DEVELOPMENT OF CARTEEH CURRICULUM FOR TRANSPORTATION EMISSIONS AND HEALTH (PHASE I)

September 2020

CARTEEH

Center for Advancing Research in
Transportation Emissions, Energy, and Health
A USDOT University Transportation Center

Texas A&M Transportation Institute | Georgia Tech College of Engineering | Johns Hopkins Bloomberg School of Public Health | College of Engineering The University of Texas at El Paso | UC Riverside CE-CERT

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16. Abstract
The Center for Advancing Research in Transportation Emissions, Energy, and Health has developed a unique, cross-disciplinary course titled Traffic-Related Air Pollution: Emissions, Human Exposures, and Health. The course is intended to form the basis for a three-credit-hour graduate-level course offered by consortium member institutions and targeted at students and practitioners in the areas of urban planning, transportation planning, transportation policy, transportation engineering, geography, environmental sciences, environmental epidemiology, environmental policy, and public health. However, the course's individual lectures are designed to stand alone, and as such, they can be mixed and matched to be transferable to other locations and other purposes. In its entirety, the course is designed to equip participants with cutting-edge knowledge and the skill sets required to understand, assess, and quantify road traffic, vehicle emissions, traffic-related air pollution (TRAP), human exposures, biological mechanisms, associated health effects, and population-based impacts and their societal costs. Further, the course will specifically explore the role of current knowledge in environmental regulation and real-world policy making and practice. The course will conclude with an introduction to the basics of policy option generation and selection, methods, and tools to assess policy feasibility and effectiveness to mitigate the adverse environmental and health effects of TRAP, and an overview of available and emerging policy and technology options. Barriers and facilitators to good practice, co-benefits to other sectors, and overlap with the sustainability agenda will be presented, alongside real-world examples and case studies. The course currently includes 60 lecture titles along with an outline of key topics that should be included, at a minimum, in each lecture. For each lecture, a list of potential lecturers has been created. In Phase II of this project, the content of each lecture will be finalized, and the 60 individual lectures, consisting of slides, with supporting notes and information will be made publicly available online.

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Executive Summary

Education is important because it is the gateway to knowledge for many individuals and a process whereby individuals enhance their understanding. Education supplements training and creates well-informed employees for the workforce. However, the current structure of the education system is lacking in collaboration and cross-disciplinary study. Traditionally, subjects are taught in an isolated manner. In particular, the transportation and health fields are two fields that have not traditionally worked together in the past and have been viewed as distinct and separate fields of education, research, and practice. For example, transportation engineering students have limited, or no health courses required in their degree plan, and public health students have limited or no transportation or urban planning courses required in their degree plan, despite many overlaps between the two fields. The educational overlap between the two types of students is usually only found in the core curriculum (i.e., general introductory courses, such as English, political science, etc.). In order to best prepare students for a growing pool of cross-disciplinary positions and to equip them with more holistic knowledge and skill sets to tackle multifaceted contemporary challenges, it is imperative to shift the current education system toward a more collaborative and cross-disciplinary format. One strategy to integrate different fields of study in an educational setting is developing and implementing cross-disciplinary curricula.

For these purposes, the Center for Advancing Research in Transportation Emissions, Energy, and Health (CARTEEH) has developed a unique, cross-disciplinary course titled Traffic-Related Air Pollution: Emissions, Human Exposures, and Health. The development of the course followed the overarching framework developed in a previous project by the principal investigator. The project used numerous models and measurement techniques and already available datasets to characterize the full chain of events between traffic activity and its associated health impacts, including the modeling and measurements of traffic, vehicle emissions, traffic-related air pollution, exposure assessment, health effects analysis, health impact and burden of disease assessment, and policy and technology solutions [1]. The outline of the curriculum intentionally follows the full-chain approach, while providing general background at the outset of the course and thorough coverage of policies and technologies to mitigate traffic-related air pollution, emissions, poor air quality, human exposures, and ultimately adverse health impacts. In addition, the outline of the curriculum was peer-reviewed by senior and junior researchers and educators and shared with multiple students, who made some suggestions and confirmed that all key topics had been adequately covered. This process was iterative with over 30 revisions of the curriculum's outline, resulting in the final outline described in this report.

As designed, this course is intended to form the basis for a three-credit-hour graduate-level course offered by CARTEEH consortium member institutions or other universities. The course is targeted at students and practitioners in the areas of urban planning, transportation planning, transportation policy, transportation engineering, geography, environmental sciences, environmental epidemiology, environmental policy, and public health. However, the course's individual lectures are designed to stand alone, and as such, they can be mixed and matched to be transferable to other locations and other purposes.

In its entirety, the course is designed to equip participants with cutting-edge knowledge and the skill sets required to understand, assess, and quantify road traffic, vehicle emissions, traffic-related air pollution (TRAP), human exposures, biological mechanisms, associated health effects, and population-based impacts including their distribution and societal costs. Further, the course will specifically explore the role of current knowledge in environmental regulation and real-world policy making and practice. The course will conclude with an introduction to the basics of policy option generation and selection, methods, and tools to assess policy feasibility and effectiveness to mitigate the adverse environmental and health effects of TRAP, and an overview of available and emerging policy and technology options. Barriers and facilitators to good practice, co-benefits to other sectors, and overlap with the sustainability agenda will be presented, alongside real-world examples and case studies.

The course currently includes 60 outlined lectures, which can be broadly categorized under the themes:

1. Basics of Air Quality, Emissions Standards, and Environmental Regulations
2. Monitoring and Modeling of Traffic Related Air Pollution
3. Exposure Assessment of Traffic-Related Air Pollution
4. Health Impacts of Traffic-Related Air Pollution
5. Health Impact and Burden of Disease Assessment

Policies, Technologies, and Mitigation Approaches

Once the preliminary content was identified, subject matter experts will be recruited within and outside the CARTEEH consortium in Phase II to develop the lectures. To the best of the author's knowledge, no similar courses exist. A modified version of the course has already been adopted at the Georgia Institute of Technology where it was taught in the spring 2019 semester as an undergraduate special topic to 34 students from various backgrounds.

In Phase II of this project, the content of each lecture will be finalized, and the complete 60 slide decks will be made publicly available online at the CARTEEH website. The principal investigator, multiple colleagues from CARTEEH, and an external collaborator at the Barcelona Institute for Global Health have also edited a book that covers the same topics included in the curriculum: *Traffic-Related Air Pollution*. While the development of the book was not funded by CARTEEH, it is complementary to the curriculum and can be used as an education or training aid. The book is now published online and available from Elsevier at https://www.elsevier.com/books/traffic-related-air-pollution/khreis/978-0-12-818122-5.

