Alternative fuels reduce harmful emissions during combustion

- Harmful emissions from combustion engines are an ongoing problem associated with fossil fuels.
- Alternative fuels from renewable sources such as biomass can be part of the solution.
- Dr Ruoyang Yuan and Dr Abdallah Abu Saleh at the University of Sheffield, UK, have been assessing emissions by alternative fuels.
- The team measured the production of oxides and soot from dimethyl ether and isopentanol, with promising results.

Transportation is a key part of our life, either directly (travelling for various purposes) or indirectly (buying products transported from elsewhere). Fossil fuels are still the most widely applied fuel for transportation purposes, given that the vast majority of engines are traditional combustion engines. The harmful emissions from these engines are well researched, and their direct or indirect contributions to climate change are well documented.

Besides greenhouse gas (GHG) emissions, particulate matter emitted from combustion engines can also have harmful effects on our health. Soot and gas emissions are associated with lung diseases, asthma, cancer, and infant morbidity. According to the UK's Department for Environment, Food & Rural Affairs, the biggest environmental danger to public health is poor air quality. This has intensified the need for alternative, renewable fuels that can be used for transportation purposes. In August 2022, the UK government approved a £37 million grant to support research in this area.

The quest for alternative fuels

Bioethanol (produced by fermentation of starchy corps like soybeans, corn, or other biomass) and biodiesel (produced by vegetable oils or cooking oils) are currently available on the fuel market in blends. Other alternatives to gasoline and diesel can be derived from fossil fuels themselves. This can be achieved from petroleum fractions previously unexploited for this purpose or via processes that have shown potential to generate products suitable for fuel use in combustion engines. Alternative fuels produced by fossil fuel streams are liquefied petroleum gas, naphtha, and dimethyl ether. Finally, alternative fuels can also be produced through electrolysis (use of electricity to break down chemicals). The electrolysis of water, for example, results in hydrogen, which is an emerging fuel with high potential.

An important point of discussion and research is the need to characterise these alternative fuels and identify their suitability in traditional combustion engines. Furthermore, it is imperative to assess the effect of such fuels on the environment and public health, and compare it to traditional fuels. Towards these goals, Dr Ruoyang Yuan and Dr Abdallah Abu Saleh at the University of Sheffield in the UK have been trying to understand the potential of alternative fuels and their suitability as replacements for fossil fuels.

Alternative fuel candidates

When deciding on suitable or promising alternative fuels, a crucial factor is the performance of the fuel during combustion and how close it is to the 'golden standard' set by traditional fuels. The performance is dictated by the energy produced per gallon of fuel, which in turn is affected by the composition of the fuel. Yuan and Abu Saleh have been researching three specific alternative fuels, dimethyl ether, ethanol, and isopentanol, to assess their harmful emissions and soot production compared to that of diesel for compression ignition engines, gasoline for spark ignition engines, and kerosene in a modelled aero-engine combustor. This article will discuss the potential of dimethyl ether and isopentanol.

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Dimethyl ether is an organic compound that can be produced directly from fossil fuels but also from renewable sources such as biomass. One of its main advantages compared to other alternative fuels is its relatively high cetane number, which indicates its ability to ignite – a property important for

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combustion, plus it can be produced at scale. Isopentanol also has a higher cetane number compared to other alternative fuels and is considered a second-generation biofuel in the sense that the crops used for its production, such as grasses, municipal waste, and other biomass rich in cellulose, are not suitable for human consumption. There have also been indications of lower risk for cancer generation from combustion emissions of current fuels blended with isopentanol.

Measuring harmful emissions

Yuan and Abu Saleh aimed to optimise the set-up of existing methods to assess the harmful emissions of dimethyl ether and isopentanol in pure form or when blended with other fuels. They focused on the emission of nitric oxides, harmful acidic emissions that can lead to acid rain, and soot. For the measurement of soot production, the chosen methods were two-colour laser-induced incandescence (LII) and planar two-colour soot pyrometry, whereas for nitric oxide emissions, planar laser-induced fluorescence was used.

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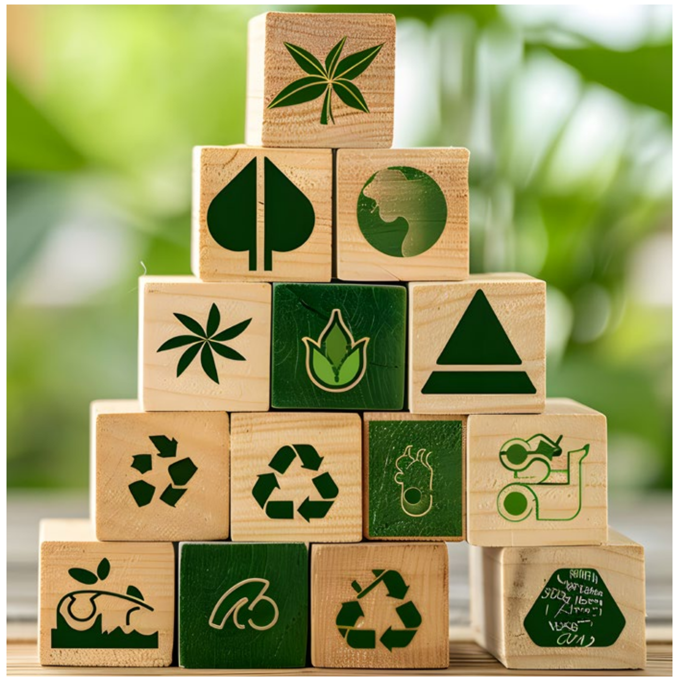


During LII, a laser beam hits the combustion gas that contains soot and the soot particles are heated to the temperature at which carbon evaporates. Upon evaporation, soot emits electromagnetic radiation (incandescence) which is picked up by a suitable camera. Through complex mathematics, incandescence can be translated to soot particle density and size. During soot pyrometry, the aim is to identify the temperature of emitted soot particles, which is done via quantification of the light emitted by the particles against certain wavelengths. This light is then 'translated' to temperature. In the case of planar laser-induced fluorescence, the flame was hit by an energy source (laser) to excite nitric oxides, and images were captured by a suitable camera, which were then processed and analysed to derive the intensity of nitric oxide emissions.

