

Memo

To: The Vermont Public Utility Commission
From: Rick Weston, Chair, on behalf of the CHS Technical Advisory Group
RE: Health Impacts and Considerations for the Clean Heat Standard
Dt: January 9, 2025

Sections from the Vermont Clean Heat Standard Statute that relate to public health are copied below:

- § 8121. INTENT
Pursuant to 2 V.S.A. § 205(a), it is the intent of the General Assembly that the Clean Heat Standard be designed and implemented in a manner that achieves Vermont's thermal sector greenhouse gas emissions reductions necessary to meet the requirements of 10 V.S.A. § 578(a)(2) and (3), minimizes costs to customers, protects public health, and recognizes that affordable heating is essential for Vermonters. It shall enhance social equity by prioritizing customers with low income and moderate income and those households with the highest energy burdens. The Clean Heat Standard shall, to the greatest extent possible, maximize the use of available federal funds to deliver clean heat measures.
- § 8127. TRADEABLE CLEAN HEAT CREDITS
(h) Review of consequences: The Commission shall biennially assess harmful consequences that may arise in Vermont or elsewhere from the implementation of specific types of clean heat measures and shall set standards or limits to prevent those consequences. Such consequences shall include environmental burdens as defined in 3 V.S.A. § 6002, public health, deforestation or forest degradation, conversion of grasslands, increased emissions of criteria pollutants, damage to watersheds, or the creation of new methane to meet fuel demand.
- § 8128. CLEAN HEAT STANDARD TECHNICAL ADVISORY GROUP
(a) The Commission shall establish the Clean Heat Standard Technical Advisory Group (TAG) to assist the Commission in the ongoing management of the Clean Heat Standard. Its duties shall include:

(3) Periodically assessing and reporting to the Commission on the sustainability of the production of clean heat measures by considering factors including greenhouse gas emissions; carbon sequestration and storage; human health impacts; land use changes; ecological and biodiversity impacts; groundwater and surface water impacts; air, water, and soil pollution; and impacts on food costs.

(8) calculating the savings associated with public health benefits due to clean heat measures.

Executive summary of health impacts and considerations for the Clean Heat Standard

This memo provides a high-level summary of potential human health impacts and considerations for individual measures or groupings of measures listed and defined in the draft Vermont Clean Heat Standard Technical Reference Manual (TRM). The focus of this analysis was on describing potential combustion-related health impacts and other health co-benefits or co-harms relating to end use of Clean Heat measures at a place of residence. Quantifying health impacts/costs and analyzing life cycle health impacts were both determined to require more time and resources than are available for this task at this time.

To best meet the intent of the Clean Heat Standard as described in Title 30, Chapter 94 to protect public health, the following summary statements can be made about potential TRM measures:

1. Public health benefits can most confidently be delivered through strategies supporting building envelope improvements and increased use of modern electric heating equipment and appliances, by reducing harmful combustion emissions while providing other health co-benefits.
2. Combustion emissions from liquid and gaseous biofuels included in the TRM may have a similar or slightly less harmful effect on health as compared to combustion emissions from fossil fuels in current use, though health effects vary by fuel type, feedstock, blend percentage, and other factors, as described in further detail in the body of this memo. There is some uncertainty about this conclusion, as liquid and gaseous biofuel emissions have not been well-studied in modern residential applications. Rather, this conclusion is derived primarily from findings of transportation engine studies that compared emissions of biofuels to emissions of fossil fuels of a similar composition to those used in residential heating applications today, and from the very small number of heating boiler studies that compared emissions from biofuels to fossil heating fuels of a similar composition to those used in heating applications today. The summary of evidence in this memo describes expected differences in emissions-related health effects between each biofuel included in the TRM and comparable fossil fuels, while also pointing out specific areas of uncertainty where research is lacking and/or scientific consensus has not been reached.
3. Wood heating produces combustion emissions that are more harmful to health than from other commonly-used fossil heating fuels. This is true even for the most modern, automated, central wood heating systems. Manually-operated cordwood stoves produce substantially more harmful emissions than automated wood heating systems.

For all potential TRM measures, it should also be considered that ensuring equitable and affordable access to home heating is essential for protecting Vermonters' health.