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Background and Introduction

Traditionally, air pollution has been recognized as an issue associated with domestic heating, coal burning, and industrial emissions [2]. In the present post-industrial city-scape, however, outdoor air pollution in many cities of the world (e.g., high-income countries) has become dominated by emissions attributable to road traffic, including dust and tailpipe and non-tailpipe emissions of a wide variety of pollutants harmful to human health and well-being [3, 4]. Nowadays, traffic-related air pollution (TRAP) represents a public health crisis, the extent and magnitude of which are large and keep growing as new knowledge and quantification methods become available.

TRAP refers to the contribution of traffic activity to ambient air pollution. Traffic activity includes the use of motorized vehicles such as passenger cars, motorcycles, buses, coaches, and light-duty and heavy-duty vehicles. These vehicles emit air pollutants including:

- Black carbon.
- Carbon monoxide.
- Nitrogen oxides.
- Particulate matter with a diameter less than 2.5 micrometers.
- Particulate matter with a diameter less than 10 micrometers.
- Ultra-fine particles with a diameter less than 0.1 micrometers.
- Hydrocarbons.

These pollutants can be directly emitted through the vehicle exhaust and are then known as tailpipe emissions [5]. They can also be emitted through non-exhaust mechanisms such as evaporative emissions, the resuspension of dust, the wear of brakes and tires, and the abrasion of road surfaces, and are then known as non-tailpipe emissions [5, 6]. Vehicle emissions disperse into ambient air depending on multiple factors, which are highly variable, such as wind speed, wind direction and atmospheric stability, local and regional terrain, and background air pollution concentrations from other sources such as industry, agricultural emissions, and coal and wood burning [5].

Air pollutants contribute to the degradation of ambient air quality and result in numerous adverse health outcomes for exposed populations. In recent estimates, a quarter of new childhood asthma cases per year in an English urban area were attributed to TRAP [7]. In conservative global estimates, 184,000 deaths a year are attributable to TRAP [8]. Similarly, Lelieveld et al. estimated that land transport-related air pollution is responsible for one-fifth of deaths from air pollution in the United Kingdom, the United States, and Germany [9]. The public health burden of many of the health effects associated with TRAP has, however, not been quantified, and therefore the full burden is yet to be fully elucidated. This is true for air pollution in general but is particularly true for TRAP because specific source apportionment or full-chain burden of disease or health impact assessments are needed to come up with these estimates. These assessments are complex and often overlooked [10].

Recent reviews and meta-analyses find robust associations between common traffic-related air pollutants and premature mortality and a wide spectrum of diseases, including but not limited to cardiovascular disease, lung cancer, diabetes, adverse birth outcomes, and adverse respiratory outcomes, especially in childhood (Table **1**). The list of adverse health outcomes associated with TRAP continues to grow. The list now includes health effects that were not associated with TRAP a decade or so ago such as autism and child behavioral problems [11-13], cognitive decline [14-16], dementia and Alzheimer disease [17-20], obesity [21], and increased osteoporosis-related fracture hospital visits and decreased bone density [22]. New adverse health effects associated with TRAP continue to emerge at a very rapid pace [23], and the body of evidence has been strengthened substantially to demand urgent action [5]. Furthermore, many credible pathological mechanisms have been elucidated, lending biological

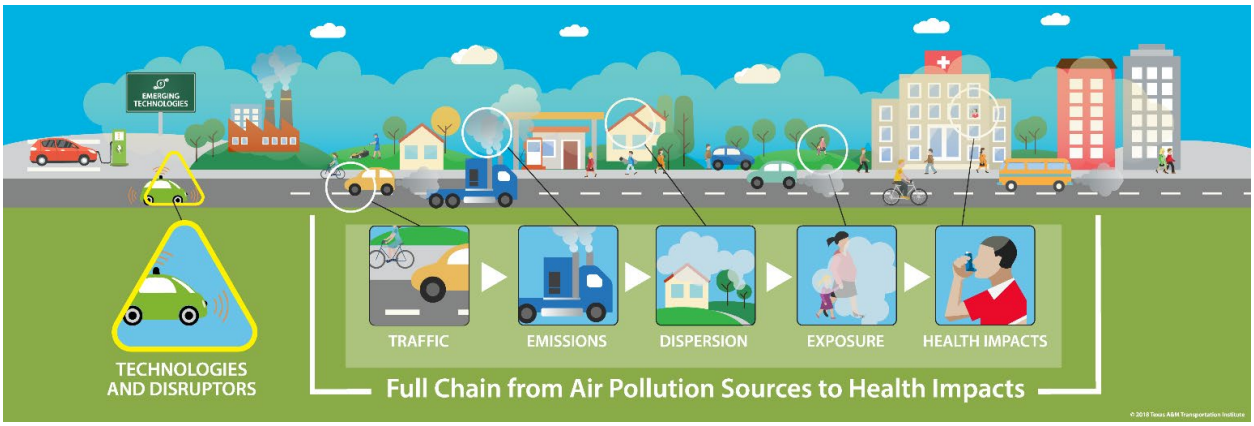
plausibility to the epidemiological findings and strengthening the case for action [24-29]. These mechanisms include airway remodeling, inflammation, oxidative stress, and a shift in immune function [30, 31].

Table 1. Diseases Associated with TRAP: A Non-comprehensive List Health Outcome Associated with TRAP	Reference
Arrhythmia	Link and Dockery 2010 [32]
Autism and child behavioral problems	Raz et al. 2015 [11]
Childhood asthma	Khreis et al. 2017 [33]
Childhood asthma and wheeze	Gasana et al. 2012 [34]
Chronic obstructive pulmonary disease	Lindgren et al. 2009 [35]
Coagulation effects	Brook et al. 2010 [36]
Congenital anomalies	Vrijheid et al. 2011 [37]
Coronary events	Cesaroni et al. 2014 [38]
Dementia	Power et al. 2016 [39]
Low birth weight	Fleischer et al. 2014 [40]
Lung cancer	Raaschou-Nielsen et al. 2013 [41]
Myocardial infarction (heart attack)	Mustafić et al. 2012 [42]
Obesity	Jerrett et al. 2014 [21]
Pneumonia	MacIntyre et al. 2014 [43]
Preeclampsia	Pedersen et al. 2014 [44]
Premature mortality	Beelen et al. 2014 [45]
Preterm birth	Sapkota et al. 2012 [46]
Reduced sperm quality	Lafuente et al. 2016 [47]
Reduced birth weight	Pedersen et al. 2013 [48]
Stroke	Stafoggia et al. 2014 [49]
Systemic inflammation	Brook et al. 2010 [36]
Type II diabetes	Eze et al. 2015 [50]

