**Brains On (APM) | Brains On! The future of fuel (and the problem with exhaust)**
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MOLLY BLOOM: Big questions help us explore our world and connect with each other in new ways. Now's your chance to come together with other *BrainsOn* listeners to support the show you love. Make a gift by June 30th to help us reach $5,000 in listener donations, and you'll unlock a $5,000 challenge from our generous board of directors. Contribute at brainson.org/donate.

**DAKARI:** You're listening to *Brains On,* where we're serious about being curious.

[CAR ZOOMS]

(SINGING) Back seat near and far. It's a Brains On road trip--

[HONKS]

--in the car.

**MOLLY BLOOM:** I spy something green and white.

**GABRIELA HOPPER:** Is it a road sign?

**MOLLY BLOOM:** Yeah. How about this? I spy something green and tall.

**GABRIELA HOPPER:** Is it a tree? Again?

**MOLLY BLOOM:** Yeah. We've been driving so long, I guess we're running out of new things to spy.

**GABRIELA HOPPER:** Wait, I got one. I spy something noisy and fun.

**MOLLY BLOOM:** Noisy and fun? Is it that car ahead? No, that's just noisy. Is it that funny billboard? No, that billboard's really not that funny.

**GABRIELA HOPPER:** Give up?

**MOLLY BLOOM:** Yeah. What is it?

**GABRIELA HOPPER:** The start of the episode. Woo! Brains On Road Trip Part Two.

**MOLLY BLOOM:** That is just what we need it. Let's turn it up.

[MUSIC PLAYING]

You're listening to *Brains On* from American Public Media. I'm Molly Bloom, and here again with me is Gabriela Hopper from Lorton, Virginia. She is my co-pilot for our road trip through the science of cars.

**GABRIELA HOPPER:** Hi, Molly.

**MOLLY BLOOM:** In the first episode, we looked at how engines work.

**GABRIELA HOPPER:** If you haven't heard it yet, the magic word is explosions.

**MOLLY BLOOM:** And we covered how cars were invented in the first place.

**GABRIELA HOPPER:** Today, we're zooming ahead in time-- to the future. The future of fuel.

**MOLLY BLOOM:** But to get to the future, we need to start with the present. And this question from Caitlin.

**CAITLIN:** My name is Caitlin from Sechelt, BC. And I was wondering, why is car exhaust so bad for the planet?

**GABRIELA HOPPER:** Great question.

**MOLLY BLOOM:** In our last episode, we explained how gas powers cars.

**GABRIELA HOPPER:** Internal combustion engines create a reaction between gas and the air. That's the explosion.

[BOOMS]

**MOLLY BLOOM:** One of the byproducts of this reaction is energy, which powers the car.

**GABRIELA HOPPER:** But there are less pleasant substances that are also created during this reaction.

**MOLLY BLOOM:** Like hydrocarbons, nitrogen oxides, and carbon monoxide. These substances are harmful to the environment.

**GABRIELA HOPPER:** However, there's a part in cars designed to reduce these three substances.

**MOLLY BLOOM:** It's called the catalytic converter.

**GABRIELA HOPPER:** It takes these harmful pollutants and transforms them into less harmful emissions.

**MOLLY BLOOM:** But even if your engine is working perfectly efficient and the catalytic converter was doing a perfect job, the basic combustion reaction creates a byproduct that cannot be avoided.

**GABRIELA HOPPER:** Carbon dioxide, also known as $CO_2$.

**MOLLY BLOOM:** It's a colorless gas with no smell. It's made from carbon and oxygen. In this case, di means "two," so that's one atom of carbon bonded with two atoms of oxygen. And carbon dioxide by itself is not a bad thing.

**GABRIELA HOPPER:** We make carbon dioxide all the time when we breathe.

[EXHALES]

[POPS]

**CO2:** Hey, guys.

**GABRIELA HOPPER:** Hey there, CO2. 'Sup?

**CO2:** Just floating through life.

**MOLLY BLOOM:** We exhale this stuff. But plants take it in and use it during photosynthesis. That process, in turn, makes oxygen for us to breathe.

**CO2:** Ooh, a fern. I'm going to hop in there. See you guys later.

[POPS]

**GABRIELA HOPPER:** Thanks, CO2. See you around.

**MOLLY BLOOM:** This is all part of something called the carbon cycle. Animals, including humans, exchange carbon dioxide with plants. The atmosphere exchanges carbon dioxide with the ocean. Carbon really gets around. It's natural.

**GABRIELA HOPPER:** When carbon dioxide makes its way to the atmosphere, it takes a while for it to leave.

**CO2:** Hey, we like it up here.

**CO2:** Great views.

**CO2:** Sky's the limit.

**CO2:** Good one, CO2.

**GABRIELA HOPPER:** And get this. Carbon dioxide in the atmosphere makes life on Earth possible.

**MOLLY BLOOM:** You see, light comes from the sun and hits the Earth. Stuff on the Earth then reflects that energy back into the air as heat.