Recommended next steps

- 1) Establish a process for reviewing, summarizing, and considering the application of new scientific evidence on a biennial basis.
- 2) Consider dedicating resources to conduct a quantitative analysis of health impacts and monetizable costs or benefits of the measures listed in the Vermont Clean Heat Standard TRM.
- 3) Consider dedicating resources to conducting a life-cycle assessment of health impacts of the measures listed in the Vermont Clean Heat Standard TRM.

Initial Review of Public Health Impacts of Clean Heat Measures

This memo provides a high-level summary of potential human health impacts and considerations for individual measures or groupings of measures listed and defined in the draft Vermont Clean Heat Standard Technical Reference Manual (TRM). The focus of this analysis was on describing potential combustion-related health impacts and other health co-benefits or co-harms relating to end use of Clean Heat measures at a place of residence. Quantifying health impacts/costs and analyzing life cycle health impacts were both determined to require more time and resources than are available for this task at this time, though we recommend dedicating resources to such an effort in the future.

The discipline of public health uses an evidence-based approach to support decision-making.¹ Ideally, decisions about policy issues that impact public health should be informed by a rich and mature body of scientific evidence which has been synthesized into unbiased, peer-reviewed, systematic reviews that establish a clear consensus on the conclusions. Contradictory findings or simply a lack of directly relevant, high-quality studies reduce confidence in conclusions drawn from individual studies. The strength of individual studies can vary widely based on the source, research methods, whether scientific peer-review occurred before publication, and other factors. Additional resources describing how scientific evidence is evaluated and applied are provided.^{2,3,4}

The scientific evidence is relatively mature and clear regarding health impacts relating to building envelope strategies, electric heating and appliances, and wood heating. These sections of the literature review were summarized at a high-level with only key resources noted in the list of references at the end of this memo. Wood heating received relatively more attention, highlighting potential harms associated with increased wood heating generally, and the different impacts of specific types of wood heating equipment and fuel characteristics.

In contrast, there is relatively little scientific evidence or consensus about the health impacts of biofuels used in residential applications, and almost none that compare emissions impacts from biofuels to emissions from fossil fuels currently used in residential settings. We identified and summarized relevant studies while also pointing out areas of concern and uncertainty that have not been definitively resolved. In an effort to be as clear and transparent as possible, the biofuels section of this memo is more detailed and includes specific citations.

For background relevant to all TRM measures, an overview of common air pollutants and their health effects can be found [here](#).

Detailed findings organized by groupings of TRM measures

- 1. Building envelope** – scientific evidence is clear that air sealing, building envelope insulation, and related home weatherization strategies result in generally positive health benefits from avoided combustion emissions, thermal comfort, and other indoor environment co-benefits.
 - Reduced combustion emissions; improved temperature control and indoor air quality; reduced humidity, mold, and pest intrusion; money saved on fuel often directly supports better health; opportunities for other health and safety improvements.
 - [OEO estimated in 2024](#) an average household savings of \$1,026 per year from reduced fuel demand.

- [VDH estimated in 2018](#) \$1,302 per year in public health savings per year from reduced outdoor air emissions and reduced resident impacts from cold, heat, and asthma.
 - Need to ensure sufficient ventilation and treatment of indoor air pollutants after weatherization.
- 2. Electric heating and appliances** – scientific evidence is clear that switching from use of conventional fossil fueled heating and appliances to modern electric heating and appliances results in largely positive health benefits, primarily as a result of avoided combustion emissions.
- Compared to conventional liquid or solid heating fuels: avoided combustion emissions; avoided indoor exposure to nitrogen dioxide and other air toxics ([particularly from gas](#) and [propane cook stoves](#)); avoided risk of carbon monoxide poisoning.
 - Heat pumps provide health co-benefits such as increasingly necessary air conditioning and dehumidification.
- 3. Wood heating** – scientific evidence is clear that emissions from wood heating result in negative health impacts, though the magnitude of impact varies by heating device and fuel characteristics.
- Residential wood heating emits substantially more fine particulate matter and air toxics than other non-woody residential fuels. Fine particulate matter (PM_{2.5}) is a critical pollutant of concern due to decades of research establishing significant associations with human mortality and morbidity.
 - This is true for all wood fuel types and heating equipment, though there is a spectrum from most -> least polluting per heat output (uncertified cordwood stove -> EPA-certified cordwood stove (noncatalytic) -> EPA certified cordwood stove (catalytic/hybrid) -> pellet stove or boiler). There is a wide range of other whole-house wood-fueled systems (boilers or furnaces using cordwood or wood chips) that are hard to place in this spectrum due to a lack of scientific emissions data.
 - Based on a [2022 VDH analysis](#) using the EPA Co-Benefits Risk Assessment (COBRA) tool:
 - 97% of the monetizable health impact from residential heating emissions in Vermont is attributable to wood fuel combustion.
 - The monetizable health impact of residential wood heating in Vermont is \$105M-\$238M (about 30x greater than for all other residential fuels combined).
 - Pollution from wood heating is associated with 10-22 early deaths (about 20x greater than for all other residential fuels combined).
 - Cancer risk from wood heating pollution is 2.5 per million (about 20x greater than for all other residential fuels combined).
 - Replacing fossil fueled heating with wood heating, especially cordwood, would likely have a harmful impact on human health due to increased emissions of multiple air pollutants. The magnitude depends on what type of wood heating equipment and fuel is used and what is being replaced.
 - Replacing cordwood stoves and boilers with pellet stoves or boilers has the potential to provide a substantial public health benefit. Pellet stoves are very low emitting for most combustion emissions except trace metals of health concern (Pb, Cd, As). In general,

