APRIL 2025

HEI
Health Effects Institute

Strategic Research Plan

2025–2030

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Summary

Major transitions are underway in the United States and globally. New technologies and fuels are being advanced in transportation and other sectors, and major investments are being made to transition energy supplies and systems. Some changes, such as technological advances, bring opportunities to reduce environmental exposures and thus improve health. At the same time, some changes might introduce new sources of pollution that pose new health threats or exacerbate recognized ones. Amid all these changes, there is a renewed emphasis on addressing elevated levels of air pollution that persist in various locales.

All these developments amplify the urgency and importance of the work of the Health Effects Institute (HEI). HEI is a nonprofit, independent research organization that provides impartial science to inform decisions that foster a healthier environment for all. With joint funding from government and industry, HEI funds, oversees, and evaluates research with a rigorous model that—applied for more than four decades—has yielded credible research for informing important technology and policy decisions.

HEI's research is directed by 5-year strategic research plans. In developing its plan for 2025–2030, HEI leadership and staff engaged with its government and industry sponsors, other government officials and industry representatives, nongovernmental organizations, and researchers over the course of more than a year to identify key themes and priority research topics. For the first time, HEI's strategic research plan highlights past accomplishments and discusses future research and activities for its three separately funded programs: Environment and Health, Energy, and Global Initiatives.

HEI's long-standing Environment and Health Program remains committed to the organization's original charter to "conduct…and to evaluate research and testing relating to the health effects of emissions from motor vehicles, and…other environmental pollutants." Accordingly, a primary focus will be investigating the effects on air quality, exposure, and health of the turnover of legacy fleets to cleaner technologies, examining the trade-offs and benefits of various new transportation systems and mobility scenarios, and assessing the implications of differential uptake of various new technologies. Given the rapid pace of technology development today, the program also plans to convene a committee on emerging technologies that will provide valuable insight into the technologies and fuels that might obtain a meaningful market share that could result in substantive changes in population exposure to environmental pollutants. That insight will also help guide HEI research and indicate which technologies and fuels would be worthwhile for further scientific

assessment in the foreseeable future.

Other themes and research topics for the Environment and Health Program that will play an integral role in the next 5 years include advancing scientific methods to address the substantive challenges that remain in assessing multipollutant exposures and associated health effects, investigating how air quality will likely change given the changing climate, and exploring and identifying critical knowledge gaps and the research needed to address unanswered questions associated with air toxics. The program will also continue to build on the important work to advance environmental health in locations that face persistent air pollution challenges.

HEI's Energy research program will continue to complement the work of HEI's Environment and Health research program by focusing on the production of energy that powers the transportation sector, among other sectors. After wrapping up its initial program of population exposure research in oil and gas regions across the United States, the program will address priority knowledge gaps that remain. With leaders in regions across the country engaged in the critical task of planning for the best mix of energy sources to promote energy security, cultivate strong economies, and enhance operational efficiencies through emission reductions, there is an opportunity to improve public health simultaneously. In response, the Energy Program's scope is expanding to other forms of energy production to take advantage of this opportunity. An early focus will be on the development of impartial decision frameworks for assessing health risk and benefit trade-offs among energy choices. Being able to make such comparisons will support decisions around the development of optimal energy technologies and the governance of energy production.

HEI's Global Initiatives will continue to provide science to improve understanding of the health effects of air pollution, build local evidence on sources and health effects of air pollution, and strengthen scientific capacity and public awareness with a focus on low- and middle-income countries. The activities will be guided by the scientific and policy needs in the geographies relevant to the program, as well as the decades of research that HEI's Environment and Health Program has supported.

The world has evolved since the founding of HEI, and this plan describes future research and activities that represent a strategic investment in the most critical environmental health issues, all in fulfillment of HEI's original mission. HEI will implement the plan with the full recognition that many transitions are underway and will place a high priority on maintaining sufficient flexibility in its planning and budgets to adapt and respond to unanticipated needs, something that is highly valued by its current government and industry sponsors. Whatever the future holds, HEI will leverage its strengths and expertise to meet tomorrow's challenges.

The Health Effects Institute

Overview: History, Mission, and Programs

HEI was created in 1980 as a nonprofit corporation to address a need among government, industry, and other sectors for impartial science of the highest quality to inform policy decisions around motor vehicle emissions. To this day, it has a unique partnership with the U.S. Environmental Protection Agency (EPA) and the automobile industry to provide independent, high-quality science on the health effects of air pollution. HEI's long-standing partnership, independent research model, and impartiality have allowed it to maintain credibility as it provides science to sponsors and other sectors, which often have competing interests.

Principal components of the HEI model include (1) an **independent Board of Directors** with senior leaders recognized for integrity who are approved by but not affiliated with sponsors; (2) **independent science committees** with leading experts who are appointed by the Board of Directors and have no perceived point of view or affiliation with sponsors; (3) a **5-year strategic research plan** that is developed with extensive input from sponsors, the scientific community, and other organizations to guide annual investments in research and serves as the basis for 5-year renewals of funding support from government and industry sponsors; and (4) **balanced funding** from industry and government to avoid the perception and reality of bias in funded research, which is selected, overseen, and peer-reviewed independently of sponsors. HEI has a commitment to make all its funded research freely available to the public in its entirety—including underlying data and all results, subject to confidentiality requirements (e.g., personal data of study participants)—and has a long-standing prohibition of taking or recommending policy positions.

As noted, HEI was originally chartered to "conduct…and to evaluate research and testing relating to the health effects of emissions from motor vehicles, and…other environmental pollutants, and to provide the results…to the public and interested governmental agencies." HEI remains thoroughly committed to that focus as is evident in the research it has conducted over the past years and in the research that it plans to conduct over the next 5 years. The world, however, has evolved since the founding of HEI more than four decades ago. Vehicle technologies have advanced, the transportation and other sectors are

moving to reduce emissions, and the world is transitioning its energy supplies and systems. Accordingly, HEI has broadened its scope over the past years to respond to sponsor concerns and the changing environment. It now fulfills its mission with three separately funded programs that provide a complementary body of research to understand exposures and health effects associated with various sources of pollution in different contexts worldwide—research that is communicated to facilitate its use in formulating health-protective policies and technology adoption.

HEI Mission and Separate Funding Sources for HEI Programs

HEI's mission is to provide impartial science to inform decisions that foster a healthier environment for all. HEI achieves its mission by

- Funding and supporting policy-relevant scientific research.
- Convening independent experts to select, oversee, and review scientific research.
- Bringing together government, industry, nongovernmental organizations, and academia to help to guide research priorities.
- Synthesizing, interpreting, and communicating scientific evidence to audiences in the United States and around the world.
- Engaging with HEI audiences to facilitate the use of its science in decision-making.

The mission is fulfilled by three **separately funded** programs:

Environment and Health is funded by the U.S. EPA and the worldwide automotive industry.

Global Initiatives is funded by philanthropies, development agencies, and others.

Energy is funded by the U.S. EPA, the oil and gas industry, and private foundations.

Environment and Health

The Environment and Health Program is the foundational program at HEI that focuses on tracing air pollution emissions from sources to ambient concentrations to health effects and puts the findings into the context of current science and policy discussions. Its research elucidates the biological mechanisms that lead to health effects, quantifies relationships between ambient air quality and health, and assesses how changes in technologies, fuels, and human activities affect air quality and the associated health burdens. For decades, this research has played a critical role in providing policy-makers with information useful in determining emissions standards and the National Ambient Air Quality Standards (NAAQS) in the United States and air quality standards around the world. Given the program's foundational focus on motor vehicle sources, it has a long record of independent research and in-depth reviews on such topics as the health effects of diesel emissions and traffic-related air pollution (TRAP). Research efforts have expanded over the years beyond tailpipe emissions to understand the role of TRAP in the overall health burden from air pollution and the relative contributions from other pollution sources, such as power plants, indoor sources, and wildland fires. In 2022, HEI launched the Community Health and Environmental Research Initiatives (CHERI) under its Environment and Health Program to facilitate, support, and fund scientific research, special projects, and research translation to advance environmental health for rural and urban communities. CHERI activities include convening individuals and organizations that represent multiple sectors, partnering with communities to address elevated environmental exposures and health effects, developing tools and research translation mechanisms for use in decision-making, and tracking progress in reducing exposures.

Information, reports, and resources: https://www.healtheffects.org

Global Initiatives

Since 2002, HEI has built on science from its Environment and Health Program to expand its air pollution and health effects initiatives beyond North America and Western Europe to include areas around the globe. This work ranges from efforts to use available scientific evidence to inform policy action globally to geography-specific initiatives aimed at addressing local science and policy needs and strengthening local capacity. The program's flagship initiative, State of Global Air (SoGA), tracks annual air pollution exposures for fine particles, ozone, nitrogen dioxide, and household air pollution in addition to the burden of disease attributable to air pollution in cities and countries around the world. The program is especially active in Asia and Africa, where several projects apply science to improve understanding of the health effects of air pollution and strengthen local evidence, technical capacity, and public awareness.

Information, reports, and resources: https://www.healtheffects.org/about/global

Energy

Given the rapid rise of unconventional oil and gas development in the 2000s, HEI formed the Special Committee on Unconventional Oil and Gas Development in 2015. That committee prepared a Strategic

Research Agenda to help guide future research about the potential impacts from the onshore development of oil and gas from shale and other unconventional resources in the United States. In 2019, HEI initiated its Energy Program to address several questions from the research agenda to improve understanding of potential population exposures and health effects from unconventional oil and gas development. It launched with an extensive planning process that included preparing reviews of the scientific literature, hosting multisector and multidisciplinary workshops to learn about research priorities, and developing an online curated database and spatial bibliography to advance both public and scientific understanding. In 2022, the program awarded its first round of research funding to projects to assess potential human exposures arising from air emissions, noise, and releases to water from oil and gas development in multiple U.S. oil- and gas-producing regions. The scope of the Energy program is expanding beyond oil and gas to other forms of energy development, with an overarching goal of providing impartial knowledge about the benefits and drawbacks associated with various technologies.
Information, reports, and resources: http://www.heienergy.org

Taken together, HEI's programs provide a cohesive body of highly credible environmental health research that assists decision-makers in evaluating data on the health effects of pollution (Figure 1). Although each HEI program has a distinct scientific focus and its own sources of funding and expert committees, all programs pursue the same mission and are unified in their approach to achieving that mission. In the science that is funded and the initiatives supported, the programs complement and build on each other to strengthen scientific evidence and promote its use in decision-making through educational initiatives, research synthesis and translation, and global technical capacity strengthening. Together, the programs are well-aligned to achieve HEI's mission of a healthier environment for all as vehicle technologies advance, the transportation and other sectors move to reduce emissions, and the world transitions its energy supplies and systems.

