**Transportation: The Road Ahead**

*by Teresa Raine and Brian Noel*

With a focus on road-based transportation, this issue looks at three distinct intersections between mobile sources and the environment: compliance, balancing energy drivers, and estimating impacts.

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**MOVES: A Mobile Source Emissions Modeling Overview**

*by Jeremy Heiken, Mark Hixson, and Jim Lyons*
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June is always a big month for A&WMA. We hold our Annual Conference & Exhibition (ACE), where we get a chance to (re)connect with colleagues, learn from topical experts, and see the latest technology in the exhibition hall. If you have not yet registered and made your travel plans, there is still time! Please review the technical program on the A&WMA ACE website (www.awma.org/ace2018). I hope to see you in Hartford!

Each year, the ACE Technical Program includes a Critical Review, a deep dive into an aspect of environmental protection that is relevant for A&WMA members and public policy. This issue of EM and the 48th Annual A&WMA Critical Review both cover environmental issues associated with transportation, focusing on the automobile. The full-length review paper is published in the June issue of the Journal of the Air & Waste Management Association (JA&WMA) and a summary is included in this issue of EM.

At the time of A&WMA’s founding in 1907, horses were a major player in transportation. Big city dwellers navigated piles of horse manure and the occasional carcass. People were happy to trade filth and the threat of disease for the automobile. A little over 100 years later, automobiles and other transportation sources of air pollution are responsible for more than half of the emissions of key air pollutants in many areas, according to U.S. Environmental Protection Agency (EPA) data.

Of the social, environmental, and economic implications of our transportation choices, the 2018 Critical Review, authored and presented by Dr. H. Christopher Frey, focuses on automobile fuel economy and air pollution emissions: trends, technology, regulation, challenges, successes, and the effects on public health. While the review will draw on data and experiences from the United States, contributors will also include relevant information from China, Europe, and elsewhere.

Some of our A&WMA Sections and Chapters are also examining transportation impacts through their work on the Ozone Advance program. Ozone Advance is an EPA program that promotes local action to improve air quality in areas that are still in attainment with the ozone National Ambient Air Quality Standard. Air pollution emissions from transportation are key drivers of atmospheric ozone formation in many areas. The Eastern Sierra Chapter hosted a successful event on Ozone Advance in February. Members of the Upper Midwest Section are engaged with Clean Air Minnesota (https://environmental-initiative.org/work/clean-air-minnesota/), a collaborative effort to reduce air pollution in Minnesota that incorporates Ozone Advance. These programs demonstrate regulatory and voluntary steps a state or region could take to improve their air quality before it is mandated. The projects are flexible, contribute to local public health, and avoid higher costs and delays associated with air quality permitting in nonattainment areas.

Beyond the immediate air pollution impacts of automobiles and transportation, the next 100 years will include exciting changes in transportation. Vehicle electrification, car sharing services, autonomous automobiles, improved bicycle and mass transit infrastructure, and improved technology for remote working arrangements will continue to reshape the transportation sector and its environmental impacts.

If you can’t attend the Critical Review and ACE in Hartford this year, please start planning to join us at the 2019 ACE in Quebec City, Canada. Our local host committee is excited to welcome you and well into planning for a great conference next year.

Thanks for reading EM, and for your contributions to A&WMA.
ACE 2018 is the most comprehensive conference on environmental technology and regulation. Here are the TOP 10 reasons YOU need to be there:

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**TO BE IN THE KNOW**

The people shaping the future of the environmental industry will be there to share information, make connections, and move forward.

Register now and help chart the future—www.awma.org/ACE2018.
With a focus on road-based transportation, this issue looks at three distinct intersections between mobile sources and the environment: compliance, balancing energy drivers, and estimating impacts.
Movement is essential to everything we do and how we assess the environmental world. How air moves, how waste is transported, emissions being emitted and dispersing, energy transmissions, and so forth; movement is key to all environmental discussions, but none likely more so than in how it relates to transportation.

A holistic discussion of the environmental impacts of transportation is needed because the transportation sector dominates usage of energy globally, yet impacts individuals daily. Historically the largest consumer of petroleum, environmental regulations for all modes of transportation have varied as widely as automotive styles in the last century, focusing on operational standards and idling, engine emissions, alternative fuels, alternative transport modes, and/or some combination of each. Regulations are promulgated by local and federal governments alike, and standards have focused on minimizing localize carbon monoxide impacts, reducing regional smog issues, or countering the impacts of global greenhouse gas emissions.

The focus of this issue is road-based transportation, as opposed to sea and air mobile sources, which each face their own unique challenges, regulations, and emission profiles. This issue looks at three distinct intersections between mobile sources and the environment: compliance, balancing energy drivers, and estimating impacts.

Unlike stationary sources, on- and off-road mobile source compliance predominantly lies with the manufacturer and not the ultimate owner or operator. In the first article, William Haak provides his insights on lessons learned from the Volkswagen Diesel Emission settlement. While specific to the elements of the settlement, the lessons learned from the outcome of this case can be related to air and waste non-compliance issues across many industries.

Understanding the interplay and connections between the energy and transportation sectors is an important consideration when assessing the environmental impacts of transportation solutions. The next article, by Brian P. Flynn and Jennifer K. Kelley, discusses the growth of electric cars and the connection to electrical generation in Texas.

In our third article, Jeremy Heiken, Mark Hixon, and Jim Lyons walk the reader through the U.S. Environmental Protection Agency’s MOtor Vehicle Emission Simulator (MOVES), which is the primary tool for developing both on-road and off-road mobile emission source inventories in the United States. MOVES is used for both State Implementation Plan (SIP) development and project specific applications, giving us another example of the local yet regional aspects that are always a part of environmental considerations for the transportation sector.

Last but not least, we include a summary of the 2018 Annual A&WMA Critical Review, “Trends in Onroad Transportation Energy and Emissions,” by Dr. H. Christopher Frey, which traces key issues and trends in the measurement, control, and regulation of onroad transportation emissions.

This issue provides an overview of the array of transportation challenges, inviting EM readers to consider the environmental road ahead.

**Cover Story by Teresa Raine and Brian Noel**

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**Teresa Raine**, Principal Consultant with ERM, currently serves as Vice Chair of EMs Editorial Advisory Committee (EAC); and **Brian S. Noel, P.E.**, Managing Consultant with Trinity Consultants, is a member of the EAC. E-mail: Tree.Raine@erm.com; BNoel@trinityconsultants.com.

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Register online and find details at www.awma.org/MEGA.
What Compliance Lessons Can We Learn from Volkswagen’s Diesel Emissions Scandal?