emissions from pellet heating systems are a much lower concern than cordwood emissions with respect to health impacts. Compared to cordwood emissions, pellet emissions have very low particulate matter, black carbon, volatile organics (including carcinogenic volatile organic compounds), and de minimus polycyclic aromatic hydrocarbons (PAHs).

- An important health consideration for those without alternative heat sources in the cold is that manually operated wood stoves can continue providing heat in the event of power loss.
- Increased fossil fuel prices may lead to increased wood heating as a more cost-effective option, which would have negative impacts on air quality and human health.

4. **Liquid and Gaseous Biofuels** - health impacts from biofuels are difficult to interpret due to very limited research about biofuels used in residential applications. Based mainly on studies of emissions from biofuel use in automotive engine applications, health impacts from biofuel combustion emissions are slightly improved or similar to emissions from conventional fossil fuels, with some variation by type of biofuel, feedstock, blend percentage, and other factors.

- Research on air quality and health impacts of liquid and gaseous biofuels is limited.
 - Most of that limited research is focused on the transportation sector, comparing biofuels (biodiesel or biomethane) to conventional transportation fuels (diesel, gasoline, or fossil gas). Very few peer-reviewed studies have been published about biofuels used for home heating or appliances. The review below prioritizes scientific findings about biofuels in this order:
 - 1) Peer-reviewed systematic literature reviews are always preferred to peer-reviewed individual studies.
 - 2) Home heating or appliance studies when the fossil fuel used for comparison was similar to fuels in real-world use today. Findings from these studies are the most directly relevant for residential uses today, but there have been very few published.
 - 3) Automotive engine studies when the fossil fuel used for comparison was similar to fuels in real-world use today – these findings may be helpful for understanding relative differences between emissions from biofuels compared to fossil fuels, while acknowledging this is an imperfect comparison. There are fundamental differences between combustion processes, operating conditions, and pollutant controls used in automotive engines versus home heating boilers that affect the composition and magnitude of emissions. However, evidence from transportation studies was often the best or only evidence available, so it was used in this assessment in a limited way. For example, evidence that switching from fossil fuels to biofuels in a transportation engine results in a change in emissions may suggest that similar emissions changes would occur if making a similar comparison in a residential heating application, but that assumption needs future validation. The composition and magnitude of emissions from transportation engines should not be generalized to residential applications.