Figure 1. HEI is governed and structured to provide impartial science that fosters a healthier environment for all. Although all HEI programs work toward achieving this mission, they do so with different but complementary scopes of work and separate sources of funding. Environment and Health is funded by the U.S. EPA and the worldwide automotive industry; Global Initiatives is funded by philanthropies, development agencies, and others; and Energy is funded by the U.S. EPA, the oil and gas industry, and private foundations.

Approach to Delivering Impartial, High-Quality Science

HEI funds, oversees, and evaluates research with a rigorous model that promotes its quality, impartiality, and relevance to environmental and public health policy (Figure 2). Applied for more than four decades, this process has yielded credible research that has informed important health-protective policy decisions. HEI staff, independent expert committees, and an independent Board of Directors provide extensive oversight and engage with a variety of individuals and organizations interested in or affected by HEI's work. Together, they provide the organizational support that allows HEI to fulfill its mission. To ensure the independence of HEI's process, Board and committee members cannot be affiliated with HEI's sponsors, and robust processes are used to identify and address conflicts of interest.

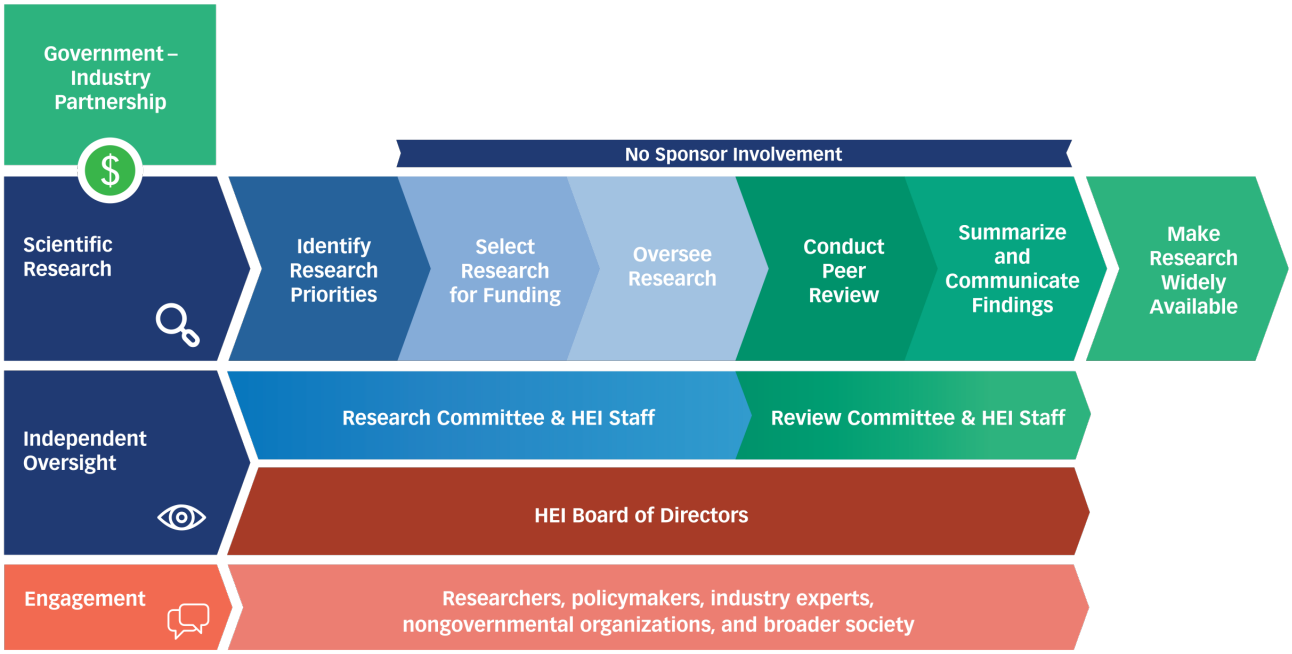


Figure 2. HEI funds, oversees, and evaluates research with a rigorous model that promotes its quality, impartiality, and relevance to public health policy. Sponsors and others with an interest in or affected by HEI's work provide recommendations on research priorities, but the final priorities are determined separately for each program by the respective research or oversight committees.

This model applies to all HEI programs. The Environment and Health Program and the Energy Program have independent research and review committees, while the Global Initiatives and CHERI programs have research committees but do not yet have review committees because they have only recently funded independent research. They will follow the same independent HEI report review procedures as the research is completed. To ensure the smooth operation of all these committees, the program directors meet regularly to discuss overlapping interests, coordinate projects or studies as appropriate, and develop institute policies and practices. Further coordination occurs, for example, by having members of the Environment and Health research committee sit on the CHERI research committee. The following sections highlight how research is selected, overseen, and reviewed and how HEI engages with its broad audience. More detailed information on the research and review processes is provided in Table 1.

Table 1.

HEI Research and Review Process [a]

Research Process

Program Development

- HEI solicits its sponsors and committees and the broader scientific community to identify critical research needs.
- HEI gathers information on research areas and assesses ongoing research by other institutions.
- Research committee and science staff develop Requests for Applications (RFAs) to meet specific research objectives and distribute to scientific community.
- HEI holds webinar to describe the RFA, review the application process, and answer questions from potential applicants.

Study Selection

- Ad hoc experts review and score applications.
- Research committee evaluates top-ranked applicants for scientific merit, relevance to RFA objectives, and contribution to a coherent research program.
- Research committee recommends studies for funding to the HEI Board of Directors who approve the evaluation process and selected studies.

Study Oversight

- Research committee reviews quality assurance plans and progress reports; science staff communicate recommendations to investigators.
- Science staff organize workshops to encourage interaction and collaboration among investigators conducting related studies.
- Mid-course study audits are performed by third-party auditors for those studies that involve human subjects or have a high potential for use in regulatory decisions.
- Investigators periodically present results and discuss study progress; examples include research committee webinars and poster presentations at the HEI annual conference.
- Investigators present a final webinar to the research committee before submitting their comprehensive final report to the review committee.

Special Attributes for the HEI Research Process

- HEI funds a broad array of studies that are relevant to policy- and decision-making, incorporating input from sponsors and other HEI audiences.
- HEI conducts rigorous oversight and quality assurance to ensure that studies meet high scientific research standards.

Review Process

Study Review

- External peer reviewers evaluate the investigator's final report.
- Review committee conducts a critical and impartial evaluation, taking into consideration the comments from the external experts.
- Science staff convey recommended revisions to the investigators from the review committee.
- Investigator revises and submits the final report. Review committee reviews the revised report and approves for publication.
- Reports for studies that required a mid-course audit also undergo an independent third-party audit. HEI may require final report audits for other studies at its discretion.
- Editorial staff prepares the report for publication, and Board approves the process by which the study was managed and reviewed.
- HEI publishes the research reports on its website and makes them freely available to the public.

Special Attributes of the HEI Review Process

- Review committee functions independently from research committee and conducts an in-depth review that ensures the credibility of the research findings.
- All HEI research is made freely available to the public in its entirety, including underlying data and all results, subject to confidentiality requirements (e.g., personal data of study participants).
- Review committee prepares a commentary on the research and results that critiques the study, interprets the findings, places the results into scientific and regulatory context, and often identifies future research opportunities.

[a] The Environment and Health Program and the Energy Program both have their own independent research and review committees. The Global Initiatives and CHERI programs also have committees that function analogously to the research committees but do not yet have review committees given that they have only recently funded independent research.

Scientific Research

To identify the highest-priority research questions, HEI begins by reviewing the state of the science and soliciting input from various groups, including HEI's sponsors, government representatives from state and federal agencies, industry representatives, nongovernmental organizations, and academia. These consultations help ensure that HEI strategically funds research that is complementary to research being conducted or funded by other organizations. Once the background information has been collected, the research or oversight committees develop research solicitations, select and fund research projects, and provide extensive oversight as the studies are conducted.

Once findings undergo HEI's extensive peer review, all research is made freely available on the HEI website. As discussed further below, HEI also engages widely to disseminate research findings and communicate their relevance for decision-making. As part of its commitment to data transparency, HEI requires that data be made accessible to the maximum extent feasible to allow for reanalysis and replication of the research. As a final note regarding research, HEI has a commitment to support young investigators and provides several awards and fellowships.

HEI Commitment to Supporting Young Investigators

HEI is committed to supporting investigators at all stages of their research careers and funds several awards and fellowships to support undergraduates, graduate students, and early career scientists in environmental health research.

Walter A. Rosenblith New Investigator Award: This award provides 3 years of research funding to new investigators with outstanding promise at the Assistant Professor or equivalent level with the hopes of bringing new, creative investigators into active research on the health effects of air pollution.

Jane Warren Award: This award provides travel support to graduate students and postdoctoral fellows from institutions in the United States to attend and present their research at HEI's Annual Conference.

Summer Fellowships: This paid fellowship pairs undergraduate students with mentors for a summer research project in the environmental health sciences in the United States. The program is funded separately by private organizations and individual donors.

Independent Oversight and Review

The research or oversight committees define and guide the research funded by HEI research programs. They prepare requests for applications (RFAs); select, oversee, and ensure the quality of all funded studies; and have the added responsibility of ensuring that HEI funds a body of research that, over time, cumulatively adds to information needed for policy decisions. Although HEI sponsors often contribute research ideas and provide comments on draft RFAs, they play no role in the selection, oversight, or review of the research. All research recommended for funding by the research and oversight committees must be approved by HEI's Board of Directors, which is charged with ensuring the integrity and impartiality of the research selection and review processes.

