Biodiesel – the hidden dangers

Drs Naomi Fukagawa and Britt Holmén are collaborating to investigate the particulate matter generated by biodiesel combustion and its human health impacts. In this shared interview, they describe their different roles within the project, and a surprising link found with inflammation.

From what concerns did your research into the impacts of biodiesel fuel emerge? What are your primary objectives?

BH: My focus area is environmental engineering, especially emissions from the transportation and agriculture sectors, with an emphasis on airborne particles. US energy security legislation and high gasoline prices in the mid-2000s led to much discussion surrounding fuels, and I became interested in the use of alternative sources to reduce our dependency on imported petroleum.

NF: My research interests relate to nutrition and metabolism across the age span. Because of the known health effects of environmental factors, ranging from chemicals to food and air quality, I sought to better understand the impact of emissions from combustion of bio-based alternative fuels on health.

Much research has been conducted in silos with little discourse between scientific disciplines. Those of us in healthcare focus on the diagnosis and treatment of disease often as a reaction to factors that were previously not recognised as being causal. With the mandate to increase use of renewable fuels and reduce dependency on foreign petroleum, it is important to determine whether there are differences in the health effects of biodiesel combustion products compared to those of petrodiesel.

How does biodiesel differ from conventional petrodiesel fuels?

BH: Biodiesel is a renewable fuel derived from animal fats and vegetable oils. These oils are subjected to a variety of chemical reactions to produce a mixture of fatty acid methyl esters (FAMEs). Petrodiesel, on the other hand, is a far more complex mixture of alkanes, alkenes and aromatic compounds. Biodiesel has no sulphur whereas petroleum has significant amounts that need to be removed in order to meet 2006 regulations for ‘clean diesel’ highway fuel.

A US Environmental Protection Agency (EPA) literature review published in 2002 states that biodiesel emissions of all criteria pollutants, except NOx, are lower when operating on biodiesel blended with petrodiesel. However, that report was mostly based on older engines; petroleum fuel with much higher sulphur content was in use at the time as the comparison base fuel, and many of the studies were on heavy-duty engines and vehicles, not light-duty cars and trucks. Our team is focused on newer engines, light-duty vehicles, using real-world transient drive cycles and collecting data on particle number, air toxics and greenhouse gas emissions.

These unregulated groups of compounds can have important effects on human health, but are understudied.

NF: Differences in fuels will likely lead to differences in the generated emissions. There is little information about exactly which components induce health effects, which is what we are trying to elucidate.

What discoveries have you made to date regarding the effects of petrodiesel and biodiesel emissions on human health and the environment?

BH: We found that biodiesel particulate matter has a higher oxygen content. In other words, the particles are more oxidised than their petrodiesel counterparts. The lack of studies reporting the comprehensive chemical composition of biodiesel exhaust particles – and the complex chemistry of these particles – led us to develop methods to characterise the particles, but we still have a long way to go in order to link specific chemical components to health effects.

NF: We were surprised to find that particles generated from biodiesel combustion induced more inflammation in cells and in an animal model. The underlying mechanism appears to be related to the induction of oxidative stress.

Can you explain your finding that inflammatory response and oxidative stress are greater in cells and animals treated with soy-based biodiesel fuel, as a result of its large polar component?

BH: We surmise that the higher polarity of biodiesel particles may explain the increase in inflammation and production of reactive oxygen species, but we cannot identify specific markers that quantitatively explain biological responses. To do that, we would need to test many more biodiesel fuel blends and employ multiple methods for particle characterisation. We are currently developing a screening method to identify exhaust samples that may be most important for the costly health effects studies in Naomi’s lab.

Keeping up with the community

The team presented their research results at the American Association for Aerosol Research (AAAR) meeting in Orlando in late October 2014. They will also be attending an Experimental Biology meeting in March 2015.
Assessing alternative fuels

Vehicles that run on biodiesel emit fewer hydrocarbons, but the health effects of their emissions are largely unknown. Researchers from the University of Vermont in the US are studying the potential health consequences, and have made some surprising findings.

In the US in particular, dependence on imported petroleum is a significant problem and the pressure to turn to alternative fuels is rising. Indeed, since 2005 US energy policy has mandated increases in the volume of renewable fuels used for transportation. A particularly promising alternative is biodiesel, a vegetable oil or animal fat based fuel similar to conventional diesel. One of the major benefits of biodiesel is that it is carbon neutral, in other words, it produces no net carbon dioxide.

Beyond its environmental benefits, the industry claims the fuel is renewable, biodegradable and nontoxic to humans, because – unlike petroleum diesel – it is effectively devoid of sulphur and aromatics. However, very little is known about its impact on human health, and Dr Naomi Fukagawa, Professor at the University of Vermont, remains unconvinced of its nontoxicity. She is therefore conducting research to better understand the biological impact of biodiesel combustion alongside Dr Britt Holmén, Professor in the School of Engineering.

The disease connection

There is a strong correlation between air pollution and the development of disease. Tiny particles in the air (particulate matter) and nitrogen oxides, both produced by diesel engine emissions, can cause respiratory illness. Over 25 years of research has linked emissions from petrodiesel to asthma, chronic bronchitis and cardiopulmonary diseases. More strikingly, a recent report by the WHO International Agency for Research on Cancer states that air pollution is linked to cancer.

Despite these alarming connections, scientists have little understanding of how the particles emitted through fuel combustion actually damage human health. The body’s cellular and molecular responses to petrodiesel remain a mystery, and the situation is no better for biodiesel. Although the combustion of alternative fuels is associated with fewer emissions, the health effects of biodiesel fumes are poorly understood. As Fukagawa explains, this is vital public health information: “If biodiesel creates health problems, we should know sooner rather than later so preventive measures can be taken”.