- 4) Studies where the fossil fuel used for comparison is no longer in real-world use or was not clearly specified in the article, or the biofuel feedstock is not listed in the Vermont Clean Heat Standard TRM, were generally not considered. For example, since 2018, ultra-low sulfur diesel is the only diesel fuel allowed for residential heating use in Vermont, but most biodiesel studies in residential settings make comparisons to higher sulfur diesel fuels that are no longer used in residential settings (explained in further detail in the Biodiesel review below).
 - Emissions impacts reported in the peer-reviewed literature differ by characteristics of the biofuel (e.g., feedstock, blend), type of combustion equipment used, consideration of part or all of the lifecycle impacts, and other factors.
 - The evidence summarized below focuses on end use combustion impacts. Life cycle impacts should be considered but are outside of the scope of this review. Additional dedicated resources would likely be needed to explore life cycle health impacts.
- One of the concluding statements from [EPA's 2022 Biofuels and the Environment: Third Triennial Report](#) summarizes the uncertainty about health effects from biofuels:
 - "The understanding of the potential health effects of exposure to biofuels and emissions from vehicles using biofuels under real-world conditions, concentrations, and exposures including to susceptible human populations is limited. Recent literature that addresses cumulative impacts of upstream processes is limited. Much of the recent published literature focuses on impacts of individual sectors only."
- Abt Associates completed a literature review in 2022 for the New York State Energy Research and Development Authority (NYSERDA) summarizing the health impacts of liquid and gaseous biofuels. The findings below are largely consistent with the Abt Associates memo, which can be read [in full here](#).

A. Biodiesel

- Compared to other biofuels, there is relatively more biodiesel research focused on emissions from home heating equipment, but most are older studies comparing biodiesel emissions to emissions from No. 2 fuel oil with a far higher sulfur content than what is allowed today ([overview of the evolution of sulfur content standards](#)). There are very few studies comparing emissions from biodiesel to ultra-low sulfur diesel (ULSD) in use today.
 - Vermont has required use of ULSD (sulfur content < 15ppm) for home heating oil since 2018. This replaced the low-sulfur diesel (LSD) standard (sulfur content <500ppm) implemented in 2014. The previous sulfur content standard was <20,000ppm, though home heating oil typically had a sulfur content in the 2000-2500ppm range.
 - Removing sulfur from fuel oil directly or indirectly reduces emissions of sulfur dioxide (SO₂), particulate matter (PM), nitrogen oxides (NO_x), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), and other emissions. For any studies comparing biodiesel to conventional or low sulfur fuels no longer used today, it should be acknowledged that those fuels generated higher emissions than the ULSD in use today.
 - [A report produced for NYSERDA](#) summarized emissions differences comparing heating oils with varying sulfur content:

- Switching from conventional heating oil (sulfur content = 2000ppm) to LSD (sulfur content = 500ppm) generally reduces emissions of SO₂ by 75-80%, PM by 75%, and NO_x by 5-10%.
- Switching from conventional heating oil (sulfur content = 2000ppm) to ULSD (sulfur content = 15ppm) generally reduces emissions of SO₂ by 97%, PM by 90-95% (estimated from graph), and NO_x by 20-30%.
- Several literature reviews have summarized the health impacts of biodiesel primarily used in automotive applications, generally reporting reduced emissions of SO₂, PM, PAHs, and CO and increased emissions of NO_x and aldehydes^{5,6,7,8,9,10,11}. Some of this evidence is based on comparisons to diesel fuels with higher sulfur content than what is used in residential boilers today. Emissions differences are typically smaller or negligible when comparing biodiesel to ULSD since many emissions depend on sulfur content differences between fuels. Even the most recent reviews draw concluding statements about the lack of certainty and need for additional research about biofuel emissions impacts on human health, for example: “Currently there is no scientific consensus on the health effects associated with biodiesel exposure.”⁵
- Few peer-reviewed studies of biodiesel used in home heating applications were identified, particularly comparing biodiesel to ULSD or similarly low-sulfur diesel fuel:
 - Biodiesel (from sunflower oil, S=2ppm) produced slightly higher CO emissions and reduced SO₂ compared to ULSD fuel oil (S=11ppm) used in a residential boiler.¹²
 - Biodiesel (unspecified feedstock, S=60ppm) produced lower CO, PM, and PAH emissions, higher SO₂ and formaldehyde emissions, and slightly higher NO_x emissions compared to LSD fuel oil (S=30ppm) used in a residential boiler.¹³
 - Biodiesel (from animal & vegetable fats, S=2) produced slightly higher CO and NO_x emissions and similarly negligible SO₂ emissions compared to ULSD fuel (S=5ppm) used in an industrial boiler.¹⁴
- Sulfur dioxide emissions largely depend on the sulfur content of the fuel. Both fossil diesel and biodiesel fuels must have sulfur content below 15ppm and biodiesel often has less sulfur content than fossil diesel. One exception was noted in our review, where the biodiesel used in a home heating fuel study was found to have a sulfur content of 60ppm.¹³ This may be an outlier, though some articles noted that sulfur content can vary by feedstock and processing methods, with potentially higher sulfur content in fuels derived from waste oils.¹⁵
- Additional literature reviews focused solely on NO_x emissions from biodiesel are provided.^{16,17} While there is some variation in NO_x emissions reported, the general consensus is that NO_x emissions are higher from biodiesel compared to diesel fuel. Variation may be due to differences in feedstock, biodiesel blend percentage, equipment, operating characteristics, and application of specific NO_x controls.
- The largest area of research uncertainty appears to be the overall toxicity and carcinogenicity of biodiesel emissions. One recent systematic review found that biodiesel emissions reduced particle toxicity in two-thirds of the comparisons reviewed, but that there were large differences between various biodiesels for five category-specific biomarkers (inflammation, oxidative stress, cytotoxicity, genotoxicity, and mutagenicity).¹⁸ The review concluded that “[a]t present, we cannot say with certainty which fuels are more or less toxic than fossil diesel, however, the present analysis does demonstrate quantitatively that we cannot assume biodiesels are