A look at the car manufacturer’s recent diesel emissions scandal from a compliance perspective—or, what not to do if you should ever find yourself, your company, or a client in a similar situation.
Anatomy of a Scandal
In mid-2016, Volkswagen (VW), a multinational automotive manufacturing company headquartered in Wolfsburg, Germany, executed the first in a series of settlements with the U.S. Environmental Protection Agency (EPA)—joined by the California Air Resources Board (CARB) by and through the State of California—to resolve a civil environmental enforcement action brought in connection with alleged violations of U.S. Clean Air Act mobile source emissions regulations for diesel vehicles. Though the alleged violations occurred over a number of years, the enforcement action first became public in September 2015 when EPA issued a notice of violation to VW accusing the company of utilizing “defeat devices” to bypass, defeat, or render inoperative diesel emission control systems during normal driving conditions.\(^2\)

It was later revealed that VW engineers had developed engine control software that enabled its diesel vehicles to detect when they were being subjected to emissions testing. The software analyzed various drivetrain data, including steering wheel position, vehicle speed, engine parameters, and atmospheric data to recognize testing conditions. During testing, the software would fully activate the vehicle’s diesel emissions control systems to ensure the vehicle could safely pass required emissions testing. During normal everyday driving, however, the software would bypass and/or partially or fully deactivate the vehicle’s diesel emissions control systems to improve engine performance.\(^2\)

By the spring of 2018, VW had completed three partial civil enforcement action settlements with EPA. All told, these settlements involved nearly 600,000 vehicles from the model-years 2009 through 2016.\(^2\) Separately, the U.S. Department of Justice pursued criminal enforcement actions against VW and several of the company’s employees—with one middle level engineer recently sentenced to 7 years in federal prison.\(^3\) The total financial impact to VW in terms of civil penalties, vehicle buy-backs, recalls, and retrofits is at or near US$30 billion. EPA September 2015 notice of violation led to VW’s stock (VLKAY) price dropping by 30 percent almost immediately.\(^3\) The company simultaneously lost almost US$20 billion in market capitalization (much of which has been recovered, as of this writing). Meanwhile, reputational damage to the VW, Audi, and Porsche brands (including loss of “goodwill”) is unquantifiable.

On its face, the VW diesel scandal is a Clean Air Act mobile source emissions enforcement case with far-reaching implications for the future of both mobile source compliance and the continued viability of consumer diesel vehicles themselves. At its core, however, the scandal is a cautionary tale about intentional violations of environmental laws and regulations, a high-level corporate cover-up, deceiving and misleading regulators and, ultimately, what not to do at almost every step if you (heaven forbid…) should ever find yourself, your company, or a client in a similar situation.

Caught in a Cascade of Lies
VW’s troubles ultimately sprang from an all-in U.S. sales strategy that began in 2006 tied to “clean diesel” vehicles that apparently ran headlong into the unfortunate reality that VW had no idea how to manufacture a “clean diesel” vehicle.\(^3\) Shortly after the sales campaign was kicked-off, a senior VW official was filmed in 2007 complaining that compliance with CARB’s diesel regulations was “impossible”.\(^4\) This perceived impossibility led not long thereafter to VW engineers refining and ultimately implementing a defeat device that had first been used by Audi in Europe only a few years earlier.\(^1\) In the following years, VW, Audi, and Porsche officials all became aware of the use of defeat devices in their vehicles to varying degrees. It appears that none of them took decisive action to investigate and/or stop the non-compliance.

The beginning of the end came in the spring of 2014 when researchers from West Virginia University presented and later published a study containing the results of real-world emissions tests that they had conducted on several diesel vehicles, including a BMW sports utility vehicle and two VW cars. While the BMW’s emissions were compliant in both laboratory and on-road tests, the VW cars were compliant only under laboratory testing conditions (on a dynamometer), while emitting 15 to 35 times the allowable limit of nitrogen oxides (NO\(_X\)) in on-road driving conditions.\(^5\)

The details of VW’s internal response at this point are not entirely clear. What is clear is that CARB and EPA regulators were not told about the presence of the defeat devices until late summer 2015. In the interim, VW promised regulators that software patches installed through vehicle recalls would fix the diesel emissions problems (even though VW likely knew this to be untrue).\(^3\) Ultimately, a VW engineer admitted to CARB in August 2015 that the company had been using defeat devices. Another VW engineer confessed in writing in early September 2015.\(^3\) EPA’s notice of violation was issued soon after.

Post-Mortem
VW’s senior leadership had the ability to dramatically alter the company’s outcome in this matter (for the better) up to and until the point where more junior VW representatives admitted wrongdoing to the State of California in 2015. Once a whistleblower comes forward (assuming the...
whistleblower has sufficient knowledge and is telling some version of the “truth”), a regulated entity’s ability to control the narrative of non-compliance is largely lost. VW lost its ability to control the narrative by continuing to hide the truth about the existence of defeat devices from CARB until it was too late.

There is some suggestion that outside legal counsel may have given VW a false sense of security by delivering an unintentionally misleading “reasonable worst case” scenario for VW to base its decisions on. Looking at the legal precedent allegedly relied upon by VW’s outside counsel (a US$100 million fuel efficiency case against Hyundai and Kia settled in 2014), the magnitude of the noncompliance, elements of intent, and lack of candor with regulators on VW’s part suggest a vastly different and arguably incomparable fact pattern.

It is impossible for us to know exactly what legal advice VW received (Thank you, attorney-client privilege...), but it is interesting to speculate whether VW’s internal response would have been different if outside legal counsel had simply said “there is no analog for this, it’s uncharted territory” or “here’s the worst thing we found, given our different facts, we could easily be facing penalties ten times greater (i.e., US$1 billion plus).”

VW appears to have conducted several different cost of compliance analyses (either formally or informally) beginning as early as 2006. It seems at one point VW’s decision was to not disclose the defeat devices because the economic damage of a continued CARB hold on the incoming 2016 model-year was seen as being too costly (given that a hold in California would simultaneously result in several other large states also banning sales pending California approval).

There are numerous compliance and corporate cultural issues to unpack here—not the least of which is that explicitly weighing and discussing the economic impact of compliance versus the economic benefits of noncompliance could be the evidentiary thread that leads the government to convert a “simple” administrative or civil enforcement case into a much more serious criminal investigation. Involving legal counsel in any such discussions is critical as it establishes the “attorney-client privilege,” which can protect certain communications involving legal advice from disclosure in an enforcement action or litigation. The benefit of establishing attorney-client privilege early in an investigation is that, while the privilege cannot prevent the release of “facts,” it can protect the often erroneous opinions and speculation that dominate the beginning stages of investigations when little is truly known.

Lessons Learned
Noncompliance is never easy to deal with no matter the magnitude. Mistakes that lead to noncompliance are made frequently in good faith. Intentional noncompliance is less common. Regardless of what initially led to an instance of noncompliance, the situation cannot be made better by doubling-down on deception or by trying to lead regulators away from facts. This is especially true given that facts are increasingly harder to hide in a digital world where e-mails, text messages, PowerPoint presentations, and voicemails are invariably stored-away for posterity’s sake.

Hindsight is 20/20, but VW’s financial outcome could have been improved (and its reputational damage lessened) if the following steps had been followed once it became clear VW’s senior leadership had the ability to dramatically alter the company’s outcome in this matter (for the better) .... VW lost its ability to control the narrative by continuing to hide the truth about the existence of defeat devices until it was too late.
internally that the company was intentionally violating diesel emissions standards by using defeat devices:

1. An internal “watchdog” function (e.g., compliance, an ombudsperson, an ethics hotline, or legal counsel) should have immediately been alerted to the possible noncompliance;
2. A full-bodied internal investigation led by outside legal counsel under attorney-client privilege should have been commissioned;  
3. Those leading the compliance investigation should have been given full and complete access to everyone involved at all levels in an effort to bring all relevant facts to light; 
4. When outside counsel was engaged, VW should have ensured that they were allowed to know everything, especially to the extent VW was seeking guidance on worst case scenario outcomes;
5. VW's internal investigation should have sought out both the contributing causes and the root causes that allowed the defeat devices and ensuing cover-up to come into being; 
6. VW should have developed meaningful internal corrective actions, including employee discipline, new or revised internal compliance policies, programs, and/or administrative controls—along with proposed external corrective actions (subject to regulatory approval), such as recalls, software updates, buy-backs, or some combination of the above to present to regulators as a “turn-key” package to resolve a potential enforcement action; and
7. In a timely manner (once all facts were known, the root cause investigation was complete, and a package of corrective actions was developed), VW should have carefully approached both EPA and CARB with a “best light” factual account of what happened—along with the company’s proposed remedies.