Source: Sanchez et al. [51]

TRAP is not yesterday's problem. The impact of TRAP on public health will remain an issue for decades to come. The global population has risen substantially over the past century and is estimated to reach 9.8 billion by the year 2050 from just 7.6 billion in 2017 [52]. With population and economic growth comes an increase in the number of vehicles being manufactured, purchased, driven, and emitting more air pollutants. Increased transportation activity continues to overpower emission regulation and advancements in vehicle and fuel technology, and therefore TRAP is expected to rise. Because of motor vehicles' mobile nature, their operation in close proximity to many people, and highly uncertain and variable exhaust and non-exhaust vehicle emissions, exposure to TRAP is very difficult to quantify and control. The rapid and unprecedented urbanization the world is currently witnessing is also worrisome in this context. The world's urban population is projected to increase to 68 percent by 2050 [53]. Cities and urban areas are hot spots for human exposure to TRAP, where traffic activity is not only higher but also acts in close proximity to people, increasing their harmful exposures and associated adverse health effects [5, 54]. Of the world's population, 92 percent lives in cities where air pollution levels exceed the World Health Organization's air quality guidelines [55], which are still too high to fully protect public health.

The impacts of TRAP on human health can be quantified and assessed using numerous approaches, one of which includes a full characterization of the events connecting the air pollution sources to the final health impacts, referred to as the *full-chain assessment* [7]. Full-chain assessment is a process that models or measures the full chain of events between traffic activity and the final health outcomes that can be attributed back to that activity's TRAP (Figure 1).



Source: Center for Advancing Research in Transportation Emissions, Energy, and Health, available from: https://www.carteeh.org/

Figure 1. The Full Chain: Linking TRAP to Health Impacts

This start-to-finish approach highlights the different components of the full chain and links them together to pinpoint the impacts of particular air pollution sources (traffic in this case) [56]. The full chain includes traffic activity, traffic emissions, dispersion and resulting air quality, exposure, and human health impacts. The strength of the full chain is in how it ties multiple components together rather than simply focusing on one piece of the puzzle. Understanding the relationship between the aforementioned elements of the full chain paves the way for discussions about policy and practice implications and for making more concrete and specific policy and technology recommendations to protect public health. In addition to the full-chain assessment, numerous existing and emerging methods and tools can quantify TRAP and its impacts.

Problem

Emerging and existing methods and tools to quantify TRAP, its health impacts, and the impacts of potential policy and new technology options are not mainstreamed in education, research, practice, or policy making. This makes the real-world impact of rapid scientific and methodological advances very limited. One strategy to disseminate this knowledge and integrate different fields of study in an educational setting is developing and implementing cross-disciplinary curriculum around TRAP and its health impacts. The reality, however, is that the current structure of the education system is lacking in collaboration and cross-disciplinary study. Traditionally, subjects are taught in an isolated manner. The transportation and health fields are two areas that have not traditionally worked together in the past and have been viewed as distinct and separate fields. For example, transportation engineering students currently have limited or no health courses required in their degree plan, and public health students have limited or no transportation or urban planning courses required in their degree plan. The educational overlap between the two types of students is usually found in the core curriculum (i.e., general introductory courses, such as English, political science, etc.).

In order to best prepare students for a growing pool of cross-disciplinary positions and to equip them to tackle multifaceted and growing challenges regarding the impacts of TRAP on human health, it is imperative to shift the current education system toward a more collaborative and cross-disciplinary format. In addition, for scientific and methodological advances to have a real-world impact, educating and training a cross-disciplinary workforce is required. The current segregated course format creates gaps between transportation engineering and planning and public health students, which typically carries over into the workplace.

Methodology

This project focused on TRAP as an adverse and modifiable environmental exposure that significantly impacts public health, especially in cities and disproportionately among different segments of the population.

The Center for Advancing Research in Transportation Emissions, Energy, and Health (CARTEEH) has developed a unique, cross-disciplinary course titled Traffic-Related Air Pollution: Emissions, Human Exposures, and Health. The development of the course followed the overarching framework developed in a previous project by the principal investigator. The project used models and measurement techniques and already available datasets to characterize the full chain of events between traffic activity and its associated health impacts. The full-chain assessment included the modeling and measurements of traffic, vehicle emissions, traffic-related air pollution, exposure assessment, health effects analysis, burden of disease and health impact assessments, a discussion of policy and technology solutions, and a validation of models wherever possible [1]. Beyond these topics, there is value in understanding the biological plausibility of the health effects associated with TRAP because this kind of knowledge can ground epidemiological findings and burden of disease and health impacts. Similarly, there is value in understanding and addressing new technologies and innovations in the transportation sectors that are emerging rapidly, such as autonomous and electric vehicles. The impacts of these technologies on TRAP levels and human health are also understudied but are critical to understand early on so that policy makers and planners can devise a proactive rather than a reactive approach to mitigating the potential adverse effects of these disruptors. For this reason, these topics—biological plausibility, epidemiological studies, and the impacts of new technologies and innovations, including their impacts on environmental justice—have been included in the curriculum outline.

The outline of the curriculum was developed to follow the full-chain approach. The course was also developed to provide general background at the outset of the course and thorough coverage of policies and technologies to mitigate traffic-related air pollution at the conclusion of the course. The outline of the curriculum was peer-reviewed by senior and junior researchers and educators and shared with multiple students, who made suggestions and agreed that all key topics had been adequately covered. After the outline was agreed upon, the principal investigator, based on her expertise and additional literature reviews where needed, outlined multiple lecture items under each topic to ensure that the basics in each lecture are always covered at a minimum. In Phase II of the project, these lecture items were provided to each lecturer, and they were asked to cover these items at a minimum as important basics to the topic of study. Finally, the principal investigator, in collaboration with CARTEEH consortium members, identified a potential pool of lecturer for each of the lectures, including primary and back-up options. In Phase II of the project, the content of the lectures is being finalized and peer-reviewed before being made publicly available online on the CARTEEH website (http://carteeh.org).