When research is complete, investigators prepare comprehensive reports that undergo extensive peer review by the review committees, which function independently of the research committees. The review committees conduct critical, in-depth evaluations of the investigators' final reports and, in collaboration with HEI staff, prepare commentaries that highlight each study's scientific contributions, limitations, and relevance to policy questions.

Engagement

HEI research is of interest to a broad array of audiences. HEI actively engages these audiences at all phases of research, from soliciting input on research priorities to disseminating study findings. Each year, HEI organizes and hosts a multiday conference to showcase the research and provide opportunities for its sponsors and other audiences to engage directly with the researchers. When appropriate to the study aims, various audiences might also be engaged directly in research design and implementation.

Approach to Facilitating Use of HEI Science in Decision-Making

Independent, impartial, and high-quality research that is relevant to policy and communicated effectively to local, state, regional, and federal decision-makers is an essential component of HEI's mission. To enhance the impact of its programs and advance its mission of informing decisions that foster a healthier environment for all, HEI complements its research with a wide array of activities aimed at facilitating the use of its science in decision-making (Figure 3).

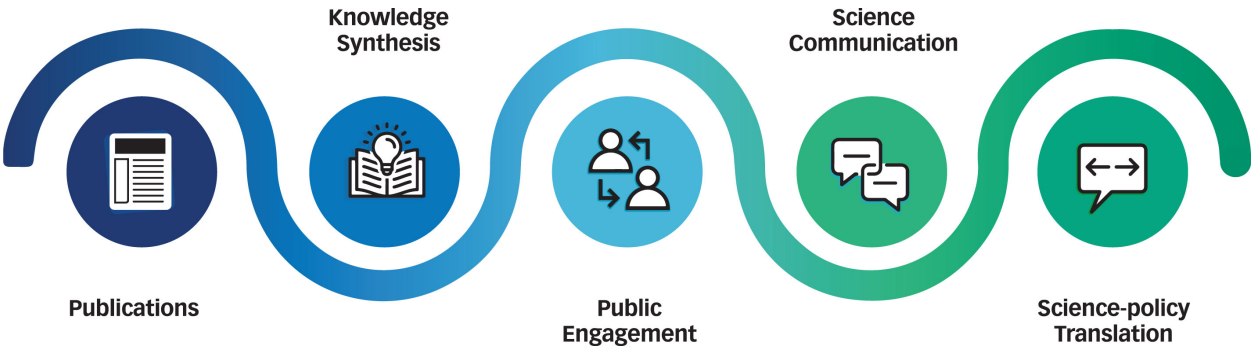


Figure 3. HEI complements its research programs with a wide array of activities aimed at fostering the use of its science in decision-making.

HEI's published reports with the associated commentaries prepared by the review committees are freely accessible on its website, are foundational to documenting the outcomes of its funded research, and provide a rich reference for anyone who uses its work. HEI staff and funded researchers also convey insights gained through the research projects in manuscripts and commentaries in peer-reviewed scientific journals for broader reach; see, for example, the journal article that synthesized results, discussed strengths and limitations, and identified remaining research needs from the research funded by HEI to assess health effects from long-term exposure to low levels of ambient air pollution.[b] Quarterly research updates from the HEI Energy Program provide regular updates on ongoing projects and summarize recent research findings. The Monitor—an HEI monthly email—provides regular updates on research and ongoing projects, announces releases of new

[b] See https://pubs.acs.org/doi/10.1021/acs.est.3c09745.

investigator reports, and highlights upcoming opportunities to apply for funding or participate in webinars and workshops.

In addition to funding individual studies, HEI also synthesizes findings across large bodies of research to elucidate broader themes, conclusions, and questions. One example is Special Report 23, which analyzed more than 350 studies conducted between 1980 and 2019 on the health effects of TRAP. To ensure that the report findings were broadly disseminated, HEI prepared executive summaries in English and German, published several journal articles, released factsheets in six languages, and held a public webinar to discuss the report findings. HEI also organized or participated in special panels at professional scientific societies and organizations to share the findings from the review broadly. To offer additional context on our ongoing research and help inform priorities for future research programs, HEI staff members also monitor the scientific literature around relevant topics and regularly summarize findings in research briefs and a literature hub.

HEI has been particularly successful using webinars, professional meetings, and social media to communicate study findings and engage with government, industry, nongovernmental organizations, and academia. For example, research reports are often released with a webinar to help explain the findings and increase visibility. HEI also uses webinars to communicate with potential applicants for research funding to ensure clarity and transparency around research priorities and guide proposal development. In 2021, the HEI Energy Program launched an educational webinar series, Energy and Health, which explores issues around unconventional oil and gas development and other energy-related topics. In 2022, Global Initiatives launched Science on the 7th, which features lively 30-minute conversations on issues at the forefront of air quality and health with experts from around the world. To complement and amplify these channels of engagement, HEI also leverages social media platforms, including X, LinkedIn, Facebook, and YouTube, to share findings and events in various formats with a broad array of audiences.

In addition to all these activities, HEI staff present posters, deliver presentations, and organize symposia or workshops at professional meetings to disseminate research findings and engage on related relevant topics. For example, in the past 5 years, HEI organized symposia for the International Society of Environmental Epidemiology on best practices for evidence synthesis and evaluation in environmental health.

In all its efforts to share the outcomes from its research programs—whether in publications, synthesis activities, engagement, or science communication—HEI takes deliberate steps to ensure the findings are relevant to and usable by a variety of decision-makers. As noted, commentaries from expert HEI review committees place novel scientific findings into context with current policies, technologies, and scientific literature. In addition, HEI regularly develops brief report statements and factsheets that distill complex scientific information into plain language to explain

and contextualize key findings and provides many of its communications products in multiple languages, including quarterly research updates from the HEI Energy Program and various factsheets from the SoGA initiative.

Highlights from 2020–2025

The HEI Strategic Plan for 2020–2025 has guided HEI's research programs over the past 5 years. That plan included four themes—Transport and Urban Health, Accountability, Complex Questions for the Air Pollution Mixture, and Global Health—and identified additional priorities in cross-cutting areas, including data access and transparency, evaluation of statistical methods, a focus on sensitive or vulnerable populations, and enhanced exposure assessment. At the time HEI prepared its 2020–2025 Strategic Plan, the HEI Energy Program was under development. For this reason, the initial phase of this program has been guided by a separate 2020 Implementation Plan. This plan along with details about the program's activities can be found at http://www.heienergy.org.

Table 2 summarizes the status of research studies in the Environment and Health Program over the past 5 years according to the various themes from the Strategic Plan for 2020–2025. The table also includes the status of research studies in the Energy Program. Figure 4 summarizes the reach of the studies in the Environment and Health Program as represented by citations. Additional details can be found on our website about ongoing projects and published work at http://www.healtheffects.org.

Table 2.

HEI-Funded Research Studies, April 2020 to March 2025 (projected) [a]

Category	Studies Initiated	Reports in Review	Reports Published
Transportation and Urban Health	**11**	**6**	**6**
TRAP and Health	4	—	2
Nontailpipe Emissions	2	1	—
Enhanced Exposure Assessment	5	3	3
Disentangling Confounding/Modifying Factors of TRAP	—	2	1
Accountability	**8**	**3**	**4**
Complex Questions for Air Pollution	**18**	**3**	**14**
Low-Exposure Epidemiology	—	—	3
Air Pollution, COVID-19, & Health	5	1	4
Wildland fires	2	—	—
Biological Mechanisms	1	1	3
Multipollutant Epidemiology	3	1	3
Community Environmental Health	7	—	1
Global Health [b]	**1**	—	**2**
Energy Studies [c]	**10**	**10**	**0**
GRAND TOTAL	**48**	**22**	**26**

TRAP = traffic-related air pollution.

[a] Additional details about ongoing projects and published work are available at www.healtheffects.org.

[b] With funding provided by philanthropies, development agencies, and others.

[c] With funding provided by EPA, the oil and gas industry, and private foundations.

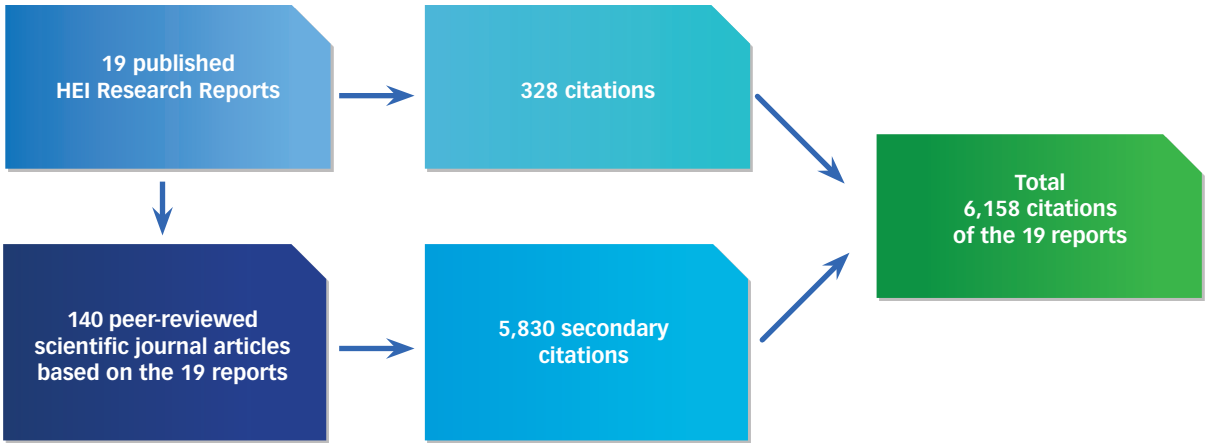


Figure 4. Citations from the 19 reports in the Environment and Health Program published between April 2020 and November 2024.