While it is impossible to know whether successful implementation of any or all of the above steps would have materially altered VW's outcome for the better, it is highly likely that a carefully controlled disclosure to EPA and the State of California would have been preferable to two separate whistleblowers coming forward. While VW could do nothing in 2015 to change what had happened from 2006 through 2014, the company could have dramatically altered its optics by coming forward and doing the right thing prior to being forced to do so by regulators.

William H. Haak is an environmental, health, and safety (EH&S) attorney and consultant, and Founder of Haak Law LLC. With over 24 years of experience (including 4 years helping to enforce the State of Ohio's air pollution control laws while working in the Ohio Attorney General’s Environmental Enforcement Section), Haak practices in all areas of the EH&S fields, with a special emphasis on complex air pollution issues (including compliance assistance and enforcement action response). Haak practices nationwide, and consults on EH&S matters with clients globally. Since 2005, Haak has been an Adjunct Professor at the University of Toledo (Ohio) College of Law teaching Air Pollution Law. E-mail: whh@haaklawllc.com.

References
1. Note: The terms “Volkswagen” and “VW” refer collectively to Volkswagen AG, Audi AG, Dr. Ing. h.c. F. Porsche AG, Volkswagen Group of America, Inc., Volkswagen Group of America Chattanooga Operations, LLC, and Porsche Cars North America, Inc.
4. See https://www.youtube.com/watch?v=zThmune955g.
5. West Virginia University performed its research under contract with the International Council on Clean Transportation. The final report is available online at: https://www.theicct.org/sites/default/files/publications/WVU_LDDV_in-use_ICCT_Report_Final_may2014.pdf.
8. Note: Facts themselves cannot be kept secret simply because a client relays them to an attorney. What a client did or did not do in any given matter cannot be protected from discovery by the privilege. Internal discussions regarding the why’s and how’s of something that was done can be protected to some extent by involving an attorney and invoking attorney-client privilege.
9. Note: The preference for outside legal counsel (vs. in-house legal counsel) is based on a body of case law that questions the width and breadth of the attorney-client privilege when it is established solely through in-house legal counsel. These cases argue that the attorney-client privilege is meant only to protect and encourage the free flow of legal advice, whereas in-house legal counsel often find themselves in the dual roles of both legal and business advisor. Any guidance provided while an in-house attorney is functioning as a business advisor is not entitled to the protection from disclosure afforded by the attorney-client privilege.
Electric Cars and Their Impact on U.S. Climate Change and the Texas Petroeconomy

The authors consider the connection between the growth of electric cars and electrical generation in Texas.
Texas has been known to take a strong position on climate change—particularly on the political level. This is not surprising given its outsized role in the primary extraction and processing of hydrocarbons for fuels. And as of recently, Texas is doubling-down on this bet: production is increasing significantly due to the fracking revolution—even in a hydrocarbon recession. But, Texas has always been a place that extols the virtues of free market capitalism.

Even though the State of Texas officially denies the human role in climate change, it has funded studies to find and eventually develop an offshore repository for carbon dioxide (CO₂) gas. If others believe that CO₂ emissions to the atmosphere should be reduced, why not sell them a place to put it?

All of this is trivial when compared to the Texan embrace of wind energy. Seeing a good opportunity to use a natural resource—windy areas in West and South Texas—and cushioned by Federal Tax Credits, 21,450 megawatts (MW) of wind generation capacity (the most of any state) have been installed as of the end of 2016,1 supplemented by a US$6.8 Billion electric transmission project to bring the energy from remote West Texas to Texas’ growing urban areas.

**Electric Vehicle Trends**

As electric cars extend their range beyond 200 miles (e.g., Chevy Bolt and Tesla Model 3) and reduce their price, the possibility of truly mass use of such vehicles seems feasible. Currently, energy use by U.S. passenger vehicles is approximately one fourth of all energy usage. Any significant changes will have significant effects on U.S. CO₂ emissions. Electric cars are often advertised as zero-emission vehicles, but they are not. The electricity for charging their batteries has to come from somewhere.

In Texas, electrical energy is produced from the sources shown in Table 1.2 Coal and natural gas make up 76 percent of power generation in Texas, both of which emit significant amounts of CO₂. By adding electric cars to the auto fleet, you essentially substitute power plant emissions for the emissions from burning gasoline.

The average age of the car and light-truck fleet is 11.6 years,3 and sales have averaged about 15 million units per year over the past 20 years. Therefore, private vehicle owners account for approximately 174 million cars and light trucks. Gasoline fuel consumption is about 126 billion gallons per year for these light-duty vehicles, as average efficiency is 22 miles per gallon.4 Current technology for electric-only vehicles has an efficiency of about 30 kilowatt-hrs. per 100 miles based on public estimates provided by Tesla, Nissan, and Chevrolet Bolt. If you substituted electric vehicles for 20 percent of current vehicle miles driven, U.S. electrical consumption would go up 165 billion kilowatt-hrs. (or 165 terawatt-hrs.) per year. Current U.S. electrical consumption is around 3762 terawatt-hrs.5 Thus, a 20-percent penetration of the passenger vehicle fleet by electric cars would raise electric consumption by a modest 4.4 percent. Complete replacement by electric cars would raise electric consumption by an estimated 22 percent.

**The Case for Texas**

Texas is a very large producer of natural gas, much of it exported via pipeline to other states. On average, natural gas power plants require 7878 BTU/kwhr and natural gas heat content averages 1035 BTU/cf. In order to produce enough

| Table 1. Texas electrical mix.² |
|------------------------------|---------|---------|
|                              | US (%)  | TX (%)  |
| Coal                         | 30      | 26      |
| Natural Gas                  | 34      | 50      |
| Nuclear                      | 20      | 9       |
| Wind and Solar               | 8       | 13      |
| Hydropower                   | 7       | 0.2     |
| Other                        | 1       | 1       |


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electricity from natural gas for the 20-percent electric car case, 1.3 trillion cubic feet or 1.3 billion mcf is needed. Current natural gas production in Texas is 8.85 billion mcf. Meaning, production would have to increase by 15 percent to supply the needs of the entire United States. Can it be done? Probably yes. Gas production is down a bit due to flat power demand, with some capacity shut in. Also, a new West Texas gas field (Alpine High) discovered in West Texas by Apache Oil has an estimated 75 billion mcf (recoverable natural gas) enough for 60 years of electric car usage.

Figure 1 depicts the breakeven curve for electrical costs versus gasoline at several different gasoline engine efficiencies. At the current gasoline cost of US$2.50 per gallon, the breakeven fuel cost for an electric car must be about 40 cents per kw hr. It currently averages about 12 cents per kW hr, making the electric car three times as economical. Conversely, under current conditions, a gasoline car would have to average about 72 mile per gallon to be as cost-effective as an electric car.