interchangeable from a health perspective.” Contradictory findings about biodiesel toxicity are also reviewed in articles cited above, and the additional literature reviews cited here.^{19,20}

- More recent studies have continued to find contradictory effects.^{21,22} One found that blending biodiesel up to 20% had minimal impact on toxicity, but that B50-B100 blends were more toxic and carcinogenic than diesel fuel.²²
- Several articles noted that although total mass of PM emissions tends to decrease with biodiesel, there is a corresponding increase in emissions of ultrafine particle emissions with a different chemical composition compared to ULSD emissions, which may contribute to greater biodiesel toxicity detected in some studies.^{5,8,9}

B. Renewable diesel

- No peer-reviewed studies were identified regarding health impacts of renewable diesel used in residential boilers.
- Based on automotive engine studies, renewable diesel is expected to reduce emissions of PM, NO_x, and PAHs as compared to ULSD, though the differences may be small using modern engines, and some contrary findings have been published about both NO_x and PAHs.^{23,24,25,26} SO₂ emissions should be similar between renewable diesel and ULSD.

C. Biomethane/RNG (not including biogas)

- No peer-reviewed studies were identified regarding health impacts of biomethane used in residential applications.
- Based on automotive engine studies, NO_x emissions from biomethane are generally lower as compared to fossil gas. Other emissions from biomethane are expected to be similar to or lower than emissions from fossil gas, though most outdoor air pollutant emissions from fossil gas are already relatively low.^{23,27,28,29,30}
- Some recent studies have raised concerns about harmful indoor emissions from cook stoves fueled by conventional fossil gas and propane.^{31,32} Using biomethane in place of fossil gas may produce similar or slightly less harmful emissions.

D. Renewable propane

- No peer-reviewed studies were identified comparing health impacts of renewable propane to fossil propane. Renewable propane is chemically identical to conventional propane so would be expected to produce similar emissions.
- Some recent studies have raised concerns about harmful indoor emissions from cook stoves fueled by conventional fossil gas and propane.^{31,32} Using renewable propane in place of propane may produce similarly harmful emissions.

E. Hydrogen

- Combustion of hydrogen alone or hydrogen blended into fossil gas may generate more NO_x emissions than fossil gas under certain circumstances.^{33,34,35,36,37,38} One article suggests that additional standards and controls may be needed to mitigate NO_x emissions from hydrogen fuel combustion.³⁹ Blending hydrogen into fossil gas should reduce SO₂ and PM emissions, though both are already low in fossil gas emissions.

Other considerations

- Equity and affordability considerations: Ensuring equitable access to heating fuels, health benefits, and protection from health harms.
- Lifecycle impacts: Extraction, production, transportation, etc. impacts on emissions, environmental health; impacts related with upstream electricity generation.
- Fuel/technology used for backup power: For example, battery backup versus fossil-fueled generator. Accidental CO poisoning has caused about 50 ED visits / year and 1-2 deaths / year in Vermont over the past 10 years. Common causes of accidental CO poisoning include improper generator use or the malfunction or improper use of heating equipment, cooking equipment, or other combustion-fueled appliances.
- Implementation and timing of benefits: It is possible that drop-in biofuels could provide more immediate but smaller benefits while weatherization and electrification may provide larger benefits that take longer to deploy. Consideration should be given to how overall benefits are affected by how fuel policies serve to complement or compete with each other.