HEI research reports continue to be an important source to inform standards and guidelines. For example, 38 HEI reports were referenced in EPA's most recent Integrated Science Assessments for particulate matter, nitrogen oxides, sulfur oxides, and ozone. HEI-funded research on the effects of the clean bus program has also been cited extensively, including in the EPA Clean School Bus Program report to Congress for Fiscal Year 2023. Although the research reports have not been published yet for Energy-funded research, HEI staff and some of its funded investigators have been asked for briefings, most recently by industry and state legislative officials in the context of decisions about science-based oil and gas setback distances.

HEI also tracks its reach and impact through several other indicators, including the number of website visitors, the number of downloads of HEI resources, and mentions of HEI's work in print and digital media. Overall, the HEI website continues to be an effective means of providing access to HEI resources. Between 2020–2024, an average of 167,000 visitors accessed the HEI websites each year and downloaded an average of 51,000 reports, special reports, statements, and other resources annually. HEI's reports and data are also widely cited in the print and digital media. Between 2020–2024, HEI was cited over 11,000 times in the media in more than 100 countries in over 40 languages.

The sections that follow provide highlights of accomplishments over the past 5 years for HEI's separately funded programs.

Environment and Health (2020–2025)

As noted, HEI's Strategic Research Plan 2020–2025 included four major themes—Transport and Urban Health, Accountability, Complex Questions for the Air Pollution Mixture, and Global Health. Highlights from three themes are provided below; the global health theme is discussed in the Global Initiatives Program section.

Transport and Urban Health

In 2022, an HEI expert panel completed its systematic review of the epidemiological evidence on the health effects of TRAP; highlights are shown in Figure 5. The large number of people exposed to TRAP, combined with the strength of the evidence for an association between long-term exposure to TRAP and several adverse health outcomes as revealed in this review, further bolstered the evidence that TRAP remains an important public health concern that warrants attention from the public and policymakers.

Building on the recommendations from that systematic review, HEI issued an RFA in 2023 and awarded funding to four studies

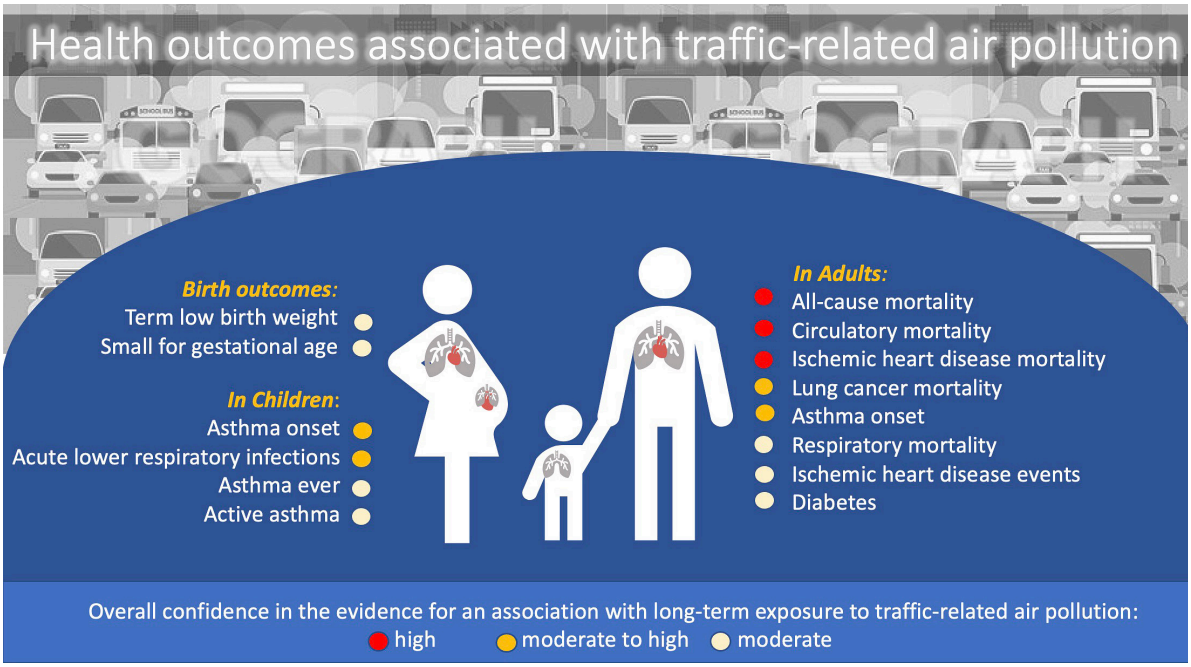


Figure 5. Highlights from a systematic review of the epidemiological evidence for associations between long-term exposure to TRAP and selected adverse health outcomes. Outcomes for which the expert panel reported associations with high, moderate to high, or moderate confidence are shown here. Outcomes for which the overall confidence in the evidence was low to moderate, low, or very low are discussed in the Panel's report.

examining the health effects of exposure to TRAP. These studies aim to create a framework for full-chain assessment of transportation systems and the effects of TRAP on population health; examine associations of TRAP with lipids and other biomarkers to explore pathways that might mediate cardiovascular disease risk; assess consequences of future urban transportation landscapes on cardiometabolic health; and develop models for relating exposures from vehicle, rail, and aircraft sources to birth-outcome data.

Research funded by HEI and others has indicated that a better understanding is needed of contextual factors that might confound or modify associations between TRAP exposure and health outcomes. Accordingly, HEI funded three studies under an RFA designed to disentangle the effects of exposure to TRAP from such spatially correlated confounding or modifying factors as traffic noise, socioeconomic status, the built environment, and green space. These studies include multiple pollutants and attempt to distinguish between tailpipe and nontailpipe motor vehicle emissions and other pollution sources while incorporating information about relevant co-exposures to strengthen the evidence on the health effects of TRAP in the context of spatially correlated factors.

A major challenge in epidemiological studies of long-term exposure to air pollution is the accuracy of exposure assessment, particularly for outdoor air pollutants that vary widely across space and time such as ozone, nitrogen dioxide, ultrafine particles, and chemical constituents of fine particulate matter ($PM_{2.5}$). To address this gap, HEI initiated five studies under an RFA focused on applying novel approaches to improve long-term exposure assessment of outdoor air pollution. These studies aimed to assess exposures to air pollution using new and conventional exposure assessment approaches, evaluate quantitative exposure measurement error to determine the added value of the novel approaches, and apply the exposure estimates in epidemiological analyses to evaluate the potential effect of exposure measurement error on health estimates. Together, these studies should provide novel insights into accounting for spatial and temporal variability in long-term outdoor air pollution exposure assessment in relation to chronic health outcomes. HEI anticipates publishing an article that provides a synthesis of the study findings and discusses lessons learned from these studies once they have all have been published in 2025.

Accountability

HEI has a long history of funding accountability research that examines the relationships between air quality actions that are intended to reduce emissions and exposure and improvements in air quality and public health (Figure 6). Accountability studies are appealing because they are the closest epidemiological equivalent to controlled experimental studies in air pollution research and thus can potentially provide supporting evidence for causal relationships. In addition, this research provides critical feedback to decision-makers to ensure that they have the most relevant information for crafting effective policies. Most accountability studies to date have focused on the effects of relatively short-term, local-scale, and sometimes temporary interventions. A common challenge encountered is a lack of statistical power due to small improvements in air quality or a small population that is affected by the action taken. Another issue is that findings might not be readily transferable to other locations and populations. Only a few accountability studies have sought to investigate large-scale, multiyear regulatory programs. These studies encounter particular difficulties such as making appropriate adjustments for background trends in air quality and health. Moreover, direct attribution of changes in air pollution and health to a single intervention among many regulatory actions remains difficult.

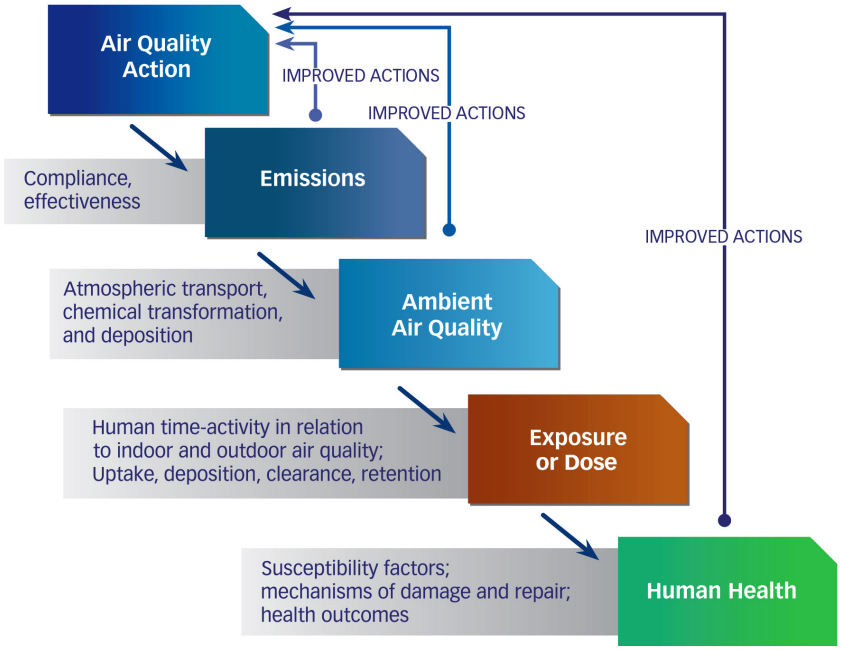


Figure 6. The chain of accountability. Each box represents a link between air quality action and human health response to air pollution. At several stages, knowledge gained from accountability assessments can provide valuable feedback to inform future air quality actions. Source: https://www.healtheffects.org/publication/assessing-health-impact-air-quality-regulations-concepts-and-methods-accountability

Hence, HEI-funded research in this area continues to develop and apply new methods that have shown promise in addressing some of the challenges, including the use of quasi-experimental and causal inference methods.