To fill in the gaps, Fukagawa received a Challenge Grant of almost US $1 million from the National Institutes of Health (NIH). In partnership with Holmén, they are studying both the chemical composition and health effects of biodiesel combustion products. “Together with Britt’s objective of understanding the chemical composition of exhaust particles, my objective is to determine the biological effects of particles from biodiesel combustion,” she elaborates.

Removing variability

Part of the debate surrounding the health effects of biodiesel comes from the many different methods of exhaust generation used in various studies, and the biological models utilised to assess their effects. The team tackled both, analysing the exhaust emissions produced using petrodiesel (B0) and a biodiesel blend of 20 per cent soybean biodiesel and 80 per cent petrodiesel (B20) – the most common commercial biodiesel blend – using the same engine and running conditions. While cells are important to understand precise pathological mechanisms, they do not reflect the interconnected changes taking place within an entire animal. For this reason, the team conducted experiments in both human cell lines and mouse models.

Characterisation of the exhaust particles revealed that the petrodiesel generated double the particulate matter by mass as the biodiesel blend, but the overall surface area of the B20-generated particles was twice as high. The chemical composition also differed between the two exhausts, with B20 containing more polar compounds and short-chain fatty acid methyl esters (FAMES) – known lung irritants.

Following this chemical characterisation, a range of biological assays were applied, assessing levels of inflammatory mediators and markers of oxidative stress. Surprisingly, levels of inflammatory mediators were 20-30 per cent higher in cells exposed to the biodiesel blend compared to those treated with petrodiesel. This was an important finding, as inflammation is involved in the pathogenesis of a number of disorders, including cardiovascular and respiratory diseases.

Protective policy

In order to elucidate the broader effects of these cellular changes, the team administered a suspension of the particles into the lungs of mice.
They found concentrations of inflammatory proteins to be two to three times higher in the lung tissue of B20-exposed mice than animals exposed to petrodiesel particles.

Worryingly, this suggests that while adding biodiesel to diesel fuels may reduce particulate matter emissions, it may also increase adverse health outcomes. Although it is as yet unclear, the researchers believe the inflammatory response generated by B20 may be due to the combination of the particles' large surface area, polar chemical composition and the presence of FAMEs. Holmén surmises that this information could ultimately influence US energy policy: “We hope to identify the renewable biodiesel fuel feedstock and blend ratio that results in the least harmful emissions. This information could be conveyed to policy makers and adopted by the Environmental Protection Agency in the renewable fuels standard,” she comments.

The boom in biodiesel

Biodiesel is a renewable, clean-burning replacement for diesel, reducing dependence on petroleum and benefiting the environment.

It is created from vegetable oil, animal fats, tallow and waste cooking oil, but the largest source in the US is soybean.

Biodiesel is the first Environmental Protection Agency-designated advanced biofuel in commercial-scale production across the US. In the past 10 years, the annual production of fuel derived from vegetable oils or animal fats has increased from 25 million to over 1.1 billion gallons.

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RATIONAL DESIGN

The study, published in *Environmental Science and Technology* last year, suggests that B20 particles may in fact have more significant biological effects per mass than B0, leading to significant risk for human health. This work sheds new light on the health risks of biodiesel combustion products, and while there is a long road ahead, Fukagawa anticipates the study will pave the way to comprehensive investigations of the relationship between fuel-derived particles and chronic disease. In turn, this understanding may even help reduce the adverse health consequences of air pollution, by designing safer fuels, or new engines or filters able to remove harmful components.

The study also highlighted the need to characterise exhaust particles from biodiesel combustion under a range of engine operating conditions. To realise this, the team is currently conducting tests with more fuel blends, in collaboration with the University of Vermont Transportation Research Center. “It is essential we know the environmental and health trade-offs of transitioning to alternative fuels, and we need reliable quantitative data in order to set policy that protects human health,” Holmén concludes.

EXAMINING THE HEALTH EFFECTS OF BIODIESEL FUEL

OBJECTIVES

- To elucidate the potential adverse health effects of and the responsible mechanisms for the responses to airborne particle exposure from engine combustion
- To optimise engine design or performance, fuel blends and combustion catalysts to reduce negative impacts on the environment and on health
- To increase awareness that food and fuel are intimately related to global health

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CONTACT

Dr Naomi Fukagawa
University of Vermont College of Medicine
Colchester Research Facility, Room 173
360 South Park Drive
Colchester
Vermont 05445
USA
T +1 802 656 4403
E nfukagaw@uvm.edu
www.uvm.edu/medicine

Dr Britt Holmén
School of Engineering
T +1 802 656 8323
E bholmen@uvm.edu
www.uvm.edu/~cems

NAOMI K FUKAGAWA is Professor of Medicine at the University of Vermont, USA. She received her MD degree from Northwestern University, Illinois, and her PhD in Nutritional Biochemistry from the Massachusetts Institute of Technology in Massachusetts, USA. Her transdisciplinary research spans the bench to the bedside and focuses on nutrition and environmental factors that impact chronic diseases.

BRITT A HOLMÉN is Professor at the University of Vermont’s School of Engineering and Director of the Transportation Air Quality Laboratory. She received her Master’s degree in Oceanography from the University of Washington, USA, and her PhD in Civil and Environmental Engineering from the Massachusetts Institute of Technology. Holmén’s postdoctoral research was carried out at the University of California, Davis, USA. Her research at the University of Vermont focuses on airborne particles.