The results presented in the next section represent the result of several iterations of the curriculum outline and lecture items, which were mainly achieved via email correspondence and some in-person and phone discussions with CARTEEH members and external collaborators, who are acknowledged in the “Acknowledgments” section of this report.

The course was designed to start with basic definitions and an overview of standards and regulations that aim at mitigating the problem of TRAP and its adverse health impacts, and at critically discussing where these standards and regulations might be inadequate including considering environmental justice issues. Afterward, the course goes through every step between road traffic activity and the ultimate health impacts of TRAP, giving the student the required knowledge, theory, methods, and tools to understand, assess, and quantify road traffic, their associated emissions, air pollution, exposures, health effects, and population-based health impacts. This knowledge is grounded in clinical and biological research to show the range of potential underlying mechanisms driving the observed effects and to highlight potential reasons for susceptibility and differential health effects in different populations. Finally, the course discusses the real-world implications of the emerging science,

overviewing policy options and scenarios that can mitigate TRAP and its adverse health effects; emerging technologies and disruptors and their documented or potential effects, barriers, and facilitators to good practice; overlap with higher-level agendas such as sustainability and climate change; and market solutions, giving real-world examples and case studies wherever possible. The results of this exercise are described next.

Results

Course Description and Target Audience

This course consists of 60 lectures and is intended to form the basis for a three-credit-hour graduate-level course offered by consortium member institutions and primarily targeted at students (and potentially practitioners) in the areas of urban planning, transportation planning, transportation policy, transportation engineering, geography, environmental sciences, environmental epidemiology, environmental policy, and public health and health policy. However, the course's individual lectures are designed to stand alone, and as such, they can be mixed and matched to be transferable to other locations and other purposes, including:

- Complementing existing academic or professional courses, including at the undergraduate level.
- Devising a smaller course with select lectures for target audiences with specific needs and/or existing knowledge.

In its entirety, the course is designed to equip participants with cutting-edge knowledge and the skill sets required to understand, assess, and quantify road traffic, vehicle emissions, TRAP, human exposures, biological mechanisms, associated health effects, and population-based impacts and their societal costs. Further, the course will specifically explore the role of current knowledge in environmental regulation and real-world policy making and practice, in addition to discussing the role of innovative technologies and transportation disruptors, such as automated and electric vehicles.

The course concludes with an introduction to the basics of policy option generation and selection, methods, and tools to assess the effectiveness and feasibility of policies to mitigate the adverse environmental and health effects of TRAP, and an overview of available and emerging policy and technology options. Barriers and facilitators to good practice, co-benefits to other sectors, and overlap with the sustainability agenda will be presented, along with real-world examples and case studies.

Tracks

Ideally, lectures in this course are delivered in their entirety, which ensures cross-disciplinary learning and training, and not operating in silos. However, some educators and institutions may have interest in a subset of the course to tailor to a crowd with existing knowledge in some topics or to tailor to a specific potential application. For this reason, three separate tracks, which are not mutually exclusive, were developed. The course can be offered in these three high-level tracks, reflecting CARTEEH's vision and tailored to the participants' existing knowledge and potential application:

- **Health track (HT)**—mainly targeted at urban planners, transportation planners, and engineers with limited knowledge of public-health-related concepts. The HT provides an overview and the basics of the health side of the spectrum (including lectures such as an introduction to epidemiology and overview of epidemiological studies, designs/types, etc.).
- **Transportation track (TT)**—mainly targeted at environmental epidemiologists and public health professionals with limited knowledge of transportation-related concepts. The TT provides an overview and the basics of the transportation side of the spectrum (including lectures such as an introduction to transportation planning, overview of traffic measurement and modeling, etc.).

- **Planning and policy track (PPT)**—mainly targeted at planners, civil servants, and policy and decision makers with particular interest in the science-policy link. The PPT mainly targets practitioners and policy decision makers and provides a more holistic overview of the health and transportation sides of the spectrum, along with a focus on the science-policy link and real-world case studies.

The HT and TT both cover policy background, policy options generation, and (scenario) analysis, and most individual lectures do not fit in one track alone but rather in both.

Key Topics

Cross-disciplinary in nature and targeted at a cross-disciplinary audience, the course covers key topics from transportation engineering, planning and policy, urban planning, the environment, exposure assessment, environmental epidemiology, public health, and public and health policy, notably including:

- Introduction to air pollution and traffic-related air pollution.
- Introduction to vehicle emissions and air quality standards and regulations.
- Traffic monitoring and modeling.
- Vehicle emissions monitoring and modeling.
- Air pollution monitoring and modeling.
- Air pollution and traffic-related air pollution exposure assessment.
- Epidemiology.
- Health impacts and burden of disease assessment.
- Health effects and impacts of traffic-related air pollution.
- Toxicological and mechanistic evidence.
- Policy option generation, selection, and implementation.
- Emerging technologies and disrupters.
- Policy (scenario) analysis, effectiveness, and feasibility.
- Barriers and facilitators to good practice and real-world examples.

Course Outcomes

Participants in this course will become equipped with a unique cross-disciplinary background that is not currently offered by any other course/curriculum. Participants are also expected to gain expertise to support policy makers, confidently use analytical tools and methods from the different disciplines and interpret and clearly communicate results and their relevance in policy and practice circles.

Preferred Prerequisites

The course is designed at the graduate level for those knowledgeable of the basics of transportation or environmental health. It is therefore preferred that participants have an undergraduate degree in one of the following:

- Civil or transportation engineering.
- Urban, regional, or transportation planning.
- Geography.
- Medicine.
- (Bio)environmental sciences.
- Public or community health.
- Public or health policy.
- Equivalent education or experience.

However, because the course covers the basics of transportation and environmental health, these prerequisites are preferred but not essential.

Delivery Methods

The content of each of the 60 proposed lectures will be developed by national and international experts as part of Phase II. These experts will also develop a set of slides in a predefined CARTEEH template and include notes and reading material which the participant can refer to for more complete and in-depth information. As much as feasible, select lecture will be turned into a 15-minute prerecorded audio lecture in Phase II or potentially a Phase III of the project, which participants can listen to either prior to or during the relevant class, depending on the instructors' preference and experience. Exams, papers, quizzes, and homework assignments can be assigned based on the instructors' preference but are not further addressed in this work. The book that was developed in parallel with the curriculum, *Traffic-Related Air Pollution*, parallels the course material and may serve as a useful reference [57]. **Error! Hyperlink reference not valid.**

Course Outline and Key Lecture Items

The 60 lecture titles are shown in the outline below, along with key lecture items that experts were asked to cover at a minimum in their respective PowerPoint slides. The content o the lectures will be developed in Phase II of the project.