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**EMS Rule Change**

Many forward thinking companies have opted to implement environmental management systems (EMSs) that conform to the ISO 14001 International Standard. The standard was substantially revised in September 2015. Those wishing to certify their systems to the revised standard must do so by September 2018. This issue will review key changes in the ISO 14001:2015 Standard, including strategies for improving and EMSs and integrating with other business systems to gain more value.
Impact on CO₂ Footprint

What is the potential effect of electric cars on the U.S. CO₂ footprint? U.S. CO₂ emissions totaled 5,333 MMT in 2016, including 1,809 MMT due to electrical generation and 1,794 MMT due to transportation. Figure 2 depicts the reduction in U.S. CO₂ emissions as a function of passenger car market penetration of electric cars. The underlying calculations account for the elimination of gasoline combustion (which reduces general automobile pollution to the atmosphere), while combustion of natural gas produces the electricity needed for the car batteries. In the 20-percent penetration base case, emissions are reduced to 5,179 MMT/yr of CO₂—an estimated 2.9-percent reduction. If all passenger vehicles were electric, the reduction would be 14.4 percent. This is significant, but is not a panacea for overall CO₂ reduction.

We can conclude that widespread use of electric cars, which are not zero-emission vehicles, will increase natural gas usage in Texas and the United States, making the U.S. CO₂ footprint smaller. The real target for truly significant reductions is in the fuel mix for electrical generation by continuing to pursue wind and solar power alternatives. Texas is well positioned to supply and benefit from all of these trends.

**References**

4. Derived from data in Federal Highway Administration, Table VM-1: Highway Statistics 2015. In “Annual Vehicle Distance Traveled in Miles and Related Data-2015”.
5. Energy Information Agency Table 1.2 In “Summary Statistics for United States, 2006-2016”. Sub table titled “Sales to Ultimate Customers.”
6. Presentation by John Christmann, CEO & President, Apache Oil at Barclay's CEO Energy Power Conference 9/7/16.
A summary of the key capabilities of the MOVES2014a model, EPA’s current tool for estimating emissions from onroad and nonroad mobile sources.
The U.S. Environmental Protection Agency (EPA) has a 40-year history of developing mobile source inventory modeling software. The first model, MOBILE1, was released in 1978 and replaced lookup tables formerly used for estimating vehicle emission factors. Since then, there have been five major revisions to the MOBILE series, ending with MOBILE6.2 released in 2004. Concurrently, the agency developed the NONROAD series of models for estimating emissions of nonroad mobile sources, which began with NONROAD1998 and concluded with NONROAD2008a released in 2009. Each successive release of both models built upon their predecessors and reflected substantive updates in terms of data, methods, and algorithms accounting for impacts of operational characteristics, ambient conditions, fleet characteristics, emission control devices, and fuel quality.

EPA fundamentally overhauled its approach to mobile source emissions estimation with release of the MOtor Vehicle Emission Simulator (MOVES) in 2009. The MOVES modeling suite—developed as a wholly revised platform, using new methods and data—replaced both the MOBILE and NONROAD models. MOVES2010, the first official version, covered onroad motor vehicles, and the first major revision, MOVES2014, added the nonroad sector.¹

**MOVES Overview**

**Platform**

MOVES is written in Java and the MySQL relational database management system, with some elements written in FORTRAN and the Go programming languages. The model is typically operated on a Windows operating system through the graphical user interface overlay, which contains several features for input development and conversion to MySQL, as well as post-processing routines.

**Features**

Key features of the model are outlined below.

- **Pollutants:** MOVES can address 156 distinct species, including criteria pollutants, toxic compounds, speciated hydrocarbons, speciated particulate matter (PM), energy consumption, and carbon-bond speciation used in certain photochemical models.

- **Emissions Processes:** MOVES accounts for emissions that occur both when vehicles are in operation and when they are at rest. Modeled emission processes include startup, running exhaust, crankcase, hoteling, permeation, fuel vapor venting, liquid fuel leaks, refueling, tire wear, and brake wear.

- **Modal Emission Rates:** For onroad vehicles, operational emissions (i.e., running exhaust) are defined at the 1 hertz resolution to support macro-scale and micro-scale modeling.

**Domain/Scale:** Macro-scale onroad and nonroad emissions can be estimated at the sub-county, county, state, or national level. Micro-scale modeling, referred to as “project level” modeling in MOVES, is available for onroad motor vehicles.

**Vehicles/Equipment:** There are 12 types of onroad vehicles supported, including motorcycles, passenger vehicles, and commercial trucks and buses, and 88 types of nonroad equipment.

**Fuels:** Fuel types supported include gasoline, E85, diesel, electricity, compressed natural gas (CNG), and liquefied petroleum gas (LPG).

**Data**

MOVES input data are contained in 222 MySQL data tables representing the default modeling database. There are multiple mechanisms for users to substitute for any number of data tables. Default tables generally fall into the fleet, activity, or emission rates categories.

Notably, the model contains default data for the entire United States; therefore, the model can be operated to represent any county in the United States without additional inputs. However, use of MOVES for purposes such as State Implementation Plan (SIP) development does require the collection of local input data.

**MOVES Uses**

**County and State Analyses**

One common use of the MOVES model is to estimate mobile source emissions inventories for counties and states, which are often developed as part of SIPs focused on bringing areas into compliance with National Ambient Air Quality Standards (NAAQS).

While MOVES contains default data for all counties and states, EPA recommends use of local data for vehicle activity, population, and fuels to more accurately represent actual emissions.² Sources of local data include Department of Motor Vehicles registrations, traffic analyses, travel demand modeling, and vehicle surveys. SIP inventories serve two main purposes: planning and modeling. The planning inventory establishes future-year emissions and emissions budgets used for transportation conformity.³ Modeling inventories are inputs developed for ambient air quality models when used to determine compliance with a given NAAQS.

**National-Level Analyses**

MOVES is used to estimate emissions at the national level to support federal rulemakings and recurring planning inventories. Rulemaking analyses include revisions to the NAAQS, onroad motor vehicle standards, fuel regulations, and interstate pollutant transport.

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The national domain in MOVES covers 50 states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands, encompassing 3,228 counties or county-level equivalents. Although EPA maintains county databases of onroad and nonroad inputs supplied by local and state agencies for each county, completing national inventories using these data would be time prohibitive. Instead, the agency has developed an inventory process that relies on estimating emission factors from “representative counties” over a range of conditions and then post-processing the national inventory externally to MOVES. That process is the subject of the below case study.

**Case Study: The NEI**

The National Emissions Inventory (NEI) is a comprehensive compilation of criteria and toxic air pollutants in the United

![Figure 1. National Emission Inventory (NEI) development process.](image1)

![Figure 2. Onroad VOC emissions by county, 2014 NEI (tons/yr).](image2)
States emitted from essentially all anthropogenic and biogenic sources. The NEI is a triennial effort using data provided by state, local, and tribal air agencies for sources in their jurisdictions and supplemented by data developed by EPA. Version 2 of the 2014 NEI is the current, complete version; the 2017 NEI is under development.

The onroad emissions inventory development process for the NEI is shown in Figure 1. The process begins by updating the national county databases, followed by an assessment of representative counties applied to the contiguous 48 states. The 2014 NEI updated onroad data inputs for more than 1,800 counties; 297 representative counties were identified for inventory processing.

Following identification of the representative counties, emissions inventory processing begins. For onroad motor vehicles, MOVES can be operated in either “inventory” or “emission rate” mode. To support the development of the NEI, MOVES is operated in emission rate mode for the representative counties over a range of vehicle speeds and ambient conditions. As shown in Figure 1, these data are combined with county-level meteorology data and activity data using the SMOKE program to produce the final on-road emissions inventory. SMOKE is an EPA emissions processing software used to develop inventories for photochemical modeling; a distinct SMOKE–MOVES model was created to estimate on-road inventories using the representative counties procedure.