Accountability studies completed during the current grant period showed that actions to reduce emissions from goods movements were effective in protecting people who had chronic respiratory conditions and lived near ports and goods movement corridors. Other studies showed that replacing older diesel-powered school buses resulted in improvements in school attendance and educational achievement and that enacting policies that reduce exposure to traffic emissions in a large urban area might improve birth outcomes. Another study showed that reductions in a relatively small proportion of emissions could yield a large societal health benefit while targeted emission reductions in certain transportation sectors could yield climate and health co-benefits. In addition to those completed studies, three studies in the review process evaluated major national and state air quality regulations that are related to power plants and mobile sources in North America and China. A fourth study underway is developing fine-scale metrics for evaluating changes in $PM_{2.5}$ from various sources to support regulatory accountability and to understand the heterogeneity in air pollution exposures across the United States.

Complex Questions for the Air Pollution Mixture

In 2022, HEI completed a comprehensive research initiative to investigate the health effects of long-term exposure to low levels of air pollution in the United States, Canada, and Europe. The three studies in this research initiative considered associations between several pollutants—including $PM_{2.5}$, nitrogen dioxide, and ozone—and a variety of health outcomes and provided information that was useful to policy- and decision-makers in evaluating the U.S. NAAQS and current and proposed European Union limit values. Heterogeneity, however, was found in both the magnitude and shape of that association within and across the studies. HEI's simultaneous funding and collaborations among the investigators created synergies among the teams and facilitated methodological developments and harmonization for pooled analyses. Some data have been made publicly available, thus facilitating transparency, reanalysis, and reproducibility. All three studies addressed critical research gaps in understanding the health effects of exposure to low levels of ambient air pollution and provided policy-relevant science.

In 2023, HEI hosted a workshop on the state of science for the health effects of particulate matter exposures. Convening thought leaders and technical experts, the workshop sought to identify critical research priorities to inform interventions or policies to protect health while integrating valuable

lessons learned from the comprehensive low-exposure epidemiology research initiative. Participants discussed a variety of topics, including the biological plausibility of health effects from chronic low-dose exposure to particulate matter, the role of the indoor environment in evaluating the health effects of outdoor air pollution, the health effects of extreme air pollution events, and the changing nature of the particulate mixture due to a changing climate and transportation landscape. HEI released a new RFA based on the workshop findings in fall 2024 with funding decisions expected by June 2025.

The COVID-19 pandemic produced unprecedented conditions that lent themselves to timely and novel air pollution research. In May 2020, only 2 months after the World Health Organization declared the COVID-19 outbreak a global pandemic, HEI issued an RFA for studies to investigate potential associations between air pollution, COVID-19, and human health. Four studies were funded to examine the relationship between air pollution exposure and COVID-19 incidence and associated health outcomes in several populations across North America and Europe. These studies revealed positive associations between exposure to ambient air pollution and COVID-19 outcomes, particularly in those with pre-existing conditions or low socioeconomic status. A fifth study was funded to examine the short-term changes in ambient air pollution resulting from COVID-19 lockdowns and the effects on mortality in various regions of the United States, China, Germany, and Italy that had low COVID-19 case numbers before and during the first lockdowns. The study showed that PM2.5 and nitrogen dioxide concentrations had decreased during the lockdowns — even after accounting for seasonal changes in weather — and that there were likely meaningful reductions in deaths related to air pollution because of the changes.

In 2022, HEI held a workshop to promote interdisciplinary exchange on the use of satellite-based remote sensing data in air quality monitoring, exposure assessment, and health applications. Participants explored approaches to incorporate satellite data products into large epidemiological studies and their application for studying the health effects of wildland fires. They also identified challenges, including the complexities of data assimilation and access, and pointed to a need for more communication between data providers and data users and better characterization of limitations. HEI plans to release an RFA in 2025 with a focus on characterizing how uncertainties and limitations in satellite-derived air quality data might affect the results of health studies. To ensure that it uses its resources most productively, HEI actively engages with other research and agency consortia.

Global Initiatives (2020–2025)

Between 2020 and 2025, with support from philanthropic organizations and others, HEI expanded its Global Initiatives. In addition to activities on a global scale, the program advanced research and capacity strengthening in specific geographies, beginning new work in Southeast Europe and East Africa and expanding its presence across South Asia. Under Global Initiatives, much of the work is conducted in close partnership with local and regional organizations and scientific experts and is meant to complement ongoing in-country activities. The program has also contributed to ongoing international efforts on air pollution, including engagement with Clean Air Catalyst and other regional programs.

State of Global Air and Global Burden of Disease

Following the publication of its 2020 report, the SoGA initiative expanded its work to produce geographically focused reports and resources, including a report on air quality and health in more than 7,000 cities worldwide. The initiative also provided resources on air pollution and health effects, including a factsheet and a video in multiple languages (Arabic, English, French, Hindi, Russian, Spanish, and Swahili). To further enhance the health data that form the foundation for the SoGA initiative, HEI also routinely undertakes projects to assess the evidence for including additional health outcomes into the Global Burden of Disease (GBD) comparative risk framework. Since 2020, HEI has supported work on nitrogen dioxide and childhood asthma that has formed the basis for the inclusion of nitrogen dioxide as a pollutant in the GBD assessment framework. Work is also underway to assess the strength of available evidence on the association between air pollution and tuberculosis.

In 2021, HEI published the first comprehensive global estimates of contributions from the most common sources of exposure to $PM_{2.5}$ and the associated burden of disease from various causes. The study estimated source contributions at global, regional, and national scales using updated emissions inventories categorized by sector and fuel, satellite data and air quality modeling, and the latest insights into the relationships between air quality and health.

Regional Initiatives

New work was launched in Southeast Europe and East Africa, and work across South Asia was expanded with the goal of advancing research, science-policy translation, and capacity strengthening on air pollution and health in key geographies.

East Africa: HEI has been working in East Africa to improve the communication of credible evidence about the effects of air pollution on people's health to inform and help drive local action toward cleaner air. In 2023, HEI co-organized a workshop on air pollution and health in East Africa in partnership with the Stockholm Environment Institute–Africa Centre, World Resources Institute, Eastern Africa GEOHealth Hub, and AirQo. To build on the momentum generated, this event was followed by a webinar series aimed at fostering engagement, collaboration, learning, and peer exchange around air quality and health research and policy in East Africa. A scoping review on the health effects of air pollution in East Africa is currently underway to identify research priorities and is expected to be published in March 2025. HEI staff also developed and maintain an interactive literature database featuring air quality and health publications from seven countries in East Africa: Burundi, Ethiopia, Kenya, South Sudan, Rwanda, Uganda, and Tanzania.

South Asia: In collaboration with the All India Institute of Medical Sciences, New Delhi, and the Indian Institute of Technology Delhi, HEI initiated support for a national research network focused on air pollution and health effects research in India called Collaborative on Air Pollution and Health Effects Research (CAPHER-India). Targeted training sessions have been conducted to strengthen skills for early career researchers in the design and conduct of air pollution and health studies. To strengthen local research and capacity further, HEI is also funding a research study led by India-based investigators to assess the association between exposure to air pollution and cardiovascular disease. Leveraging HEI's long-standing accountability research experience, HEI has launched a new project to assess the changes in air quality in Indian cities since the launch of India's National Clean Air Programme. HEI staff also developed and maintain an interactive literature database cataloging publications on air quality and health from six countries in South Asia: Afghanistan, Bangladesh, India, Nepal, Pakistan, and Sri Lanka.

Southeast Europe: Between 2021 and 2023, HEI worked with technical partners in Southeast Europe to produce three reports on air quality and health focused on Southeast Europe broadly and on Bulgaria and Serbia specifically. Accompanying materials were produced in English and relevant regional languages, and HEI fostered networking among individuals and organizations working on air pollution and health to catalyze further collaborations in the region. Two workshops were also organized; the first workshop brought together more than 100 regional experts to share data, research findings, and policy

priorities across Southeast Europe and the second workshop, organized in partnership with Medical University of Plovdiv, Bulgaria, sought to identify research priorities to advance clean air action in Bulgaria.

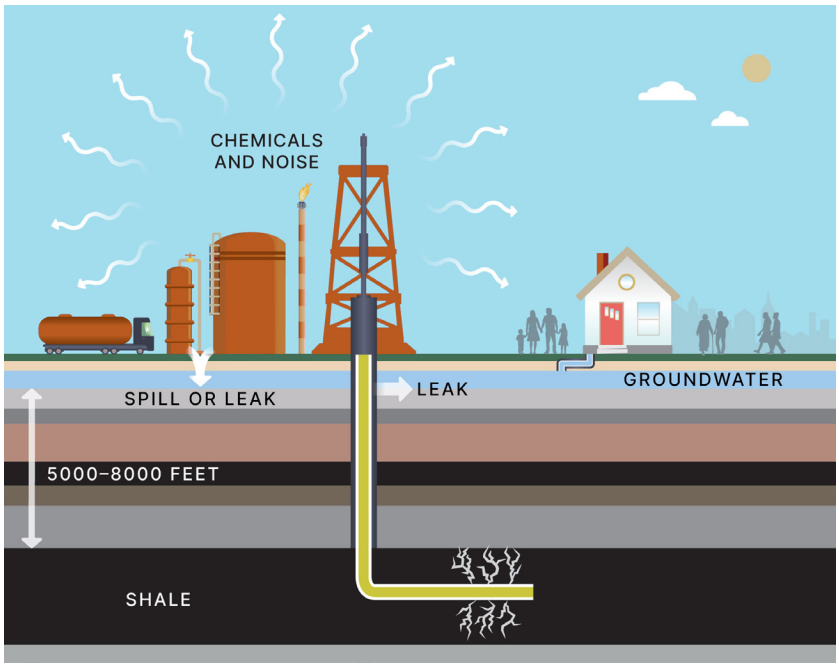
Energy (2020–2025)

The HEI Energy Program has made substantial progress toward achieving objectives set out in its 2020 Implementation Plan to improve understanding of community exposures and health effects associated with unconventional oil and natural gas development (UOGD). As called for in the plan, the initial program of funded research is focused on understanding population exposures and was informed by HEI reviews of relevant literature and recommendations shared at a series of research planning workshops. Proposals were selected based on HEI's long-standing requirements for high-quality, impartial, and policy-relevant research in addition to two general study design features: applicability beyond study locations and flexibility to anticipate and respond to fluctuating UOGD contexts in terms of technology, markets, and governance.