Recommended next steps

- 1) Establish a process for reviewing, summarizing, and considering the application of new scientific evidence on a biennial basis.
- 2) Consider dedicating resources to conduct a quantitative analysis of health impacts and monetizable costs or benefits of the measures listed in the Vermont Clean Heat Standard TRM.
- 3) Consider dedicating resources to conducting a life-cycle assessment of health impacts of the measures listed in the Vermont Clean Heat Standard TRM.

TAG Vote to approve the content of this memo and forward to the PUC:

- 10 votes in favor (Rick Weston, Emily Levin, Matthew Bakerpoole on behalf of DPS, Brian Woods, Emily Roscoe, Luce Hillman, Ken Jones, Jared Ulmer, Michelle Keller, Emily Grubert)
- 3 votes objecting (Floyd Vergara, Sam Lehr, Matt Cota)
- 2 members absent during vote (Patrick Wood, Casey Lamont)

Key references

- Building envelope strategies
 - [ENV CH WxHealthReport.pdf \(healthvermont.gov\)](#) - 2018 Vermont Department of Health synthesis of scientific evidence describing health impacts of home weatherization. More recent studies below:
 - [Cascading benefits of low-income weatherization upon health and household well-being - ScienceDirect](#)
 - [Saving lives by saving energy? Examining the health benefits of energy efficiency in multifamily buildings in the United States - ScienceDirect](#)
 - [Health and financial benefits of weatherizing low-income homes in the southeastern United States - ScienceDirect](#)
 - [A dollar well spent: Monetizing the societal benefits of low-income weatherization programs in the United States - ScienceDirect](#)
- Electric heating and appliances
 - [Heat pumps and our low-carbon future: A comprehensive review - ScienceDirect](#)
 - [Residential home heating: The potential for air source heat pump technologies as an alternative to solid and liquid fuels - ScienceDirect](#)
 - [US residential heat pumps: the private economic potential and its emissions, health, and grid impacts - IOPscience](#)
 - [Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes | Environmental Science & Technology \(acs.org\)](#)
 - [Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States \(mdpi.com\)](#)
 - [Gas Stoves and Respiratory Health: Decades of Data, but Not Enough Progress | Annals of the American Thoracic Society \(atsjournals.org\)](#)
- Wood heating
 - [Criteria, Greenhouse Gas, and Hazardous Air Pollutant Emissions Factors from Residential Cordwood and Pellet Stoves Using an Integrated Duty Cycle Test Protocol | ACS ES&T Air](#)
 - [Particulate matter emission control from small residential boilers after biomass combustion. A review - ScienceDirect](#)
 - [Full article: Introduction to Special Issue on Residential Wood Combustion \(tandfonline.com\)](#)
 - [An overview of particulate emissions from residential biomass combustion - ScienceDirect](#)
 - [Full article: Residential wood heating: An overview of U.S. impacts and regulations \(tandfonline.com\)](#)
 - [Full article: Online measurement of PM from residential wood heaters in a dilution tunnel \(tandfonline.com\)](#)
 - [Full article: Impacts of wood species and moisture content on emissions from residential wood heaters \(tandfonline.com\)](#)
 - [Emission factors from small scale appliances burning wood and pellets - ScienceDirect](#)
 - [Toward the ultra-clean and highly efficient biomass-fired heaters. A review - ScienceDirect](#)