The county-level on-road inventory of the 2014 NEI is presented in Figures 2 and 3 for volatile organic compounds (VOC) and oxides of nitrogen (NOx), respectively. The national total onroad inventory in 2014 equals 2.3 and 4.8 million tons per year of VOC and NOx, respectively.

**Project-Level Analyses**

Project level is the MOVES equivalent of micro-scale. The model estimates running exhaust emissions for roadway segments (links) while assigning other emissions (e.g., startup exhaust) to locations off of the roadway (off-network). In this manner, the model can evaluate individual intersections and facilities that include both roadway and parking locations. These features give MOVES the ability to support a wide range of project-level analyses.

**GHG Inventories**

With respect to greenhouse gas (GHG) emissions, MOVES generates estimates of carbon dioxide (CO2), nitrous oxide (N2O), and methane (CH4). EPA has issued guidance on the use of MOVES for GHG inventory development for state and local agencies. EPA’s official national GHG inventory is prepared following Intergovernmental Panel on Climate Change (IPCC) guidelines in which the MOVES model is used to provide N2O and CH4 emission rates, with CO2 emissions being derived from fuel consumption estimates.

MOVES2014a reflects all current light-duty GHG regulations and the Phase 1 heavy-duty onroad fuel efficiency
regulations; the Phase 2 regulations will be included in a subsequent MOVES update. Notably, EPA has used various versions of MOVES to analyze the impact of national GHG and fuel efficiency regulations on GHG emission inventories.7

**MOVES Going Forward**

EPA is tentatively planning to release a minor update, MOVES2014b, in summer 2018. EPA is referring to the next major model revision as MOVES201X, with a release in early 2019 at the soonest. em

Jeremy G. Heiken, founder and president of Oak Leaf Environmental, has 29 years of experience developing and applying mobile source emissions models. He led the original NONROAD model development and his direct hands-on experience with MOBILE and MOVES dates back to MOBILE3.9. Mark Hixson is a senior consultant in the Mobile Source and Fuels business line of Trinity Consultants with 11 years of experience (including four years as a researcher at the University of California, Davis). Hixson’s primary practice areas include mobile source emissions modeling, photochemical grid modeling, and regional emissions development. James M. Lyons is principal consultant in Trinity’s Sacramento office and head of Trinity’s Mobile Source and Fuels business line, has extensive experience related to fuels issues and emissions, including the emission impacts of changes in gasoline and diesel fuel composition and substitution of alternative fuels for petroleum-based fuels. E-mail: JLyons@trinityconsultants.com.

**References**

1. U.S. Environmental Protection Agency. MOVES and Other Mobile Source Emissions Models; available online at https://www.epa.gov/moves.
2. 40 CFR part 51, Subpart Z.
3. 40 CFR 51.1012(a)(2).
Trends in Onroad Transportation Energy and Emissions

The 2018 Critical Review focuses on the historic and more recent developments and trends relating to on-road vehicles in some detail. The review covers the major advances in engine design, control technologies, and fuels that have made it possible to reduce emissions and fuel use despite sustained growth in on-road vehicle miles travelled. The full-length review appears in the June 2018 issue of the Journal of the Air & Waste Management Association (JA&WMA). A brief summary follows.
Globally, 1.3 billion on-road vehicles consume 79 quadrillion BTU of energy, mostly gasoline and diesel fuels, emit 5.7 gigatonnes of carbon dioxide (CO₂), and emit other pollutants that are responsible for an estimated 200,000 premature deaths annually. In the 20th century, the vast majority of the exponential growth in global vehicle stock and vehicle miles traveled (VMT) occurred in the United States and Europe. However, most of the current growth in vehicle stock and fuel consumption is shifting to China and the rest of Asia (see Figure 1). Petroleum-based fuels remain the predominant transportation energy source globally.

Despite the emergence of a variety of alternative fuel and electric drive vehicles in the last two decades, the share of on-road transportation energy from fuels other than gasoline or diesel is currently trivial. Growth in demand for fossil fuels for transportation has been mitigated, but not eliminated, by improvements in vehicle fuel economy. In 2009, the U.S. Environmental Protection Agency (EPA) found that six greenhouse gases (GHGs) endangered public health and welfare, leading to more stringent fuel economy and new GHG standards effective starting in 2012. In the last decade, fuel economy and GHG emissions of the U.S. light-duty vehicle (LDV) fleet have improved significantly (see Figure 2). Fuel economy standards in many other countries are leading to concurrent improvements. However, consumer interest in heavier vehicles, most notably in the United States and China, offset potential reductions in energy use. EPA announced on April 3, 2018, that it will revise the LDV GHG emission standards for the 2022 to 2025 model years, which could slow the development and diffusion of more energy efficient vehicle technologies.

**Technology-Forcing Standards**

Beginning with the 1970 U.S. Clean Air Act, the United States implemented aggressive standards that forced the deployment of relatively new technologies and led to emissions reductions from gasoline and diesel vehicles that comprise the vast majority of the onroad fleet. The three-way catalyst (TWC) is one of the most important emission control technologies of the 20th century and is responsible for a greater than tenfold decrease in gasoline vehicle emissions of carbon monoxide (CO), oxides of nitrogen (NOₓ), and volatile organic compounds (VOCs). Effective TWC operation depended on phasedowns of gasoline lead and sulfur content and computer-controlled fuel injection for more precise control of air/fuel ratio. The air quality benefits of reduced CO, NOₓ, and VOC emissions are indicated by the virtual elimination of CO and nitrogen dioxide (NO₂) air quality nonattainment areas in the United States and a general trend of decreasing ambient ozone (O₃) ambient concentrations. Ongoing evolution of the TWC and its applicability to a wide variety of fuels used in stoichiometric engines worldwide promise to accrue ongoing health benefits into the foreseeable future.

![Figure 1. Global annual sales of new onroad vehicles.](image-url)
Because fine particles are a major contributor to health effects from the transportation sector, expanding application of diesel particulate matter (PM) controls is a priority. The suite of post-combustion controls now commonly used in the United States and Europe for new diesel engines, including diesel oxidation catalyst (DOC), diesel particle filter (DPF), and selective catalytic reduction (SCR) for NOx, are likely to be among the most important environmental technologies of the 21st century. The ability of these technologies to reduce real-world emissions requires the use of low-sulfur diesel fuel. The real-world effectiveness of these technologies has been validated empirically using many measurement methods. Some questions remain regarding the long-term durability of these technologies, emissions from DPF regeneration, SCR effectiveness related to low exhaust temperature, and the potential for SCR ammonia slip.

**Emerging Challenges**

Gas direct injection (GDI) engines introduced commercially in LDVs in the last 10 years are more energy efficient, but have higher exhaust particle emissions than the port fuel injection (PFI) gasoline engines that they displace. Thus, they may require mitigation with a gas particle filter (GPF) to achieve increasingly stringent particle mass emission standards in California and particle number standards in Europe.

There is growing recognition that vehicle emissions of higher molecular weight VOCs contribute to the formation of secondary organic aerosols (SOAs). Thus, it is important to continue research on organic particle formation and development of targeted prevention options, most likely related to more efficient control of releases of SOA precursors, as well as consideration of control of ambient peroxy radical precursors.