Yuan and Abu Saleh's work applying these techniques on different fuel emissions showed potential for the more robust characterisation of the emissions, either gaseous or black carbon. This is in line with the newly introduced requirements for emission certification testing. Their results could be used towards the improvement of calibration protocols, in combination with additional emission characterisation methods.

Are dimethyl ether and isopentanol better than fossil fuels?

Are alternative fuels better than fossil fuels? This depends entirely on which aspect we focus on. In terms of renewability, dimethyl ether and isopentanol are better options than fossil fuels, but the question of economic feasibility for production at scale remains. In terms of combustion performance, the answer depends on the conditions used, the optimisation of the combustion process, and the blend ratio with other fuels. Currently, alternative fuels show potential with performances close to fossil fuels, but there is hope that the performance will increase if engines are optimised towards the use of alternative fuel.

Yuan and Abu Saleh's work showed that using alternative fuels could lead to reduced emissions. Blending n-heptane (one of gasoline's main components) with isopentanol can lead to reduced emissions and reduced soot production. Mixing dimethyl ether with other fuels showed reduced emissions at higher blend ratios. Overall, there is certainly potential in the development and use of alternative fuels. However, more research is necessary towards the optimisation of blends, but also towards the optimisation of methods able to provide exact information on the harmful emissions.

Personal response

What inspired you to conduct this research?

My research focus on the combustion and emissions characteristics of biofuels is driven by multiple motivations. One key motivation is environmental concerns; the continued increase in pollutant and greenhouse gas levels produced from burning fossil fuels contributes largely to air quality degradation. My current research aims to help, even if just a little bit, in finding better alternatives that can potentially be used in the near future to reduce harmful emissions and mitigate environmental damage. Another key motivation is the existence of advanced combustion technologies available today, providing the opportunity to improve and optimise combustion processes for better efficiency and lower emissions. These two inspirations together drive my commitment to contribute towards the fundamental understanding of low-carbon biofuel combustion and emissions characteristics, aiming to contribute to creating a sustainable energy future.

How should the combustion engines change to support higher fuel efficiency for dimethyl ether and isopentanol?

There are multiple considerations that need to be taken into account when modifying combustion engines to support higher fuel efficiency for dimethyl ether and isopentanol. Some of these include injection timing, control system, and fuel system adaptation. More general considerations for both fuels include engine materials and the fuel injection system. For both dimethyl ether and isopentanol, we need to ensure that materials used in the engine are compatible with the fuel to avoid degradation. Additionally, the fuel injection system needs to be modified to prevent wear and ensure precise fuel delivery. For example, specialised injectors may be required to handle the different properties of these fuels.

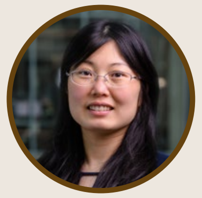
Besides isopentanol and dimethyl ether, are there other promising alternative fuels?

There are a number of other promising alternative fuels, most of which require further investigation. For aviation, we are looking at sustainable aviation fuels (SAF) produced from bio and non-bio feedstock, including both drop-in SAF, and non drop-in low/zero carbon fuels, such as ammonia. For marine applications, bio-methanol and ammonia are also good candidates. For domestic applications, bio-methane or hydrogen upgraded biogas are other alternatives besides dimethyl ether.

Do you think one day transportation can be fully dependant on alternative fuels?

Technically, transportation can fully depend on alternative fuels, including e-fuels. However, it may not be the most sustainable and viable solution. A combined approach, including electric vehicles (pure, hybrid, or plug-in), might be optimal.

Details



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w: www.supergen-bioenergy.net/research/rdme-for-off-grid-energy

Funding

The researchers acknowledge funding from EPSRC David Clarke Fellowship Grant (EP/S017259/2) for their fundamental study of biofuel combustion and emission. In addition, they acknowledge the funding from UKRI, through the Supergen Bioenergy Impact Hub (EP/Y016300/1), for the work on rDME production and utilisation for the off-grid energy project.

Bio

Dr Ruoyang Yuan is a senior lecturer in Fuels and Combustion in the Department of Mechanical Engineering and a member of the Energy Institute at the University of Sheffield. She was a David Clarke EPSRC Fellow. She received a Bachelor of Science in Power Engineering and Engineering Thermo-physics, and a Master of Science in Fluid Machinery and Engineering from Tsinghua University, China. She obtained her PhD from the University of Cambridge in 2015.

Dr Abdallah Abu Saleh is a research associate at the University of Sheffield. He graduated with BEng (Hons) in Mechanical Engineering from the University of Sussex in 2018. In 2019, he was awarded his MSc in Mechanical Engineering by University College London (UCL). He obtained his PhD from the University of Sheffield in 2023.

Further reading

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