Theme 1: Basics of Air Pollution, Air Quality, and Vehicle Emission Standards and Environmental Regulation

1. Air quality and air pollution

   Proposed lecture items:

   - Definition of air pollution.
   - Examples of air pollutants.
   - Sources of air pollution.
   - Range of air pollutants (i.e. primary, secondary, criteria, and toxics).
   - Chemistry of air pollution.
   - General health and environmental effects.
   - Examples of major poor air quality events and their impacts.

2. Traffic-related air pollution

   Proposed lecture items:

   - Specific traffic-related air pollutants.
   - Sources and vehicle fleet mix (e.g., petrol versus diesel) contributions.
   - Chemistry (i.e. combustion processes, secondary formations, and others).
   - Source apportionment.
   - Spatial trends.
   - Temporal trends.
   - Critical factors affecting concentrations.
   - Key differences compared to air pollutants from other sources.

3. Other transportation-related emissions and air pollution

   Proposed lecture items:

- Broader transportation-related emissions and air quality issues.
- Examples of non-on-road emissions and their health impacts including rail, aviation, ports, truck terminals, on-road facilities, etc.
- Key pollutants.
- Use in policy decision making.

4. Air quality standards and health

   Proposed lecture items:

   - Definitions and rationale of air quality standards.
   - Covered and not covered pollutants.
   - Air quality standards across the world (e.g. comparison of Europe, the United States, Canada, the World Health Organization) and comments on differences.
   - Health effects at exposure levels below current air quality standards.
   - Underlying evidence base (e.g. health and environmental impacts of different air pollution levels, thresholds).
   - Development and revision of air quality standards.
   - Compliance and noncompliance and how to establish this.

5. Air quality monitoring and use in compliance determination

   Proposed lecture items:

   - Regulatory air quality monitoring around the world.
   - Global perspectives.
   - Use in compliance determination.
   - Representativeness and comprehensiveness of air quality monitoring.
   - Noncompliance with air quality standards and consequences.

6. Vehicle emission standards and underlying evidence base

   Proposed lecture items:

   - Definitions and rationale of vehicle emission standards.
   - Vehicle emission standards across the world (e.g. comparison of Europe, the United States, Canada, China, etc.).
   - Development and revision of vehicle emission standards.
   - Underlying evidence base (e.g. health and environmental impacts of different emission levels, thresholds, etc.).
   - Regulatory certification, type approval, and compliance determination, strengths and weaknesses.
   - Diesel gate and examples.
   - Research gaps and future direction.

7. History of key laws and regulations and quantifiable impacts

   Proposed lecture items:

   - Key air quality regulations (e.g. Air Pollution Control Act, Clean Air Act, the London Smog).
   - Consequences of laws and regulations.

- Quantifiable impacts and analysis.
- Future predictions or trends.
- Air pollution as a public health problem including explanation of health risks (at the individual level versus community level).
- Research gaps and future direction.

8. Environmental justice

   Proposed lecture items:

   - Background/history and definitions.
   - Environmental justice in the transportation context.
   - Environmental justice, traffic and/or transportation emissions, and health.
   - Research gaps and future direction.

Theme 2: Monitoring and Modeling of Traffic, Traffic-Related Emissions, and Traffic-Related Air Pollution

Subtheme 2.1: Introduction to Traffic Monitoring and Modeling

9. Transportation and land-use planning

   Proposed lecture items:

   - Introduction to transportation planning.
   - Scope of work, planning criteria, and role in public planning and policy.
   - Integration with land-use planning.
   - Key data and information collection.
   - Key issues and trends including air pollution.
   - Transportation planning and sustainable development including alternative modes of transportation.

10. Traffic measurement methods and data sources

    Proposed lecture items:

    - Traffic data (e.g. information/items, formats, and examples).
    - Traffic fleet composition determination.
    - Traffic data sources (e.g. publicly available counters, other counters, own campaigns).
    - Use in policy decision making.
    - Research gaps and future direction.

11. Traffic modeling methods and data sources

    Proposed lecture items:

    - Overview of macro-scale, meso-scale, and micro-scale models.
    - Models/software and availability.
    - Inputs.
    - Processes.

- Outputs.
- Validation.
- Use in policy decision making.
- Research gaps and future direction.

Subtheme 2.2: Introduction to Traffic Emissions Monitoring and Modeling

12. Emission measurement/characterization methods and data sources

    Proposed lecture items:

    - Methods to measure emissions (e.g., portable emission monitoring systems, remote sensing devices).
    - Results from emission measurement campaigns (e.g., vehicle fleet trends, fuels).
    - Factors affecting vehicle emissions.
    - Comparison of vehicle emission standards and laboratory measurements.
    - Available data sources and platforms for vehicle emission measurements.
    - Use of emission measurement/characterization in emission modeling.
    - Use in policy decision making.
    - Research gaps and future direction.

13. Emission modeling methods and data sources

    Proposed lecture items:

    - Overview of macro-scale, meso-scale, and micro-scale models.
    - Models/software and availability.
    - Inputs.
    - Processes.
    - Outputs.
    - Validation.
    - Use in policy decision making.
    - Research gaps and future direction.

Subtheme 2.3: Introduction to Air Pollution Monitoring and Modeling

14. Air pollution measurement methods and data sources

    Proposed lecture items:

    - Methods to measure gaseous ambient air pollution (e.g., diffusion tubes, fixed-site continuous monitoring).
    - Methods to measure particulate ambient air pollution (e.g., filters, fixed-site continuous monitoring).
    - Strengths and limitations.
    - Physical and chemical principles.
    - Temporal and spatial resolutions.
    - Data sources and platforms for air pollution measurements.
    - Examples.

15. Air pollution dispersion modeling methods and data sources

    Proposed lecture items:

- Models/software and availability.
- Inputs.
- Processes.
- Outputs.
- Validation.
- Strengths and limitations.

16. Photochemical modeling methods and data sources

    Proposed lecture items:

    - Models/software and availability.
    - Inputs.
    - Processes.
    - Outputs.
    - Validation.
    - Strengths and limitations.

Theme 3: Exposure Assessment of Traffic-Related Air Pollution

Subtheme 3.1: Introduction to Air Pollution Exposure Assessment

17. Air pollution exposure

    Proposed lecture items:

    - Exposure definitions.
    - Exposure dimensions (e.g., duration, concentration, and frequency).
    - Exposure pathways.
    - Exposure routes.
    - Exposure variability and distribution.

