Environmental side effects of using ammonia to power global shipping

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Why shipping?

What are you reading this article on? I am assuming your laptop or tablet or maybe a printed version. There is a very high chance that most parts of the device you are using to read this article came from different parts of the world, mainly on large container ships. These large, container, commercial ships carry out about 85% of the world's trade in terms of volume. There are about 100,000 of these large ships, moving continuously day and night through almost all the major global water bodies, to make sure that the plastic bags from Xiamen in China reach a clothing company in Milwaukee, USA on time; or manufactured cell phones in Chennai, India reach Istanbul, Turkey on time via the Suez Canal. But have you ever wondered what fuels these ships and what impact they have on the environment and climate?

The evil of shipping fuel

Most ships currently use heavy fuel oil (the last of the last products from oil refining) which contains a lot of sulfur and other nasty chemicals. So, when these ships burn these fuels in engines like (but much larger than) your car, they emit a lot of smoke and polluting gas. Many scientific studies estimate that the smoke and polluting gas produced by international cargo ships cause a lot of air pollution near ports, and contribute to public health issues, such as asthma and lung irritation. The smoke from these big ships is thus harmful to most human and wildlife populations but is an evil necessity since most global trade happens via ships. On top of the smoke and polluting gas, the burning of heavy fuel oil in ships also emits a large amount of carbon dioxide, a gas that efficiently traps heat and warms the Earth's atmosphere. It is this gas that is responsible for global warming and climate change. These ships are responsible for about 2% of the total carbon dioxide that humans emit in one year. So, the use of heavy fuel oil in ships has a two-fold problem: it causes air pollution near ports, and it emits global-warming gas.

New fuel as a solution?

To avoid these emissions, many shipping companies are trying out a new fuel: ammonia. I will get to the question of why ammonia is being used in place of heavy fuel oil in a bit, but first, it is important to know a few things about this fuel. Ammonia is a colorless gas that has been historically used to make nitrogen-based fertilizers for farming. Ammonia is made by fusing nitrogen and hydrogen atoms using heat and pressure. The production of ammonia is also an energy-intensive task that requires burning fossil fuels such as coal and natural gas. Energy companies estimate that global ammonia production also contributes to about 2% of the total man-made carbon dioxide emissions in a year. Now let's talk about why shipping companies want to move from using heavy fuel oil to ammonia as a fuel. For one, burning ammonia in engines does not emit harmful air pollutants, such as smoke, and it does not emit carbon dioxide, the climate warming agent. Second, existing shipping engines can be modified easily to use ammonia in place of heavy fuel oil. So, it is a win-win for everyone, right? Shipping companies can easily use a different fuel and the common public gets to enjoy the air pollution and climate change benefits.

Complications with the new fuel

Unfortunately, it is not as straightforward as it appears. Ammonia is a difficult gas to produce and store. It is notoriously leaky and likes to leak out into the atmosphere from any tiny crack it finds. Moreover, ammonia as a gas likes to fuse with sulfur and nitrogen products in the atmosphere to make tiny liquid particles, called aerosols. This phenomenon is called secondary aerosol formation.

To understand secondary aerosol formation, we need to know what aerosols are and what makes them primary or secondary. Aerosols are tiny solid or liquid particles suspended in the air around us, meaning they are in the air we breathe. They are everywhere around us and come from a vast number of sources: from roadside dust to your local power plant that burns coal, and from the tailpipe of your car to, you guessed it, the stacks in the fossil-fuel-burning ships. If a tailpipe or a power plant stack directly emits particles in the air, those particles are called primary particles, or primary aerosols. However, some particles are not emitted directly but are formed in the atmosphere by chemical reactions between different air pollutants. For example, ammonia and sulfur pollutants like to fuse to form ammonium sulfate aerosols. After their formation, these secondary aerosols act just like the primary ones: they all cause eye, throat, and lung irritation.

My research

In the research I did at the La Follette School of Public Affairs, I asked the natural questions on this topic: how much ammonia is required if we were to replace all heavy fuel oil with it? How much will leak into the air? And what will happen to local air quality and public health if the leaked ammonia fuses with sulfur pollutants and makes secondary aerosols??

Answering difficult questions

To answer these questions, I used some mathematical tools and a lot of literature review. First of all, how much ammonia will be required to replace all heavy fuel oil? Well, ammonia contains half the energy as heavy fuel oil when compared ounce to ounce. So, naturally, the world will require two ounces (or liters, for my metric readers) of ammonia for every one ounce of heavy fuel oil the ships use right now. This value comes out to be around 450 million tons!! To compare, this value of 450 million tons of ammonia is about 250% of the current global ammonia production of 180 million tons (all for fertilizers). I don’t know how and where that will happen. But let’s assume that it is possible.