Exposure Research and Engagement

The overarching goal of this research program is to inform policy decisions by endeavoring to identify links between specific oil and gas processes and population exposures. This information can then be used to understand how exposure varies among subpopulations, define science-based setback distances, understand how to mitigate any exposures of concern for health, and assess the efficacy and co-benefits of specific mitigation approaches. To engage those affected by or interested in the work throughout the research process, HEI shares individual study updates, hosts webinars, and periodically briefs government, industry, and nongovernmental organizations.

Under this program, scientific teams have been working to improve understanding of population exposures associated with air quality changes, noise, and water quality



Conceptual diagram of the community exposures under investigation by the Energy Program.

changes from UOGD and associated processes. A collaborative effort, "TRAcking Community Exposures and Releases (TRACER) from UOGD," assessed acute and chronic human exposures in three U.S. regions and developed a model that captures scientists' collective current understanding of UOGD emission sources, predicts their influence on local and regional air quality, and can be updated as UOGD operations change over time. For this collaboration, researchers leveraged the previously developed Methane Emission Estimation Tool, adding additional UOGD operations and chemicals of concern for human health and evaluating the model with monitoring data from Colorado, Texas, and Pennsylvania.

The research has benefited from data and access to monitoring locations provided by several oil and gas companies in addition to local volunteers who helped to facilitate air quality monitoring.

Early progress from the TRACER collaboration informed the selection of three additional studies that will be completed in early 2025 that aim to assess trends in air quality and population exposures in three major oil- and natural gas–producing states. To the extent feasible, these studies will apportion the sources of any observed trends in air quality among UOGD and other sources.

To improve understanding of water quality changes attributable to UOGD, two studies combined existing water quality data and modeling to provide frameworks for identifying areas of potential water contamination, apportion the sources of contamination, and identify exposure

pathways. This research has benefited from state officials sharing UOGD operational and water quality monitoring data and focus group discussions. One of the research teams working in western Pennsylvania has discovered evidence consistent with relatively infrequent groundwater contamination near certain geologically problematic areas or natural gas wells, which could be locations of ongoing contamination. In 2024, the team initiated follow-up research to evaluate its model predictions by assessing groundwater quality in these locations.

Based on early research findings that suggest the importance of UOGD-related spills to population exposures, an additional study was launched in 2024 to conduct regional groundwater quality modeling to help understand how documented spills associated with UOGD might affect groundwater used as a source of drinking water in a major natural gas–producing region. A related workshop explored exposures to spills and other accidental releases of UOGD wastewater (also known as produced water) in the context of growing interest in reusing produced water for applications such as crop and cattle irrigation and road application. Workshop participants reviewed what is known about these potential exposures—expanding on a research brief that summarized the literature on this topic—and shared recommendations on how potential future research investments could help inform decision-making in this area.

The Challenges Ahead

Identifying the highest priority needs and concerns of air pollution policymakers has always been and continues to be a critical element in HEI's research planning. Although air quality goals remain an important focus of public interest and heated debate, the gradual transition to electric vehicles, the use of new fuels and technologies in the transportation sector, and questions about air quality in a changing climate have raised new health concerns and research priorities. Changes in energy systems and underlying technologies that are underway also raise expectations about potential opportunities to reduce exposures but also raises concerns about the introduction of new pollution sources.

As investments are made and technologies develop to address current challenges, it will be essential to produce science that helps understand the consequences for health and the environment and the possible trade-offs between new and established technologies. Impartial science will be needed to help set priorities for the allocation of state and federal resources for future investments, track progress and impacts over time to provide feedback on the design of future emissions reduction programs, and demonstrate whether the benefits that accrue from efforts to reduce emissions improve air quality, the environment, and ultimately public health.

The review of the latest science on criteria air pollutants and the consideration of current and future ambient air quality standards is continuing at a sustained pace. EPA's next review of the ozone NAAQS is expected over the next 5 years, as well as a planned near-term review for nitrogen oxides and regulatory considerations for air toxics. All those activities underscore the importance of impartial science for decision-makers when setting the NAAQS and standards for other pollutants.

There is a recognition that the transition to new transportation technologies, new fuels, and new energy sources and systems will continue to be gradual. As such, there remain scientific questions about the legacy vehicle fleet, as well as locomotives and multimodal transportation, especially at ports and other freight hubs. Despite the important progress in new technologies, it is likely that many light-duty vehicles that will be introduced over the next 5 years will continue to have enhanced efficiency internal combustion engines, primarily using gasoline direct injection technology. Furthermore, although light-duty vehicles have become increasingly more energy-efficient over the years, there has been an upward trend in average vehicle miles traveled. Continued use of legacy technologies signifies that health effects from TRAP will remain an important public health concern.

Research is also needed to address the uncertainties around exposure and health effects of known and emerging air toxics. People who live in many rural and urban locations experience an array of economic, environmental, social, and health factors that can benefit or harm their health.

Understanding how these factors interact with air pollution exposure to affect health would help in understanding why some populations experience higher levels of adverse health outcomes than others.

Although much of the world is taking meaningful steps to reduce emissions, environmental health challenges remain related to traditional mobile and stationary air pollution sources. The complex problems that we face now and that lie ahead require solutions that span multiple sectors and disciplines. Thus, the need for systematic, comprehensive, and health-centered assessments of optimal solutions grows more important. HEI has a critical role to play in informing decision-making with sound science in the coming years with an eye toward immediate, near-term and long-term air quality and health trends. The work that HEI started over this long history and particularly over the past 5 years continues to bring real value to health-protective policy decisions. HEI will continue to invest in and build on its successful work while also responding to the evolving landscape of pollution challenges, policy questions, and scientific capabilities to ask new types of questions and answer them with novel approaches.

The complex problems that lie ahead require solutions that span multiple sectors and disciplines. HEI's research agenda (described below) is designed to inform new policy and regulatory developments and to take advantage of new scientific approaches, measurement technologies, and more powerful means of assembling and analyzing data, such as through artificial intelligence, which provides unprecedented opportunities to advance air pollution-associated exposure and health science for decision-making. HEI has a critical role to play in informing decision-making with sound science in the coming years.

The Strategic Planning Process

The process for developing HEI's Strategic Research Plan for 2025–2030 as illustrated in Figure 7 extended for more than a year to allow for a full exploration of where important knowledge gaps remain, what outstanding policy questions could benefit from HEI's science, and where HEI could contribute to meeting the challenges ahead. After careful deliberation and discussion with sponsors, scientific committees, and other interested individuals and organizations, a draft plan was presented for discussion of recommended research priorities at HEI's 2024 Annual Conference. The draft plan was broad and ambitious by design; it was refined based on suggestions and comments received throughout the process and the five criteria presented below. These criteria will be used throughout 2025–2030 to guide decisions about what research to pursue.

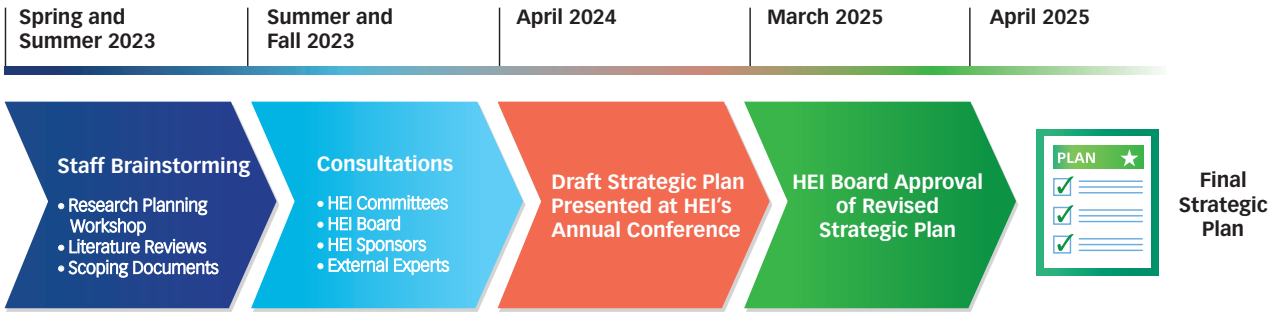


Figure 7. HEI's strategic planning process and timeline.

Criteria Used to Select Topics for HEI Strategic Research

The criteria below were used to select themes and research topics for HEI's next 5-year cycle. The criteria will also be used throughout the next 5 years to guide HEI's decision-making as to what research to pursue.

- The current state of knowledge about topics of potential interest.
- The importance of topics for public health to the general population and specific groups, including rural and urban locations that continue to face elevated levels of air pollution.
- The relevance of topics to upcoming policy or regulatory decisions and emerging technology developments.
- The extent to which other organizations are addressing the topics.
- The likelihood that scientific work by HEI will produce useful findings about the topics within the foreseeable future.

Major Themes for 2025–2030

The strategic planning process reaffirmed that HEI's three established, separately funded programs—Environment and Health, Global Initiatives, and Energy—continue to provide an optimal organizational structure for its activities. Key themes and specific priority areas that will guide the efforts within each program are discussed below. HEI's programs are also united by many common threads and contribute to a unified body of work. For example, accountability, exposure modeling, cumulative exposure, emerging pollutants, shifting sources of exposure, effects from the changing climate, and other factors that contribute to health effects are topics that span the programs and themes. Although specific research topics are highlighted below, HEI maintains the ability to be flexible to address the emerging needs of its sponsors and others in the coming years.

Many of the topics described below will appeal to various government agencies and industry organizations beyond our current sponsors, and where appropriate, HEI will explore opportunities to engage with them.

In addition to the research that will be funded, HEI will continue and expand its communication efforts as discussed above to facilitate the use of its funded research in policy development and decision-making. The organization will also continue to devote resources to synthesizing and integrating evidence so that the key messages, as well as strengths and limitations of its funded research, are transparent. And, it will continue to foster an active exchange of information, ideas, and tools among staff, expert committees, funded researchers, and the broader network to inform its investments and enhance programmatic impacts.