- [Estimating State-Specific Contributions to PM2.5- and O3-Related Health Burden from Residential Combustion and Electricity Generating Unit Emissions in the United States - PubMed \(nih.gov\)](#)
- [Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005 - ScienceDirect](#)
- [Indoor wood-burning from stoves and fireplaces and incident lung cancer among Sister Study participants - ScienceDirect](#)
- [Fine particulate air pollution and human mortality: 25+ years of cohort studies - ScienceDirect](#)
- [Woodsmoke Health Effects: A Review: Inhalation Toxicology: Vol 19 , No 1 - Get Access \(tandfonline.com\)](#)
- [Review: Woodsmoke and emerging issues - ScienceDirect](#)
- **Biofuels, broadly**
 - [Effect of Low-Carbon Fuels and Energy Technologies on Co-Pollutant Emissions \(Abt Associates literature review\)](#)
 - [Biofuels and the Environment: Third Triennial Report to Congress \(External Review Draft\) | Biofuels | US EPA](#)
- **Biodiesel**
 - [Biodiesel Emissions: A State-of-the-Art Review on Health and Environmental Impacts \(mdpi.com\)](#)
 - [Health impacts of liquid biofuel production and use: A review - ScienceDirect](#)
 - [Performance and emissions of biodiesel in a boiler for residential heating - ScienceDirect](#)
 - [Fuel effects on PAH formation, toxicity and regulated pollutants: Detailed comparison of biodiesel blends with propanol, butanol and pentanol - ScienceDirect](#)
 - [Technological, technical, economic, environmental, social, human health risk, toxicological and policy considerations of biodiesel production and use - ScienceDirect](#)
 - [Re-assessing the toxicity of particles from biodiesel combustion: A quantitative analysis of in vitro studies - ScienceDirect](#)
 - [Effect of biodiesel on engine performances and emissions - ScienceDirect](#)
 - [Biodiesel exhaust particle airway toxicity and the role of polycyclic aromatic hydrocarbons - ScienceDirect](#)
 - [Environmental sustainability of biofuels: a review | Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences \(royalsocietypublishing.org\)](#)
 - [Biodiesel fuels: A greener diesel? A review from a health perspective - ScienceDirect](#)
 - [A paler shade of green? The toxicology of biodiesel emissions: Recent findings from studies with this alternative fuel - ScienceDirect](#)
 - [Breathing easier? The known impacts of biodiesel on air quality. - Abstract - Europe PMC](#)
 - [Desulfurization of biodiesel produced from waste fats, oils and grease using \$\beta\$ -cyclodextrin - ScienceDirect](#)
 - [Study of combustion process of biodiesel/gasoil mixture in a domestic heating boiler of 26.7 kW - ScienceDirect](#)
 - [Emissions and energy/exergy efficiency in an industrial boiler with biodiesel and other fuels - ScienceDirect](#)
 - [Biodiesel Multimedia Evaluation \(California Environmental Protection Agency\)](#)

- Renewable diesel
 - [Comprehensive review of combustion, performance and emissions characteristics of a compression ignition engine fueled with hydroprocessed renewable diesel - ScienceDirect](#)
 - [Low Emission Diesel \(LED\) Study: Biodiesel and Renewable Diesel Emissions in Legacy and New Technology Diesel Engines - Final Report](#)
 - [Assessment of carbonyl and PAH emissions in an automotive diesel engine fueled with butanol and renewable diesel fuel blends - ScienceDirect](#)
 - [Renewable Diesel Multimedia Evaluation \(California Environmental Protection Agency\)](#)
- Biomethane/RNG
 - [Chemical and Toxicological Properties of Emissions from a Light-Duty Compressed Natural Gas Vehicle Fueled with Renewable Natural Gas | Environmental Science & Technology](#)
 - [Ultrafine Particle Emissions from Natural Gas, Biogas, and Biomethane Combustion | Environmental Science & Technology](#)
 - [Assessment of the Environmental Impact of Using Methane Fuels to Supply Internal Combustion Engines](#)
 - [Environmental impact assessment of the production of biomethane from landfill biogas and its use as vehicle fuel - ScienceDirect](#)
- Hydrogen
 - [Optimising air quality co-benefits in a hydrogen economy: a case for hydrogen-specific standards for NO_x emissions - Environmental Science: Atmospheres \(RSC Publishing\)](#)
 - [Analysis of NO_x Formation in a Hydrogen-Fueled Gas Turbine Engine | J. Eng. Gas Turbines Power | ASME Digital Collection](#)
 - [Investigations on performance and emission characteristics of an industrial low swirl burner while burning natural gas, methane, hydrogen-enriched natural gas and hydrogen as fuels - ScienceDirect](#)
 - [Impact of Hydrogen/Natural Gas Blends on Partially Premixed Combustion Equipment: NO_x Emission and Operational Performance](#)
 - [The Impact of Hydrogen Admixture into Natural Gas on Residential and Commercial Gas Appliances](#)
 - [Combustion performance of low-NO_x and conventional storage water heaters operated on hydrogen enriched natural gas - ScienceDirect](#)
 - [Ultra-low NO_x emissions from catalytic hydrogen combustion - ScienceDirect](#)