A key issue that has emerged in the last decade in Europe and elsewhere is a widening disparity regarding real driving emissions (RDE) compared to laboratory-based measurements of emissions. Although manufacturer cheating could be a contributing factor, the European-type approval procedure is clearly a key factor. In Europe, only one low power demand driving cycle (NEDC) has been used for type approval and a new replacement cycle (WLTC) is only a small improvement. In the United States, fuel economy rating and emissions certification are based on multiple cycles that represent a much wider range of vehicle operating conditions and, therefore, are more accurate with regard to real-world fuel economy and emissions. The planned use of portable emission measurement systems (PEMS) in Europe and China to measure RDE should lead to improved conformity between real world and official values. As hot stabilized emissions decrease, the relative importance of cold start emissions may increase.

Emission factor models such as the Motor Vehicle Emission Simulator (MOVES) are typically based on a relatively small number of driving cycles. However, with the growing availability of data on real-world driving cycles, it is now possible to assess inter-cycle variability as a contributing factor to variability and trends in mean emission rates. Mean emission rates based on sampling of a large number of cycles are likely to be more accurate than emission rates estimated based on a limited number of default cycles.
**Inspection and Maintenance**

Evaporative emissions from the crankcase and from fuel tank venting are effectively controlled with well-established technologies in conventional vehicles. However, the shift from emission test-based to onboard diagnostic (OBD) check-based inspection and maintenance (I/M) programs in most states may be leading to unacceptably high rates of both false positive and false negative outcomes. Validation is needed that OBD checks are a sufficiently robust indicator of either tampering or failure of emission control systems. The institutional and technical approach to I/M for heavy-duty vehicles has generally not kept pace with the changes in emission control technologies in any country, and requires incorporation of measurement methods relevant to the lower emissions of modern diesel vehicles.

The Volkswagen scandal was discovered because of measurements with PEMS made in a research program, not because of I/M programs. Given that there was a heavy-duty diesel engine NO\textsubscript{x} emissions scandal (NO\textsubscript{x} defeat devices installed on heavy-duty diesel engines) in the United States more than a decade prior to the Volkswagen scandal, the threat of penalties is not sufficient to deter cheating. The EU approach to developing RDE regulations means that manufacturers will not know exactly under what conditions their vehicles will be tested.

**Challenges in Managing Future Consumption and Emissions**

As older vehicles are removed and cleaner, more fuel-efficient new vehicles enter the fleet, the average emission rate (g/mile) will decline substantially for many non-GHG pollutants (see Figure 3). However, without other interventions, the growth in vehicle stock, vehicle miles traveled (VMT), and fossil fuel consumption and concomitant GHG emissions could increase. Shifts from transportation fossil fuels to electric drive vehicles will lead to substantial GHG emissions reductions only if the power generation fuel mix is decarbonized. The attempt at the latter in the United States, the Clean Power Plan, is threatened with roll-back under the current political administration. With the forecast continued use of fossil transportation fuels, CO\textsubscript{2} emissions would inevitably increase.

Because methane is a potent greenhouse gas, shifts from liquid fuels to natural gas may offer marginally reduced GHG emissions only if fugitive emissions from natural gas production, transport, and distribution are appropriately managed. Shifts to hydrogen from steam reforming of methane would offer little marginal benefit.

Although technological solutions to reducing emissions and fuel consumption rates of vehicles continue to provide

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**Figure 3.** Trends in U.S. national average NO\textsubscript{x} emissions rates for gasoline-fueled passenger cars for calendar years 2015 to 2050 and ages 0 to 30 years, estimated using MOVES2014a with default inputs.
remarkable benefits, the demand for travel is an integral part of trends in vehicle energy use. Land use patterns, demographic factors, economic factors, design and operational factors, and societal values affect demand for transportation, mode choice, energy use, and emissions. Some of these factors, individually, may provide only small potential for reducing energy use and emissions, but in combination, coupled with technology-based solutions, could be part of an integrated approach to energy and emissions management.

**Disruptive Technology: Autonomous Vehicles**

Currently, it is difficult to predict how full adoption of autonomous vehicle (AV) technology will affect energy use or whether emissions of GHGs, criteria pollutants, and air toxics will be higher or lower. The net effect depends in part on a number of factors, including whether such vehicles ultimately will increase or decrease VMT. It is possible that adaptive management could mitigate against large increases in energy use via pricing or cordonning schemes. Given the wide range of potential results, it is critical to promote integrated and iterative consideration of energy, emissions, exposure, and health impacts along the AV development and deployment path.

**Research Needs**

The regulatory emission factor model used in the United States, MOVES, needs to account for some newer technology vehicles, such as hybrid electric vehicles (HEVs) and plug-in HEVs. MOVES also does not explicitly account for some of the trends in conventional LDV technology, such as from PFI to GDI. As emission rates generally decrease, the omission of

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**Attend the 48th Annual A&WMA Critical Review Presentation at ACE**

**Trends in Onroad Transportation Energy and Emissions**

by H. Christopher Frey

**Tuesday, June 26**

9:00–11:45 a.m.

Connecticut Convention Center, Hartford, CT

Following the review presentation, a panel of invited experts will critique the presentation and offer their own views on the topic. This year’s invited discussants are: Alberto Ayala, Executive Director, Sacramento Metropolitan Air Quality Management District; Susan Collet, Executive Engineer, Toyota Motor North America; Rashid Shaikh, Director of Science, Health Effects Institute; Eric Stevenson, Director of Meteorology, Measurement and Rules, Bay Area Air Quality Management District; and Michael P. Walsh, Independent Consultant/Board Member, International Council on Clean Transportation.

**Join the Discussion**

Comments also will be solicited from the floor and from written submissions to the Critical Review Committee Chair. The Chair will then synthesize these points into a Discussion Paper that will be published in the October 2018 issue of JA&WMA. Comments should be submitted in writing to Samuel L. Altshuler, Critical Review Committee Chair, at altshule@pacbell.net by no later than July 31, 2018. The full-length review will be published in the June 2018 issue of JA&WMA.

**Get Involved**

Get involved with the Critical Review Committee and help further our scientific understand by attending the Annual Meeting of the Critical Review Committee on Tuesday, June 26, 2018, at 3:00–4:00 p.m.

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such sources of variability may lead to biases in emission estimates. The effect of vehicle weight and payload needs to be addressed adequately in the development of vehicle emission factors and requires further characterization. The role of ambient conditions, and auxiliary loads such as air conditioning, are also inadequately characterized.

More research on organic particle formation and development of targeted prevention options is needed. Methodologically, more work is needed to better quantify and communicate uncertainties in emission inventories.

Mean emission rates based on sampling of a large number of cycles need to be incorporated into emission factor models. Comparisons of real-world driving cycles illustrate that some driving patterns can lead to lower emission rates. The concept of eco-driving has been tested mainly with respect to fuel consumption and should be further evaluated with regard to emissions. Lessons learned from comparative analysis of driving cycles need to be considered in designing advice for human drivers and algorithms for automated driving.

Non-exhaust emissions from evaporation and wear (e.g., brake pads, tires) are an important contributor to the environment from motor vehicle operation. Given their complexity in terms of gaseous and particle species, these emissions need to be better characterized. There will be an ongoing need to characterize and manage non-exhaust emissions, as illustrated by venting processes for compressed natural gas (CNG) vehicles, challenges in dealing with fuel tank venting for HEVs, and the effect of increased vehicle weight on wear emissions for battery electric vehicles.