Environment and Health (2025–2030)

Themes identified for the Environment and Health Program for 2025–2030 build on the successful research that HEI has supported in the past, while also looking ahead to anticipated future scientific opportunities, societal challenges, and sponsor needs.

The sections below identify high-priority research topics within the overarching themes and other activities in which the Environment and Health Program might engage.

The Evolving Transportation Landscape

Research on the health effects resulting from exposure to transportation emissions has been a foundation of HEI's work over the past decades. This research will continue to play a pivotal and primary role in the coming years while evolving to address the changing mobility landscape. The research described here will build on recently funded studies noted above that assess the health effects of exposure to all relevant transportation-related air pollutants, as technologies and fuels change, the fleet turns over, mobility transforms, and electrification in various sectors advances.

- **Light-Duty Vehicles.** Investigation of the effects on air quality, exposure, and health of the turnover of the legacy light-duty (on-road) vehicle fleet to electric vehicles and possibly other new technologies and fuels. This topic includes an examination of trade-offs *and* benefits of various new transportation systems and mobility scenarios and implications of differential uptake of various new technologies.
- **Medium- and Heavy-Duty Vehicles.** Investigation of the effects on air quality, exposure, and health of the turnover of the legacy medium- and heavy-duty (on-road) vehicles to cleaner vehicle technologies. Future research in this area will build on the work of the HEI Panel on Heavy-Duty Diesel Fleet Turnover and a study initiated in 2024 to evaluate potential emissions, air quality, human exposure, and health benefits that could be achieved by replacing older medium- and heavy-duty diesel vehicles in the United States with cleaner vehicle technologies.
- **Nonroad Vehicles and Engines.** Assessment of emissions from nonroad vehicles and engines, including locomotives and those used in construction and agriculture, and potential impacts of implementing new engine technology, emissions control technologies, and fuel efficiency measures for this class.
- **Transportation Hubs and Goods Movement.** Assessment of air pollution exposure and health effects in areas near railyards, ports, airports, warehouses, and goods distribution centers with particular attention to multimodal air pollution sources. A particular focus here is the effect on air quality and health from goods movement corridors and urban freight distribution networks.
- **Nontailpipe Emissions.** Evaluation of exposure to and health effects of emissions from brake and tire wear, road surface abrasion, lubricating oils, and resuspended dust and identification of better markers of nontailpipe emissions in ambient air. As electric vehicle adoption advances and powertrain technologies evolve, a focus on these emissions becomes more important. Future work in this area would build on two studies initiated in 2022 to investigate short-term respiratory health effects from exposure to these emissions and to estimate real-world population exposures.
- **Accountability.** Continuation of HEI's long-standing commitment to assess the effects of national, regional, and local air quality actions on air pollution and health using novel methods. This topic would include studies of regulatory or other actions implemented for goals other than improving air quality—for example, to reduce traffic congestion.

One activity that HEI plans to pursue in 2025–2030 is convening a committee on emerging technologies similar to a past HEI committee that met from 2001–2013. HEI has a long history of investigating new vehicle technologies and fuels, and given the rapid pace of technology development today, such a committee would provide valuable insight into the technologies (e.g., hydrogen internal combustion engine) and fuels (e.g., biofuels and ammonia) that might obtain a meaningful market share that could result in substantive changes in population exposure to environmental pollutants. That insight would also help to guide HEI research and indicate which technologies and fuels would be worthwhile for further scientific assessment in the foreseeable future.

Pollutant Mixtures

Air pollution is a complex mixture of gaseous, liquid, and solid components, which varies greatly in composition and concentration across time and space due to differences and proximity to sources, weather, and topography. Most studies of air pollution and health have focused on estimating the adverse effects associated with ambient exposure in single-pollutant models; in some cases, results are adjusted for exposure to other pollutants as possible confounders, mostly in two- and three-pollutant models. HEI will continue to invest in advancing scientific methods to address the substantial challenges that remain in assessing multipollutant exposures and associated health effects. Of particular interest are the effects of air pollution mixtures and whether those effects differ from the effects of the individual pollutants within the mixtures.

- **Multipollutant Exposure and Health Estimation.** Development of multipollutant approaches to improve estimates of exposures and health effects from pollutant mixtures using novel models, methods, and data sources that can be applied in epidemiological studies and risk assessment. Examples include machine-learning-enabled models, deep learning image analysis, and advanced multipollutant statistical approaches primarily used for -omics analyses in the study of the exposome. New datasets could include next-generation satellite data and new sensor networks.
- **Particle Mixtures.** Assessment of the changing nature of the particle mixture and the effect of those changes on health, including investigation of chronic health effects from repeated versus low-level long-term exposures. As discussed in the section "Complex Questions for the Air Pollution Mixture" above, this topic is being addressed in an RFA released in fall 2024 with funding decisions expected by June 2025.
- **Ozone.** Assessment of health effects of short- and long-term exposure to ground-level ozone to address unanswered questions about adverse health effects, impacts on sensitive groups, and other factors relevant to the NAAQS review, including the interactive effects of nitrogen oxides and $PM_{2.5}$. This topic is especially relevant in the context of a changing climate, given that changing air pollution patterns and high-heat events are associated with changing patterns of ground-level ozone and its precursors.

- **Biological Mechanisms.** Investigation of the relationship between air pollution exposures and disease development (e.g., frailty) versus exacerbation of disease (e.g., sequelae effects). This topic might also include the investigation of the biological plausibility of health effects from chronic low-dose exposure to ambient air pollution.

Air Quality and the Changing Climate

Air pollution and changes in the climate are closely linked, and the relationship between air pollution and health will likely change given the changing climate. Direct effects on air quality will likely occur, for example, through changes in meteorology and atmospheric chemistry. Emissions and exposure could also be affected by societal responses and behaviors related to changes in the climate. Various recent studies have already indicated that the changing climate might result in a worsening of air quality in some regions. Efforts will be made to consider these factors in all HEI research, but targeted research in this area will be vital. Specifically, HEI will focus on the interplay of air quality and climate and leave the broader climate and health issues to others.

- **Effects on Air Quality from a Changing Climate.** Evaluation of changes in air quality, emissions, and exposures related to a changing climate and how those changes affect health. HEI is currently funding two research projects to address changes in air quality and related health effects from wildfires and prescribed burns. Future work will investigate, for example, the impact of extreme heat as an effect modifier for mortality and morbidity outcomes related to air pollution under current conditions and a changing climate.
- **Intervention Effectiveness.** Assessment of the effectiveness of adaptation, resilience, and mitigation measures that are aimed toward reducing exposures to extreme heat and air pollutants and preventing adverse health outcomes. Examples include air quality and heat warnings and the use of filtration systems in indoor environments.

Air Toxics

Air toxics, also known as hazardous air pollutants or noncriteria pollutants, are components of the ambient air pollution mixture that are emitted from both mobile (tailpipe and nontailpipe) and stationary sources and are known or suspected of causing cancer or other adverse health effects. Many knowledge gaps exist concerning exposures and health effects of both known and emerging air toxics, and questions have been raised about their ability to modify the effects of criteria pollutants. Although much of the recent HEI-funded research has focused on criteria air pollutants, HEI recognizes the need to address these knowledge gaps and build on the air toxics research that it

has previously funded. As a first step, HEI plans to hold a workshop to explore and identify critical knowledge gaps and the research needed to address questions, for example, concerning exposure assessment, various dose–response relationships, and the availability of cost-effective approaches for assessing the composition of the mixture of air toxics to which individuals are exposed. Information from this workshop will be used to guide future HEI-funded research to ensure that it is complementary to other organizations or programs, such as EPA's Integrated Risk Information System. HEI sees this theme as a bridge between its work on criteria pollutants and the topic of community health described below.

Advancing Environmental Health of Communities

Despite nationwide improvements in air quality, many rural and urban communities in the United States continue to experience high exposures to environmental pollutants and nonchemical stressors such as noise, heat, and lack of access to health care. HEI has explored how it can contribute to research aimed at advancing the environmental health of rural and urban communities across all its programs. Over the past few years, HEI hosted a workshop on the topic, assembled two advisory groups to guide its work, and funded studies on accountability research and community–academic partnerships that will investigate cumulative exposures. The three accountability studies will assess the extent to which vehicle emission control policies and interventions improve air quality, exposures, and health effects for communities that face persistent environmental challenges. In addition to those studies, three recent recipients of the Rosenblith award will focus their research on populations that typically experience elevated exposures and will provide valuable insights on pollution sources, optimal policies to reduce air pollution, and the distribution of exposure reductions across population groups. HEI will continue to expand this work in the coming years.

- **Methods Development.** Development of methods to assess combined exposure to chemical and nonchemical stressors at high spatial resolution, including characterization of uncertainties, biases, and accuracy. This effort includes the collection and evaluation of data at neighborhood and individual-level scales to quantify variability in air pollution exposures in populations that experience high air pollution levels and are not well represented in current national-level studies.
- **Cumulative Exposures and Effects and Their Contributing Factors** Assessment of cumulative exposures and effects and identification of the factors, especially those that can be changed, that contribute most to adverse outcomes. Specifically, research will focus on the health effects of multiple indoor and ambient air pollution exposures along with nonchemical stressors; other exposure pathways might be included if they are relevant to the specific decision context.

Ultimately, this work can help to inform the focus of future assessments and ensure that the most relevant factors are included in those assessments.

- **Effective Actions and Interventions.** Evaluation of actions or interventions that have been proposed or undertaken to address elevated air pollution levels in various locales. Identification of effective actions or interventions would provide valuable information to rural and urban communities. At the same time, questions remain about the effects of goods movement corridors and zero emissions control technologies on rural and urban communities. This topic would grapple with the issue of transferability and identify under which conditions or contexts the results are transferable to other communities or scalable to a state, regional, or national level.

HEI also plans to learn from local experts about their environmental health priorities and needs and to develop resources and tools that can provide technical assistance to conduct research. Activities could include providing support to build and strengthen academic–community partnerships, creating a literature database and spatial bibliography on local exposures, aggregating environmental data collected in locations with elevated exposures, developing methods for enhancing access of research results, developing a database for facilitating connections between academic and community groups, and convening local leaders and researchers to share lessons learned that could help to inform best practices for research and policy development and identify transferable findings.