**GABRIELA HOPPER:** Now, lots of molecules in the atmosphere like oxygen and nitrogen just let that he pass right through back out to space.

**MOLLY BLOOM:** But carbon dioxide is different. It traps that heat, acting like a kind of blanket.

**CO2:** Hey, heat, not so fast. Why don't you stay a while?

**CO2:** Yeah, join our party in the sky.

**CO2:** Let's mingle.

**CO2:** We love heat.

**GABRIELA HOPPER:** And life on Earth needs that heat to survive. Without some carbon dioxide, the planet would be an icy frozen mess. It would be like a party with too few guests.

[WIND HOWLING]

**CO2:** Hey. Anyone else hanging out here?

**CO2:** Yeah. I'm over here.

**CO2:** Oh, cool, cool. You see any heat around?

**CO2:** No, bro. Man, this party is too chill, you know?

**CO2:** You're telling me.

**GABRIELA HOPPER:** That scenario is not great for life as we know it. But too much CO2, and things would get super hot. Also not great for life. It's like a party with too many guests in the sky.

[PARTY MUSIC]

**CO2:** What's up-- oh, excuse me.

**CO2:** Ow, my toe!

**CO2:** Watch it!

**CO2:** Trying to get through.

**CO2:** Is it just me, or is it hot in here?

**CO2:** Yeah, there's a lot of heat here these days.

**CO2:** We need a bigger atmosphere.

**CO2:** Can gases sweat? Ooh, it's a scorcher today.

**MOLLY BLOOM:** For the most part, the carbon cycle on its own can keep the amount of carbon dioxide in the atmosphere in check so we don't get too cold or too hot.

**GABRIELA HOPPER:** The blanket won't get too thick and make us too hot. And it won't get too thin, freezing us out.

**MOLLY BLOOM:** But lately--

**CO2:** Hey, guys!

**MOLLY BLOOM:** --humans have started pumping more carbon dioxide into the atmosphere than the carbon cycle can handle on its own.

**CO2:** Hey, guys!

**MOLLY BLOOM:** It's not just from cars, but also power plants and factories.

**CO2:** Hey, guys!

**CO2:** Hey, guys!

**MOLLY BLOOM:** They also burn carbon based fuels and release CO2.

**CO2:** Hey, guys!

**GABRIELA HOPPER:** How do we know this extra carbon dioxide is coming from burning gas and other fossil fuels? And there's just not more people breathing.

**MOLLY BLOOM:** That's because the carbon dioxide produced by burning fuel is slightly lighter than carbon dioxide found naturally in the atmosphere.

**CO2:** Hey, carbon dioxide.

**CO2:** Hey, carbon dioxide.

**CO2:** How do you like it up here in the atmosphere?

**CO2:** Not too shabby. Party on.

**MOLLY BLOOM:** The amount of carbon dioxide produced by burning carbon based fuel has been on the rise since the 1850s thanks to the Industrial Revolution, which gave rise to factories.

**GABRIELA HOPPER:** And with the popularity of gas powered vehicles, CO2 levels continue to climb.

**MOLLY BLOOM:** Even though carbon dioxide makes up a small part of the atmosphere--

**CO2:** Who you calling small?

**CO2:** Who invited her anyway?

**CO2:** Right?

**MOLLY BLOOM:** As I was saying. Even though CO2 is only part of the atmosphere, this increase has an impact.

**GABRIELA HOPPER:** And remember how we said that plants use CO2 during photosynthesis? Well I bet you can guess which plants take in a lot of it. If you guessed trees, you're right.

**MOLLY BLOOM:** But some of our biggest trees, like in the tropical rainforests, they get chopped down or cleared for other purposes. Without those giant forests taking up the CO2, we are left with a lot more in the atmosphere.

**GABRIELA HOPPER:** It means more and more heat is getting trapped in the atmosphere. That's making average temperatures here on Earth slowly rise, leading to changes in our climate.

**MOLLY BLOOM:** But reducing the amount of carbon dioxide we put into the atmosphere would help fight this change. We're going to talk to one scientist who is working on making that possible. But first, it's time for the mystery sound.

[MYSTERY SOUND CUE]

**AUDIO TRACK:** Mystery Sound.

**MOLLY BLOOM:** Here it is.

[SCUTTLING]

That was a short one, so I think we should probably hear it again.