18. Air pollution exposure assessment methods

    Proposed lecture items:

    - Overview of available methods for ambient air pollution exposure assessment (e.g., fixed-site monitoring data, personal monitoring data, multiple models applied to exposure assessment [atmospheric dispersion, land-use regression, geo-statistical interpolation, hybrid models, etc.], and surrogates for exposure [proximity to air pollution sources]).
    - Pros and cons of available methods.
    - Examples of application of exposure assessment in air pollution epidemiology.
    - Strengths and limitations.
    - Research gaps and future direction.

19. Traffic-related air pollution exposure assessment methods

    Proposed lecture items:

    - Overview of available methods (as above but **specifically oriented at traffic** including traffic-related air pollution surrogates [e.g., proximity to major roadways, remote sensing, and micro-environmental exposure assessment]).

- Pros and cons of available methods.
- Specificity to traffic and potential to assess traffic contribution.
- Examples of application in exposure assessment in air pollution epidemiology.
- Strengths and limitations.
- Research gaps and future direction.

Subtheme 3.2: Air Pollution Exposure Assessment Methods

20. Air pollution dispersion modeling

    Proposed lecture items:

    - Overview.
    - Use in exposure assessment.
    - Validation compared to personal exposure.
    - Pros and cons.
    - Specificity to traffic and potential to assess traffic contribution.

21. Land-use regression modeling

    Proposed lecture items:

    - Overview and definition.
    - Use in exposure assessment.
    - Validation compared to personal exposure.
    - Pros and cons.
    - Specificity to traffic and potential to assess traffic contribution.

22. Exposure surrogates

    Proposed lecture items:

    - Overview.
    - Use in exposure assessment.
    - Validation compared to personal exposure.
    - Pros and cons.
    - Specificity to traffic and potential to assess traffic contribution.

23. Personal monitoring in exposure assessment and the contribution of traffic

    Proposed lecture items:

    - Overview.
    - Use in exposure assessment.
    - Pros and cons.
    - Specificity to traffic and potential to assess traffic contribution.
    - Research gaps and future direction.

24. Source apportionment and micro-environmental exposures

    Proposed lecture items:

- Overview.
- Use in exposure assessment.
- Exposures across different transport-related micro-environments.
- Pros and cons.
- Specificity to traffic and potential to assess traffic contribution.
- Research gaps and future direction.

Theme 4: The Effects and Impacts of Traffic-Related Air Pollution Exposure on Human Health

Subtheme 4.1: Epidemiological Studies, Designs, and Need for Exposure Indices

25. Introduction to air pollution epidemiology

    Proposed lecture items:

    - Air pollution epidemiology.
    - Basic definitions and methods.
    - Short-term and long-term health effects.
    - Key air pollution epidemiology studies.
    - Public health relevance.
    - Policy relevance.
    - Health effects at low exposure levels (e.g., below guidelines).
    - Research gaps and future direction.

26. Observational descriptive epidemiological studies

    Proposed lecture items:

    - Basic definitions and methods.
    - Study designs and types.
    - Surveillance and surveys.
    - Ecological studies.
    - Strengths and limitations.
    - Examples from air pollution epidemiology.

27. Observational analytical epidemiological studies

    Proposed lecture items:

    - Basic definitions and methods.
    - Study designs and types.
    - Cross-sectional studies.
    - Cohort studies.
    - Case control studies.
    - Time series studies.
    - Strengths and limitations.
    - Examples from air pollution epidemiology.

28. Experimental studies

    Proposed lecture items:

- Basic definitions and methods.
- Study designs and types.
- Clinical studies.
- Natural experiments.
- Strengths and limitations.

29. Prevalence, incidence, and measures of associations

    Proposed lecture items:

    - Basic definitions and methods.
    - Calculations.
    - Available data sources.
    - Examples from air pollution epidemiology.

30. Systematic reviews and meta-analyses

    Proposed lecture items:

    - Basic definitions and methods.
    - Assessment of strength of evidence.
    - Assessment of quality.
    - Meta-analysis methods and assessment of bias.
    - Key examples.
    - Strengths and limitations.
    - Use in policy decision making.
    - Use in burden of disease and health impact assessments.

Subtheme 4.2: Evidence of the Effects of Traffic-Related Air Pollution Exposure on Human Health

31. Effects of traffic-related air pollution on human health—well-established evidence

    Proposed lecture items:

    - Range of health effects.
    - Summary of well-established effects from epidemiological studies.
    - Summary of well-established effects from systematic reviews and meta-analyses.
    - Research needs.

32. Effects of traffic-related air pollution on human health—emerging evidence

    Proposed lecture items:

    - Range of health effects.
    - Summary of emerging effects from epidemiological studies.
    - Summary of emerging effects from systematic reviews and meta-analyses.
    - Research needs.

33. Effects of traffic-related air pollution on human health—toxicological and mechanistic evidence

    Proposed lecture items:

- Evidence from toxicological studies.
- Summary of established mechanisms.
- Summary of proposed mechanisms.
- Strengths and limitations.
- Importance for epidemiological studies and burden of disease assessments.

34. Transferability of toxicological evidence and human relevance

    Proposed lecture items:

    - In-vivo studies and transferability.
    - In-vitro studies and transferability.
    - Animal studies and transferability.
    - Strengths and limitations.

35. Biomarkers including omics (genomics, proteomics, or metabolomics) of health effects associated with traffic-related air pollution

    Proposed lecture items:

    - Introduction to omics.
    - Use of omics to pinpoint health effects of TRAP.
    - Use of omics to elucidate mechanisms underlying the health effects of TRAP.
    - Applications and knowledge gaps.
    - Examples and case studies.

36. Sensitive subpopulations (children, the elderly, the ill, and lower socioeconomic classes) and differential health effects in sensitive subpopulations

    Proposed lecture items:

    - Identifying sensitive populations.
    - Differential health effects in sensitive populations.
    - Reasons for different health effects.
    - Examples.
    - Use in policy decision making.

Theme 5: Health Impacts and Burden of Disease Assessment of Traffic-Related Air Pollution

37. Qualitative health impact assessment

    Proposed lecture items:

    - Definitions.
    - Methods.
    - Examples including traffic-related air pollution.
    - Strengths and limitations.
    - Research gaps and future direction.

38. Quantitative health impact and burden of disease assessment

Proposed lecture items:

- Definitions.
- Methods.
- Examples including traffic-related air pollution.
- Strengths and limitations.
- Research gaps and future direction.