Lower cost micro-portable emissions monitors, low-cost air quality sensors, and new open path measurement methods may make it easier for governments, communities, businesses, or individuals to monitor local emissions and air quality. Deployment of sensors on roving vehicles, such as Google Street View or mass transit vehicles, can enable extensive spatial and temporal data collection that can be used to develop, calibrate, and validate high-resolution transportation air pollutant exposure models.

More work is needed to characterize spatial and temporal variability in traffic-related air pollution exposures, especially in the onroad and near-road environments. Vehicle activity, energy use, emissions, exposure, and health effects are highly heterogeneous, which implies the need to develop effective sampling strategies to account for the myriad of factors that contribute to variability and to have large enough sample sizes to obtain robust findings. This implies a need for adequate commitment of resources for measurements, data collection, data analysis, model development, and data interpretation.

### About the Author/Presenter

**Dr. H. Christopher Frey** is the Glenn E. Futrell Distinguished University Professor of Environmental Engineering in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University. Dr. Frey is an internationally recognized expert in transportation energy use and emissions.

Dr. Frey has served as a member and chair of the U.S. Environmental Protection Agency (EPA) Clean Air Scientific Advisory Committee (CASAC). He has reviewed National Ambient Air Quality Standards for all criteria pollutants. He was lead author of the uncertainties chapter on in the 2006 International Panel on Climate Change (IPCC) Guidelines on National Greenhouse Gas Emission Inventories, and in 2016 was an invited expert regarding the updates to those guidelines. He was also a technical contributor to the U.S. Department of Transportation 2010 Report to Congress regarding transportation’s role in reducing U.S. GHG emissions. He is a Fellow of the Association, serving on the A&WMA Board of Directors. He is a past president of the Society of Risk Analysis. He has a bachelor’s of science degree in mechanical engineering from the University of Virginia, a master’s of engineering in mechanical engineering from Carnegie Mellon University, and Ph.D. in engineering and public policy from Carnegie Mellon.

### Reference

As seasoned EH&S project managers know, the selection, application, and verification of voluntary consensus standards to projects can be quite challenging.

Project management involves the application and integration of processes for financial, technical, and personnel management. In some cases—communication procedures and authorities, for example—processes are project-specific and must be designed by the project manager to address detailed and specific project needs. Other processes, such as employee hiring and training, are defined by organizational policy and procedures. Additionally, technical processes, procedures, and requirements for many environment, health, and safety (EH&S) projects are determined by voluntary consensus standards (VCS). A key role of the EH&S project manager is to select and implement the range of processes required for the project. Although there are often checks and balances that govern the application of company policy and project-specific procedures, the selection, application, and verification of VCS to projects can be challenging.

**Standard Setting Organizations**
The American National Standards Institute (ANSI) coordinates and promotes VCS and serves as the U.S. representative in non-treaty international and regional standards-setting activities. VCS are published by standard setting organizations (SSOs) and SSOs exist for virtually every aspect of commerce.
EH&S project managers in the United States are readily familiar with the following SSOs:

- American Society of Mechanical Engineers (ASME)
- ASHRAE (formerly American Society of Heating and Refrigeration Engineers)
- ASTM International (formerly American Society for Testing and Materials)
- American Water Works Association (AWWA)
- Indoor Air Quality Association (IAQA)
- International Organization for Standardization (ISO)
- National Fire Protection Association (NFPA)
- PMI (Project Management Institute)
- TNI (formerly The NELAC Institute)
- Underwriters Laboratories (UL)

Beyond these listed organizations there are hundreds of other SSOs in the United States and thousands of SSOs around the world.

SSOs can be prolific in the generation of standards. ASTM, for example, provides several hundred environmental standards in five areas: Atmospheric Analysis Standards, Environmental Assessment Standards and Risk Management Standards, Environmental Toxicology Standards, Waste Management Standards, and Water Testing Standards. Further, SSOs may publish complementary or contradicting VCS. For example, ASTM and IAQA both publish standards related to mold growth in buildings. Similarly, ASTM and AWWA both publish standards related to water supply systems. It is therefore important for the project manager to understand the focus of SSOs and how VCS published by different SSOs may complement or contradict one another.

The National Technology and Transfer Act (NTTAA) was signed into law in 1996 to foster innovation and commercialization of technology. The NTTAA requires that federal agencies use technical standards developed by voluntary consensus bodies instead of unique government standards if compliance with the VCS is consistent with applicable law. Accordingly, many VCS are incorporated into federal regulations.

**Accreditation**

Once the appropriate VCS has been identified for the project, it is important to verify that the standard is implemented properly. In some cases, independent, third-party accreditation may serve as evidence that an organization is properly implementing the standard. For example, most environmental laboratories are accredited to ISO 17025 and/or TNI standards, which means that they have the management systems, equipment, personnel, and proficiency testing programs in place to support the analytical methods they perform. In other cases, an organization may self-declare that its products or services conform to a VCS. In this case, the project manager is best-served by obtaining supporting documentation, by an independent auditor if necessary, that the product or service does indeed conform to the requirements of the standard.

VCS are an important component of EH&S projects. Project managers who understand the SSOs that issue VCS, know the relationship of VCS to federal regulations, ensure conformance of products and services with VCS, and who actively engage in the revision and development of VCS will employ VCS effectively.

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To remain relevant, VCS must evolve as technology advances. Some VCS must be retired, some must be revised, and, in some cases, new VCS must be developed.
Sustainability Implications of Enhanced in situ Bioremediation Implementation

by Michael Cheatham, Warren Brady, and Brent Lazenby

The authors use a sustainability analysis to quantify greenhouse gas emissions associated with the implementation of enhanced in situ bioremediation for contaminated groundwater as an alternative to an extended period of monitored natural attenuation.

Numerous technologies exist within the realm of groundwater remediation, and while selecting the optimal remedy is often driven by existing site-specific conditions, the performance of a sustainability analysis can be a useful tool when evaluating remedial alternatives.

Goal 3 of the U.S. Environmental Protection Agency’s (EPA) Strategic Plan, 2014-2018 fiscal years, is cited as “Cleaning Up Communities and Advancing Sustainable Development…hazardous waste programs…are working to reduce the energy use and environmental footprint during the investigation and remediation of hazardous waste sites.”

To compliment these goals, EPA has established five core elements to be evaluated when selecting greener cleanup approaches, which may be measured in quantitative units...
to evaluate sustainability:

(1) Materials & Waste,
(2) Energy,
(3) Air,
(4) Water, and
(5) Land & Ecosystems.

By considering the environmental footprint of various technologies on these elements, project teams may tailor a green remediation approach that mitigates negative environmental impacts while still accomplishing project goals (see Figure 1).

**Bioaugmentation**

In nature, there are a number of processes that reduce contaminants in the environment. For example, bioremediation is the abatement of compounds by biological fauna that may be indigenous to a contaminated area or introduced by bioaugmentation. Many bacteria have been documented to degrade a wide variety of contaminants as a result of their growth and/or respiration. Monitored natural attenuation (MNA) is a remedial approach that may be viewed as a passive strategy, as it relies on naturally-occurring environmental processes (e.g., biodegradation, dilution, sorption, and/or evapotranspiration) to reduce contaminant concentrations over time.