¹ [Evidence-based public health: a fundamental concept for public health practice - PubMed](#)

² [Can science help people make decisions? | National Academies](#)

³ [How to Evaluate Trustworthiness in Science | National Institutes of Health \(NIH\)](#)

⁴ [Sources of Evidence - Evidence-Based Public Health - Research Guides at University of Alabama - Birmingham \(uab.edu\)](#)

⁵ [Biodiesel fuels: A greener diesel? A review from a health perspective - ScienceDirect](#)

⁶ [Effect of biodiesel on engine performances and emissions - ScienceDirect](#)

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- ⁷ [Biodiesel Emissions: A State-of-the-Art Review on Health and Environmental Impacts \(mdpi.com\)](#)
 - ⁸ [Environmental sustainability of biofuels: a review | Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences \(royalsocietypublishing.org\)](#)
 - ⁹ [Breathing easier? The known impacts of biodiesel on air quality. - Abstract - Europe PMC](#)
 - ¹⁰ [Health impacts of liquid biofuel production and use: A review - ScienceDirect](#)
 - ¹¹ [Biodiesel Multimedia Evaluation \(California Environmental Protection Agency\)](#)
 - ¹² [Study of combustion process of biodiesel/gasoil mixture in a domestic heating boiler of 26.7 kW - ScienceDirect](#)
 - ¹³ [Performance and emissions of biodiesel in a boiler for residential heating - ScienceDirect](#)
 - ¹⁴ [Emissions and energy/exergy efficiency in an industrial boiler with biodiesel and other fuels - ScienceDirect](#)
 - ¹⁵ [Desulfurization of biodiesel produced from waste fats, oils and grease using \$\beta\$ -cyclodextrin - ScienceDirect](#)
 - ¹⁶ [Impacts of biodiesel combustion on NO_x emissions and their reduction approaches - ScienceDirect](#)
 - ¹⁷ [Review of the effects of biodiesel on NO_x emissions - ScienceDirect](#)
 - ¹⁸ [Re-assessing the toxicity of particles from biodiesel combustion: A quantitative analysis of in vitro studies - ScienceDirect](#)
 - ¹⁹ [A paler shade of green? The toxicology of biodiesel emissions: Recent findings from studies with this alternative fuel - ScienceDirect](#)
 - ²⁰ [Technological, technical, economic, environmental, social, human health risk, toxicological and policy considerations of biodiesel production and use - ScienceDirect](#)
 - ²¹ [Biodiesel exhaust particle airway toxicity and the role of polycyclic aromatic hydrocarbons - ScienceDirect](#)
 - ²² [Fuel effects on PAH formation, toxicity and regulated pollutants: Detailed comparison of biodiesel blends with propanol, butanol and pentanol - ScienceDirect](#)
 - ²³ [Effect of Low-Carbon Fuels and Energy Technologies on Co-Pollutant Emissions \(Abt Associates literature review\)](#)
 - ²⁴ [Comprehensive review of combustion, performance and emissions characteristics of a compression ignition engine fueled with hydroprocessed renewable diesel - ScienceDirect](#)
 - ²⁵ [Low Emission Diesel \(LED\) Study: Biodiesel and Renewable Diesel Emissions in Legacy and New Technology Diesel Engines - Final Report](#)
 - ²⁶ [Assessment of carbonyl and PAH emissions in an automotive diesel engine fueled with butanol and renewable diesel fuel blends - ScienceDirect](#)
 - ²⁷ [Assessment of the Environmental Impact of Using Methane Fuels to Supply Internal Combustion Engines](#)
 - ²⁸ [Chemical and Toxicological Properties of Emissions from a Light-Duty Compressed Natural Gas Vehicle Fueled with Renewable Natural Gas | Environmental Science & Technology](#)
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 - ³⁰ [Environmental impact assessment of the production of biomethane from landfill biogas and its use as vehicle fuel - ScienceDirect](#)
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 - ³² [Gas and Propane Combustion from Stoves Emits Benzene and Increases Indoor Air Pollution | Environmental Science & Technology](#)
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