39. Undertaking health impact and burden of disease assessment of traffic-related air pollution—Part 1

Proposed lecture items:

- Data requirements.
- Data sources.
- Methods and calculations.

40. Undertaking health impact and burden of disease assessment of traffic-related air pollution—Part 2

Proposed lecture items:

- Strengths.
- Limitations.
- Assumptions.
- Examples including traffic-related air pollution.

41. The impacts of traffic-related air pollution on health in policy and decision making

Proposed lecture items:

- Use of health impact and burden of disease assessment studies in policy and decision making.
- Examples of such assessments and policy impacts, such as global burden of disease study.
- Streamlining burden of disease and health impact assessment in transportation planning and policy.
- Strengths and limitations.
- Research gaps and future direction.

42. Differential burden of disease of traffic-related air pollution in sensitive subpopulations

Proposed lecture items:

- Established sensitive subpopulations.
- Factors affecting sensitivity/susceptibility.
- Differential burden of disease and health impacts.
- Advances in methods to establish differential burden of disease/health impacts.
- Examples.
- Use in policy decision making.

Theme 6: Policies and Technologies to Mitigate Traffic-Related Air Pollution and Adverse Health Effects and Impacts

Subtheme 6.1: Policies, Strategies, and Effectiveness

43. Transportation decision making—overview and process

    Proposed lecture items:

    - Transportation decision-making overview and processes.
    - Responsibilities.
    - Key stakeholders.
    - Implementation and evaluation.
    - Role of the environment and human health in transportation decision making.
    - Examples.

44. Transportation decision making—tools and methods

    Proposed lecture items:

    - Appraisal methods and tools, such as cost-benefit analysis and multi-criteria analysis.
    - Science-to-policy transfer overview, gaps, and future direction.
    - Examples including traffic-related air pollution and health.

45. Option generation and policy selection

    Proposed lecture items:

    - Definitions and significance.
    - Methods.
    - Available tools.
    - Data sources.
    - Strengths and limitations.
    - Research gaps and future direction.
    - Use in policy decision making.

46. Option generation tools

    Proposed lecture items:

    - Demonstration of tools use.
    - Case studies and examples.
    - Health impacts of included policies.

47. Cost-effectiveness calculations and feasibility of policies

    Proposed lecture items:

    - Cost-effectiveness and cost—utility definitions.
    - Cost-effectiveness and cost—utility analysis.
    - Strengths and limitations.
    - Research gaps and future direction.

- Use in policy decision making.
- Examples.

48. Policies to mitigate traffic-related emissions

    Proposed lecture items:

    - Range of policies.
    - Implementation considerations and contingencies.
    - Documented emission reductions.
    - Documented health benefits.
    - Unintended consequences.
    - Case studies.

49. Policies to mitigate traffic-related air pollution

    Proposed lecture items:

    - Range of policies.
    - Implementation considerations and contingencies.
    - Documented air pollution reductions.
    - Documented health benefits.
    - Unintended consequences.
    - Case studies.

50. Policies to mitigate traffic-related air pollution exposures

    Proposed lecture items:

    - Range of policies.
    - Implementation considerations and contingencies.
    - Documented human exposure reductions.
    - Documented health benefits.
    - Unintended consequences.
    - Case studies.

51. Overlap with sustainable transportation and built environment policies

    Proposed lecture items:

    - Sustainability—definitions and history.
    - Sustainable transportation policies and overlap with above including other modes of transportation.
    - Unintended consequences.
    - Case studies.

52. Barriers and facilitators

    Proposed lecture items:

    - Definitions.
    - Barriers to policy implementation.

- Facilitators to policy implementation.
- Examples/case studies.

53. Co-benefits

    Proposed lecture items:

    - Definitions.
    - Range of co-benefits.
    - Documented co-benefits.
    - Implications to policy and cross-disciplinary collaboration.
    - Examples/case studies.

Subtheme 6.2: Emerging Technologies, Disruptors, and Market Solutions

54. Alternative and emerging technologies—connected and automated vehicles

    Proposed lecture items:

    - Definitions.
    - Examples.
    - Patterns and projections.
    - Implications, impacts, and evidence in relation to traffic-related emissions, air pollution, exposure, and health.
    - Unintended consequences.
    - Spatial and temporal shifting of emissions, air pollution, exposures, and health.
    - Contingencies.

55. Alternative and emerging technologies—shared mobility

    Proposed lecture items:

    - Definitions.
    - Examples.
    - Patterns and projections.
    - Implications, impacts, and evidence in relation to traffic-related emissions, air pollution, exposure, and health.
    - Unintended consequences.
    - Spatial and temporal shifting of emissions, air pollution, exposures, and health.
    - Contingencies.

56. Alternative and emerging technologies—zero and near-zero emission vehicles

    Proposed lecture items:

    - Definitions.
    - Examples.
    - Patterns and projections.
    - Implications, impacts, and evidence in relation to traffic-related emissions, air pollution, exposure, and health.
    - Unintended consequences.

- Spatial and temporal shifting of emissions, air pollution, exposures, and health.
- Contingencies.

57. Alternative and emerging fuels

    Proposed lecture items:

    - Definitions.
    - Examples.
    - Patterns and projections.
    - Implications, impacts, and evidence in relation to traffic-related emissions, air pollution, exposure, and health.
    - Unintended consequences.
    - Contingencies.
    - Case studies and uses.

58. Implications to environmental justice and health equity

    Proposed lecture items:

    - Technology and potential environmental justice impacts.
    - Environmental justice and health equity considerations of connected and automated vehicles.
    - Environmental justice and health equity considerations of shared mobility.
    - Environmental justice and health equity considerations of zero and near-zero emission vehicles.
    - Environmental justice and health equity considerations of alternative and emerging fuels.

59. Market solutions

    Proposed lecture items:

    - Range of market solutions such as face masks, ventilation and cleansers, air purifiers, and creams.
    - Trends and projections.
    - Differences across regions.
    - Unintended consequences.
    - Environmental justice and health equity implications.
    - Case studies.

60. Concluding inspirational talk—How do we make health a priority? Are we doing the right research?

Guidance for the Preparation of Slides

In addition to the lectures and lecture items under each topic, the following guidelines were also prepared to ensure a high and consistent standard for the delivered lectures.