Enhanced in situ bioremediation (EISB), on the other hand, is a remediation approach that relies on bioaugmentation and/or biostimulation to promote favorable conditions for growth of bacteria that have a propensity to degrade targeted contaminants. One tool often used as a biostimulant in EISB is emulsified vegetable oil (EVO). As a by-product of the carbon sequestered during the growth of soybeans used to make EVO, the overall carbon footprint associated with EVO is negative, making it a sustainable tool in the EISB process.

Coupled with the soluble nature of chlorinated volatile organic compounds (cVOCs), decades of their production, transportation, and disposal have made them a prevalent class of contaminants in groundwater throughout the developed world. Remediation of cVOCs in groundwater is a widely studied science with numerous proven technologies and largely established regulatory oversight, outside of sustainability.

**Sustainability Study**

A study was conducted to evaluate and compare select sustainability metrics associated with the implementation of EISB at a confidential site in lieu of an extended period of MNA to remediate cVOCs in groundwater. Chlorinated ethenes and chloroethane are present in groundwater at the site, with detected concentrations ranging from 7 to 61 micrograms per liter (μg/L). The impact parameters associated with the two approaches were selected based on their ability to be realistically quantified throughout phases of the projects and then directly compared to one another (see Table 1).

Select sustainability implications stemming from the implementation of EISB as a more aggressive, five-year remedial alternative were compared to portions of the life-cycle assessment that assumed 30 years of MNA. Carbon dioxide-equivalent (CO₂-eq) emissions were used as the sustainability impact indicator to compare greenhouse gas (GHG) emissions associated with each remedial alternative.

The 30-year MNA option involved two phases: (1) semianual groundwater sampling and reporting; and (2) plug and abandonment of existing wells. Sampling was assumed to be performed by a non-local firm using commercially available passive and no-purge samplers to collect groundwater across the site’s monitoring network. Reporting efforts were based on the site’s regulatory requirements. Plug and abandonment of the site’s monitoring network, assuming successful MNA, was quantified based on the firm’s previous experience at similar sites and equipment details provided by subcontractor estimates.

The five-year EISB implementation and monitoring option included six phases: (1) EISB design document production; (2) injection well installation and surveying; (3) permitting; (4) amendment addition to the subsurface (EVO injection); (5) semiannual sampling and reporting; and (6) plug and abandonment of wells. Quantities of consumables were based on a proposed conceptual EISB implementation approach for the site.

Quantified impact parameters for each remedial alternative can be found in Table 1. Impact parameters were compared
<table>
<thead>
<tr>
<th>Impact</th>
<th>Units Parameter</th>
<th>Parameter Units</th>
<th>Emissions (pounds CO₂-eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MNA</td>
<td>EISB</td>
</tr>
<tr>
<td>LDPE Plastic</td>
<td>(pounds)</td>
<td>44</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDPE Plastic</td>
<td>(pounds)</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>PVC Plastic</td>
<td>(pounds)</td>
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<td>1,018</td>
</tr>
<tr>
<td>Paper</td>
<td>(pounds)</td>
<td>219</td>
<td>49</td>
</tr>
<tr>
<td>EVO</td>
<td>(pounds)</td>
<td>0</td>
<td>8,907</td>
</tr>
<tr>
<td>E10 Gasoline</td>
<td>(gallons)</td>
<td>1,351</td>
<td>288</td>
</tr>
<tr>
<td>Diesel Generator</td>
<td>(gallons)</td>
<td>0</td>
<td>158</td>
</tr>
<tr>
<td>Diesel Drilling</td>
<td>(gallons)</td>
<td>180</td>
<td>540</td>
</tr>
<tr>
<td>GHG emissions (tons CO₂-eq):</td>
<td>16</td>
<td>8.5</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
- MNA - Monitored Natural Attenuation
- EISB - Enhanced in situ Bioremediation
- LDPE - Low Density Polyethylene
- HDPE - High Density Polyethylene
- PVC - Polyvinyl Chloride
- EVO - Emulsified Vegetable Oil
- CO₂-eq - carbon dioxide equivalent

with published values of GHG emissions per unit from various sources, largely based on cradle to gate analyses with few exceptions.

CO₂-eq emissions associated with MNA and EISB resulted in emissions of 16 and 8.5 tons, respectively, as shown in Table 1. Eighty percent of the emissions associated with MNA stem from the transportation associated with 30 years of sampling, whereas drilling resulted in roughly eighty-six percent of the emissions associated with EISB. Utilization of EVO offset the GHG emissions of the EISB approach; however, even without the roughly 6-ton CO₂-eq offset, EISB would still result in fewer emissions than 30 years of MNA, under the assumptions of the study.

Summary
EISB is a sustainable remediation approach that relies on engineering to streamline and enhance natural processes that make them more efficient at meeting the needs of society to manage human health and the environment. While aggressive remediation technologies may appear to be less economical on the front end, passive approaches can result in less sustainable cleanup initiatives and higher costs due to prolonged operation. When coupled with cost, labor, and material considerations for alternative technology analyses, sustainability studies can aid in remedial system decision-making to shed light on often-overlooked effects of implementation, and aid in the selection of approaches that are more suitable for the sustainability goals set-forth by EPA and sustainably-conscious organizations.

Reference

YP Perspective is a regular column organized by A&WMA’s Young Professional Advisory Council (YPAC). YPAC strives to effectively engage professionals within the Association by developing services and activities to meet the needs of today’s young professionals (YPs). A YP is defined by the Association as being 35 years of age or younger. Each YP is encouraged to get involved with the Association, whether within their local Chapter or Section or within the Association’s four Councils (Education Council, Technical Council, Sections and Chapters Council, and YPAC). YPs interested in getting involved may contact YPAC for more information on current volunteer and leadership opportunities. Call for Submissions: If you have a topic you would like to see YPs discuss, e-mail: Christopher Whitehead at cwhitehead@trinityconsultants.com.
Long-time A&WMA Member and Fellow of the Association, Dr. Timothy (Tim) C. Keener, passed away unexpectedly on April 9, 2018. He was 69.

Born on June 21, 1948, in Sevierville, TN, Prof. Keener attended Olney Boarding School, and completed undergraduate and graduate degrees at the University of Tennessee. He joined the University of Cincinnati as an assistant professor in the Department of Civil and Environmental Engineering in 1982. In 1988, he was promoted to associate professor with tenure, and in 1993 promoted to professor. Dr. Keener was Professor Emeritus at the University of Cincinnati, where he had been a Professor of Engineering and Senior Associate Dean for 32 years until his retirement in 2015.

An internationally renowned scholar, he was the proud recipient of a Fulbright Scholarship from the U.S. State Department, among many other honors. He developed a strong research program focused on the reduction of air pollution and secured funding from agencies, such as the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the Ohio Coal Development Office. He was also a dedicated mentor to his undergraduate and graduate students.

He was a Qualified Environmental Professional (QEP), QEP examiner, and lead for the Institute of Professional Environmental Practice (IPEP). An active Association member since 1982, he became a Fellow of the Association in 1996, and was awarded the Lyman A. Ripperton Award for his distinguished achievement as an educator in air pollution control in 1997. Most recently, Dr. Keener served as Technical Editor-in-Chief of the Journal of the Air & Waste Management Association (JA&WMA) from 2012 to 2015, helping to shepherd JA&WMA from a traditional manuscript submittal system to a fully online manuscript submittal process.

Prof. Keener will be remembered for his lasting friendships, strong sense of family, and keen sense of humor. He is survived by his wife, Sumana, and two children. Personal condolences and tributes can be found at http://www.springgrove.org/obituary.aspx?id=3719.
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