Global Initiatives (2025–2030)

HEI's Global Initiatives will continue to focus primarily on low- and middle-income countries (LMICs), where the public health impacts of air pollution are the most profound and the need for solutions the greatest. Broadly, the program will continue to focus on communicating about sources and health effects of air pollution, strengthening local technical capacity, and supporting local scientific research where possible. The program will also prioritize the exchange of ideas and knowledge across LMICs through convenings and regular dialogue.

State of Global Air Initiative

In many places, the increased availability of data has fueled growing attention to the need for credible information about air quality, the health effects of pollution, and effective solutions. However, understanding of air pollution and its health effects remains low in regions with the highest exposures and health impacts. Since its launch in 2017, the SoGA initiative has successfully informed science and air quality action at local, national, and regional scales in locations around the world. Many geographies still need further attention. HEI will continue its efforts to communicate and expand access to compelling data on air pollutant concentrations and their sources and related health impacts worldwide using the SoGA platform.

- **Reports.** Produce periodic, in-depth reports that leverage GBD and other global or local datasets on such key topics as air pollution and noncommunicable diseases, air quality, and household air pollution and energy access.
- **Synthesis of Available Evidence.** Conduct a review of literature on new health outcomes for inclusion in GBD and other disease burden estimates (e.g., tuberculosis, chronic kidney disease).
- **Resources.** Produce curated materials on air pollution and health in multiple languages and formats (e.g., factsheets, videos, infographics), leveraging GBD and other global and regional data sources.
- **Trainings.** Facilitate in-person and virtual training sessions for researchers, policymakers, and nongovernmental organizations on air pollution and health, including GBD methods and data applications, in geographies of interest.

Bolstering Technical Capacity

LMICs experience the most significant effects of air pollution but have limited representation at regional, and global scales. Experience across many fields has shown that long-term improvement is driven by sustained local investments and engagement in funding, infrastructure, and technical expertise. HEI will continue to expand its efforts to strengthen local technical capacity toward these goals, especially through support for early career researchers.

- **Pilot Early Career Grants.** Award multiyear grants and mentorship to promising early career researchers based in LMICs on topics related to HEI's mission and work. Also, provide topic-driven grants for targeted, locally relevant research led by in-country investigators in geographies of interest.
- **Training.** Conduct targeted training for scientists on exposure and epidemiology research methods and methods for communication and science-to-policy translation.
- **Resources and Tools.** Continue the maintenance of interactive literature databases on air pollution and health for target geographies of interest.

Supporting Research Synthesis

Leveraging existing knowledge and innovation can enable LMICs to progress at a substantially faster pace than higher-income countries, including the possibility of disassociating rapid economic growth and industrialization from worsening air pollution.

- **Epidemiology.** Evaluate the health effects of short- and long-term exposures to air pollution in select geographies with high pollution levels.
- **Accountability.** Examine the relationships between air quality actions that are intended to reduce emissions and exposure and improvements in air quality and public health, with a focus on target geographies of interest.
- **Sources of $PM_{2.5}$.** Quantify the contribution of key sources to $PM_{2.5}$ at high temporal and spatial scales.
- **Air Quality, Climate, and Health.** Evaluate changes in air quality, emissions, and exposures related to a changing climate and how those changes affect population health.
- **Heterogeneity in Environmental Exposures.** Map differences in exposure patterns across different locations and population groups in target geographies of interest.

Energy (2025–2030)

The initial program of UOGD exposure research funded by the Energy Program shows great promise for informing policy that protects the health of people in regions across the United States where oil and natural gas are produced. Meanwhile, energy technologies continue to evolve and highlight the importance of expanding the Energy Program's scope to understand population exposures and the health effects associated with other forms of energy production. The sections below identify overarching themes along with high-priority areas of focus within those themes.

Oil and Gas Development: Direct Follow-up to the Current Program of Exposure Research

Research on population exposures and health effects associated with UOGD has been the initial focus of the HEI Energy Program. Given that UOGD is projected to continue for decades, this research will continue to be important in guiding health-protective policy in oil– and natural gas–producing regions of the United States.

- **Exposure Modeling.** Continued development of the TRACER emissions model to quantify local and regional air quality and noise exposures in multiple U.S. oil and gas regions. The model has numerous applications, such as predicting expected changes in air quality resulting from evolving technology and industry practice and improving exposure assessment in epidemiology research.
- **Wastewater Use.** Identification of current and planned use of oil and gas wastewater, referred to as produced water, outside the oil field for road treatment, agriculture, drinking water aquifer recharge, and other applications that might result in human exposure. This topic will include the assessment of exposure and health risks from the produced water uses of greatest potential concern for health.
- **Accountability.** Assessment of the relationships between specific interventions to reduce emissions and exposures associated with oil and gas development and improvements in air quality and public health.
- **Oil and Gas Supply Chain.** Assessment of exposure and health risks associated with oil and gas distribution and transport (e.g., leaky pipelines and combining natural gas with hydrogen), refining, processing (e.g., cracker plants), and waste streams.

Health Effects of Changing Energy Systems and Technologies

Decisions are being made today and in the coming years that are likely to transform our energy systems. In response, the scope of the Energy Program is expanding beyond oil and gas to other forms of energy development, with an overarching goal of providing impartial knowledge about the benefits and drawbacks associated with various technologies. Although there is substantial uncertainty as to what the energy landscape will look like in 5 years, 10 years, and beyond, history tells us that all change brings both beneficial and adverse consequences. To provide the research needed to maximize health benefits and minimize adverse health consequences across all subpopulations, it is important to continually assess the energy landscape for opportunities to contribute impartial science that can inform energy choices. Some energy topics can be studied empirically today, such as electrification, the battery value chain, and alternative fuels, while others would by necessity involve projections because they do not yet exist, such as large-scale hydrogen and geothermal production.

- **Systematic Framework for Assessing Health Benefits and Risks of Energy Choices.** Creation of a decision analytic framework that can compare health risks and benefits associated with alternative energy technologies and production pathways. The framework would require multidisciplinary collaboration, with HEI and its funded investigators bringing necessary health expertise and working in collaboration with energy modelers and other experts.
- **Carbon Capture, Use, and Storage.** Assessment of the health risks and co-benefits associated with emissions and wastes from carbon capture technology in heavy industry and other applications.
- **Alternative Fuels**. Assessment of the health risks and benefits associated with the production of alternative fuels, such as hydrogen (e.g., hydrogen internal combustion engine vehicles), corn-based biofuels, and renewable natural gas.
- **Electrification and the Battery Value Chain.** Assessment of the health risks and benefits associated with an expanded and modified electricity infrastructure, including battery manufacturing and the acquisition of critical minerals from the earth or recycled from produced water and wastes.
- **Large-Scale Geothermal.** Assessment of the health risks and benefits associated with large-scale geothermal operations involving the same preproduction processes used for oil and natural gas development.
- **Hydrogen Hubs.** Research to determine how best to assess and respond to the health risks and benefits associated with hydrogen hubs. This work would help to inform large-scale demonstrations of hydrogen production, storage, transport, and consumption in regional hubs.

Meeting the Challenges Ahead

Air pollution is now widely acknowledged to be an urgent and growing threat to public health worldwide. This recognition has led to expanded efforts to improve air quality locally, nationally, and globally in recent years, and new technologies and policies offer great potential to reduce harmful emissions and their associated health effects. However, despite these encouraging developments, new sources of environmental pollution have also emerged, and new and previously unrecognized health effects have become more apparent. A scarcity of data on environmental pollution and health in certain locales has left many decision-makers uncertain about the pollutants that affect them and about the optimal opportunities to intervene.

All this underscores the continuing importance and urgency of research and policies to evaluate the health effects of environmental pollutants. This Strategic Plan outlines key priorities for HEI's activities to address these critical issues over the next 5 years, while maintaining flexibility to respond to unanticipated needs. It highlights many opportunities to take HEI's previous research investments a step further by incorporating new scientific methods, a broader array of stakeholder perspectives, and emerging technologies into assessments of pollution challenges and the effectiveness of solutions. It also points to opportunities to leverage a history of robust research to forge a path forward on some of the most complex and pressing issues in environmental health, such as the substantive challenges of assessing multipollutant exposures, understanding the complex interplay between air pollution and the changing climate, and considering health in energy decisions.

HEI's aims are ambitious. In addition to the substantial research investments that are necessary to meet these goals, HEI places a high priority on maintaining sufficient flexibility in its planning and budgets to adapt to and respond to unanticipated needs, something that is highly valued by its current government and industry sponsors. Given the impact of inflationary erosion, funding—even maintained at current levels—presents a challenge. Fortunately, HEI's past success in maintaining funding sources and raising additional funds from other private and public entities, often for specific projects or programs, strongly indicates that a variety of organizations will continue to find value in supporting HEI's vital mission and activities.

There is a critical need for independent and trusted science to inform evidence-based decisions. Looking ahead, HEI remains committed to its mission and approach to providing high-quality, impartial science. Through the research priorities identified in this Strategic Plan, we are poised to advance a research program that produces results and insights to inform effective policies and decision-making. By funding rigorous research, synthesizing scientific evidence, convening a broad range

of interested stakeholders, and supporting effective communication and collaboration, HEI will leverage its strengths and expertise to meet tomorrow's challenges.

Acronyms and Abbreviations

CAPHER-India	Collaborative on Air Pollution and Health Effects Research
CHERI	Community Health and Environmental Research Initiatives
GBD	Global Burden of Disease
HEI	Health Effects Institute
LMIC	low- and middle-income country
NAAQS	National Ambient Air Quality Standards
$PM_{2.5}$	fine particulate matter
RFA	request for applications
SoGA	State of Global Air
TRACER	TRAcking Community Exposures and Releases, a study supported by the HEI Energy Program
TRAP	traffic-related air pollution
UOGD	unconventional oil and natural gas development
U.S. EPA	U.S. Environmental Protection Agency

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Strategic Research Plan

2025–2030

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