Presentation Template Requirement

Guidance in using the PowerPoint template to prepare a presentation includes the following:

- Include comprehensive notes in the notes tab for every slide with substantive content (excluding the cover slide with the title and lecturer information, List of Abbreviations, References, Reading List, and Acknowledgements slides).
- Include a slide on each of the following:
    - A **Cover** slide with the name and number of the lecture, including the lecturer's full name, affiliation(s), contact information, and, importantly, declaration of any conflicts of interest. Label the lecture as HT, TT, PPT, or any combination.
    - An **Introduction** slide with a brief introduction to the topic.
    - All minimum required lecture items (which are different for different lectures) in slides between the Introduction slide and the Discussion slide.
    - A **Discussion** slide with discussion of major points related to the lecture topic.
    - A **Research Gaps and Future Direction** slide to advance the state of the knowledge and practice.
    - A **Take-Home Messages** slide that summarizes the most important take-away points (between the Introduction and Research Gaps and Future Direction slides) that the instructor wants the student to remember. Include three to five bullet points.
    - A **List of Abbreviations** slide with abbreviations used throughout the presentation.
    - A **References** slide for references cited in the presentation. The references should be accurate and outlined in Harvard format.
    - A **Reading List** slide for references that are not cited in the presentation but that are useful for students for further information.
    - An **Acknowledgments** slide.

Format and Editorial Requirements

Guidance in formatting and editing the presentation includes the following:

- Only use the CARTEEH PowerPoint template provided.
- Make sure the font type of the slides' text is Calibri Body and the body text is at least 24 points in size.
- Make sure the number of slides from the Introduction slide to the Take-Home Messages slide does not exceed 20.
- Make sure the presentation is free of typos and grammar mistakes.

Content Checklist

Ensure that the presentation includes the following content:

- Comprehensive notes are included in the notes tab for every slide with substantive content (excluding the first cover slide with the title and lecturer information, List of Abbreviations, References, Reading List, and Acknowledgements slides).
- All required slides are included and complete.
- All minimum required lecture items are covered (different for different lectures) between the Introduction slide and the Discussion slide.
- The appropriate lecture track(s) is marked (HT, TT, or PPT).
- The CARTEEH PowerPoint template is used.
- The font is Calibri Body, and all body text is at least 24 points in size.
- The number of slides from the Introduction slide to the Take-Home Messages slide does not exceed 20 slides.
- There are no typos or grammar mistakes.
- The presentation has global perspectives and is not focused on one region or country.
- Each individual lecture is stand-alone; that is, it does not cite or rely on other lectures in the course.

- Abbreviations are all spelled out the first time they occur and are all included in the List of Abbreviations slide.
- Any tables or figures used are properly referenced with a clear indication of the source.

The instructor is responsible for the scientific quality of the content. The presentation has been peer-reviewed and has been returned to the contributors for further edits and corrections as necessary.

Conclusions and Recommendations

This report summarizes the work conducted to develop the CARTEEH curriculum outline for the cross-disciplinary course titled Traffic-Related Air Pollution: Emissions, Human Exposures, and Health. An outline of the course, including the specific titles of 60 complementary lectures covering the full chain between traffic activity and human health, and the key topics to be covered under each lecture, was developed over 30 iterations. These iterations were mainly achieved via email correspondence and some in-person and phone discussions with CARTEEH consortium members and external collaborators, who are acknowledged in this report. In parallel to the development of this course, CARTEEH leaders, in collaboration with the Barcelona Institute for Global Health in Spain and involving all CARTEEH consortium members, also edited a complementary book on the same topic, *Traffic-Related Air Pollution*, published by Elsevier and available at https://www.elsevier.com/books/traffic-related-air-pollution/khreis/978-0-12-818122-5. While the book was not funded by CARTEEH, it is complementary to the curriculum and can be used when delivering the course at partner institutions and beyond.

To the best of the author's knowledge, there are as yet no similar courses or books, and these deliverables fill a niche whose time has come. The course is intended to form the basis for a three-credit-hour graduate-level course offered by consortium member institutions and targeted at students and practitioners in the areas of urban planning, transportation planning, transportation policy, transportation engineering, geography, environmental sciences, environmental epidemiology, environmental policy, and public health. However, the course's individual lectures are complete and designed to stand alone, and as such, they can be mixed and matched to be transferable to other locations and other purposes. So far, a modified version of the course has been adopted at the Georgia Institute of Technology where it was taught in the spring 2019 semester as an undergraduate special topic to 34 students from various backgrounds.

This curriculum is a unique product of CARTEEH that challenges the current structure of the education system, which is lacking in collaboration and cross-disciplinary study, especially in integrating the transportation and health fields. The curriculum represents one effective strategy to integrate different fields of study in an educational setting for education, training, and workforce development.

In Phase II of this project, which is ongoing, the content of each lecture is being finalized, and the complete 60 slide decks will be made publicly available online at the CARTEEH website (http://carteeh.org) and disseminated widely.

Outputs, Outcomes, and Impacts

The outputs of this project are the outline and lecture items, in addition to a general checklist for the preparation of the presentation slides. The published book, despite not being funded by CARTEEH, is another related output and can be used as a training aid when delivering the lectures at partner institutions and beyond.

A modified version of the course has been adopted at the Georgia Institute of Technology where it was taught in the spring 2019 semester as an undergraduate special topic to 34 students from various backgrounds. Because of the nature of this project, most changes are expected after the implementation of Phase II of the project.

Expected impacts are in education, training, and workforce development.

Research Outputs, Outcomes, and Impacts

Because of the nature of this project, which is not a research project, no research outputs are available to report. One peer-reviewed report of the initial development of the outline can be found in the following:

> Khreis, Haneen, in collaboration with Center for Advancing Research in Transportation Emissions, Energy, and Health consortium member institutions. *CARTEEH Curriculum for Transportation Emissions and Health*. College Station, Texas: Center for Advancing Research in Transportation Emissions, Energy, and Health, July 2019. Available from https://www.carteeh.org/wp-content/uploads/2019/08/CARTEEH-Curriculum-for-Transportation-Emissions-and-Health_Final.pdf.

Technology Transfer Outputs, Outcomes, and Impacts

Because of the nature of this project, which is not a research project, no technology transfer outputs are available to report.

Education and Workforce Development Outputs, Outcomes, and Impacts

Because of the nature of this project, most changes are expected after the implementation of Phase II of the project. Expected impacts are in education, training, and development of a cross-disciplinary workforce with unique expertise in the transportation and health fields. The vehicle will be the developed lectures, which will also be posted online and made publicly available. Kristen Sanchez, a master's student in public health at Texas A&M University, was involved in this project.

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