0.22	0.22	0.21

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