One significant port

Singapore. Singapore is a tiny nation in Southeast Asia with a population of 5.5 million people. Even though it is a tiny nation, its geographical location, and the tax benefits it provides to ships, mean that about 20% of the global heavy fuel oil is sold from here. Imagine that the corner gas station in your town sells about 20% of your city's total daily gas supply. Isn't it mind-boggling and incredible at the same time? You probably don't want to imagine the long line you will encounter at that gas station though.

I brought up Singapore because in this research I narrowed my focus to investigate the impact selling ammonia in those quantities would have on the country. Think of it this way, if your giant corner gas station started selling ammonia beginning tomorrow, how would it affect the air you breathe? In other words, how might selling ammonia at its port affect the air that Singapore's citizens breathe? Will it be more polluted than in the current case in which it sells heavy fuel oil? Why?

So now I have a specific question to answer: How much air pollution does heavy fuel oil combustion create in Singapore's port area, and how much air pollution does ammonia combustion create?

To answer the first part, I used mathematical models that estimate how and where the smoke will travel after being emitted from the ships. Not all smoke will end up in Singapore. Some will end up in Indonesia, some in Malaysia, and so on. These mathematical models take in the location and amount of smoke emissions and estimate the location where they will end up. Hence it is crucial to know the *where* and *how much* components. I took those estimates from a published study by the International Institute for Applied Systems Analysis, Austria. Then, I fed those emission estimates of smoke from heavy fuel oil into this mathematical model. I found out that the current heavy fuel oil combustion in ships contributes to about 10% of Singapore's smoke air pollution. This 10% of smoke air pollution in turn leads to about 80 people (on average) being severely hospitalized every year.

Figure 1. Showing the Port of Rotterdam with fuel storage tanks (in case of a future ammonia-fueled shipping, these tanks will store ammonia). https://www.portofrotterdam.com/en/news-and-press-releases/study-ammonia-cracker-realistic-and-safe-method-for-large-scale-hydrogen

As you may recall that in contrast to heavy fuel oil, ammonia combustion itself does not emit smoke or carbon dioxide, but it is the uncombusted, raw ammonia itself that fuses with other air pollutants (such as sulfur) to make secondary aerosols. In the case of ammonia, raw ammonia is emitted at ports from two major sources: the leaks from the storage tanks and the leaks during the fueling process. I obtained the leak rates from both these sources from an extensive scientific literature review and found that only 0.052% of the total ammonia stored in the tanks will ever leak. So, it is a small amount, right? Yes and no. For any other tiny port, it is a small amount, but Singapore supplies about 20% of global shipping fuel requirements, so even a small leak rate multiplied by a large volume will lead to a large amount of ammonia leaking into the atmosphere.

Using the mathematical models, I estimated that the additional ammonia emissions from leaks from the storage tanks and during the fueling process are about 2-5 times higher than all of

Singapore's other ammonia emissions, combined. These additional ammonia emissions then fuse with atmospheric sulfur to create secondary aerosols comparable to 10-50% of Singapore's air pollution. I also estimated that this additional pollution due to ammonia leaks from storage and fueling can cause about 65-460 people to be severely hospitalized from lung and throat issues every year.

In sum, heavy fuel oil combustion in ships accounts for approximately 10% of Singapore's air pollution, resulting in the hospitalization of approximately 80 individuals annually due to severe lung and throat issues.

In the future, the emergence of ammonia as a potential heavy fuel oil substitute could escalate Singapore's air pollution levels to 10-50% above the current levels, potentially leading to an annual surge in hospitalizations ranging from 65 to 460 people, severely affected by respiratory ailments.

Public significance

You and I want a greener and cooler planet than what we have right now. Ships contribute a lot to both issues: they cause local air pollution, and they also emit climate-warming carbon dioxide. To solve a huge part of this, shipping companies are considering a switch to ammonia as fuel, which theoretically can solve both these problems: its combustion does not lead to air pollution or carbon dioxide emissions. However, the solution may not be as clean as we think. Ammonia storage and fueling leads to a lot of leaks, and the air pollution caused by ammonia's fusion with atmospheric sulfur could be even worse than that caused by burning heavy fuel oil, at least in port areas.

I also performed some analysis on what happens if we curb some of these ammonia emissions. I found that if we can curb or abate over 50% of ammonia emissions, then ammonia isn't as bad as heavy fuel oil, and still provides a lot of climate benefits by avoiding carbon dioxide emissions. This work forms a small part of the larger discussion on just transition everywhere: what happens to certain communities and areas when the whole world wants to move from one energy source to another? Do they lose their jobs? Do they experience poverty? Do they experience more environmental impacts since now they are at the center of a new energy source? Looking ahead, stakeholders such as policymakers, energy companies, and local communities must collaborate to thoroughly explore the intricate ramifications for local communities as the world undergoes transitions between energy sources.