**GABRIELA HOPPER:** Yeah.

[SCUTTLING]

**MOLLY BLOOM:** Any guesses?

**GABRIELA HOPPER:** It sounds like somebody unlocking a door and then opening it.

**MOLLY BLOOM:** Excellent guess. We will back with the answer right after this.

**GABRIELA HOPPER:** Our next versus episode is coming up in July, and we want to know which side you're on.

**MOLLY BLOOM:** Which do you think is cooler, deep sea or outer space?

**GABRIELA HOPPER:** Send your argument to hello@brainson.org.

**MOLLY BLOOM:** It's your answers, questions, and mystery sounds that make this show possible.

**GABRIELA HOPPER:** And in order to thank all the kids who share their energy and ideas with us, we started the Brains Honor Roll.

**MOLLY BLOOM:** Listen for the most recent group to be added to this illustrious list at the end of the show.

**GABRIELA HOPPER:** And if you're looking for some more fun to keep you busy in the car, you should subscribe to our newsletter.

**MOLLY BLOOM:** If you do, we'll send you some downloadable activity sheets dreamed up by the Brains On team that will help you pass the time in style.

**GABRIELA HOPPER:** You're listening to *Brains On* from American Public Media. I'm Gabriela Hopper.

**MOLLY BLOOM:** And I'm Molly Bloom. Gabriela, you ready to hear that mystery sound one more time?

**GABRIELA HOPPER:** Yep.

[SCUTTLING]

**MOLLY BLOOM:** Any new guesses?

**GABRIELA HOPPER:** No.

**MOLLY BLOOM:** Sticking with the opening, unlocking the door?

**GABRIELA HOPPER:** Yeah.

**MOLLY BLOOM:** All right, here's the answer.

**ELLIOT:** Hi, I'm Elliot. I'm five years old.

**HARRISON:** And I'm Harrison, and I'm seven years old. That was the sound of a Tesla electric car charge port opening and being plugged in. A Tesla is a car that runs only on electricity. No gas at all.

**MOLLY BLOOM:** Yeah, that was tricky. Have you ever seen an electric car?

**GABRIELA HOPPER:** I have. I've seen somebody plug their electric car into a plug.

**MOLLY BLOOM:** Yes, that's what was happening with this car. But you probably weren't listening to the sound super closely because it's pretty quiet, so that's a tough one.

**GABRIELA HOPPER:** Yeah.

**AUDIO TRACK:** Brains On!

**MOLLY BLOOM:** Cars have come a long way since they were first invented, and we'll have more on that evolution in a coming episode.

**GABRIELA HOPPER:** But a key way they're changing is in the way we fuel them.

**MOLLY BLOOM:** Anne Co is a professor of chemistry at Ohio State University and an associate fellow at the Center for Automotive Research.

**GABRIELA HOPPER:** That's CAR for short. Clever, right?

**MOLLY BLOOM:** Shout out to acronyms.

**ANNE CO:** I'm an electric chemist by training. Basically looking at, how do you manipulate chemicals with electricity, or how do you generate electricity from a chemical reaction?

**GABRIELA HOPPER:** She got interested in this field thanks to electrons.

**MOLLY BLOOM:** Those tiny subatomic particles that are a part of atoms. And atoms are the things that make up, well, everything.

**ANNE CO:** I was just so interested in the topic. Electrons moving. And you can manipulate these electrons, how they move, and why they move.

**MOLLY BLOOM:** And this expertise comes in handy when you're thinking about the future of cars.

**ANNE CO:** So in the car world, there's a push towards electrification. So this means that in the future, our cars will have more electric engines running our cars. And for an electric vehicle, for example, there's two ways to power an electric vehicle. You can use a battery to power an electric vehicle, or you can use fuel cells to power an electric vehicle.

**GABRIELA HOPPER:** If you've heard of hydrogen powered cars, it's fuel cells that are used to harness the energy from hydrogen.

**MOLLY BLOOM:** The electricity generated by these fuel cells can power a car, the same way electricity generated by batteries can. If you have a battery powered car, you need to charge it, just like charging your phone. But a fuel cell needs to be, well, refueled.

**ANNE CO:** So hydrogen is a gas molecule, and we use fat as a fuel. So it will be similar to driving up to a gas station. But instead of filling up your car with gasoline, you would then fill it up with hydrogen.

**GABRIELA HOPPER:** The fuel cells work like this.

**ANNE CO:** In a fuel cell, you typically have an anode and a cathode.

**MOLLY BLOOM:** These parts can also be found in batteries. Electrical current comes in through the anode and flows out through the cathode.

**ANNE CO:** At the anode, you will introduce hydrogen.

**MOLLY BLOOM:** It's at the anode and cathode where chemical reactions occur.

**GABRIELA HOPPER:** And electricity is produced.

**MOLLY BLOOM:** Electricity is generated by moving charged particles.

**GABRIELA HOPPER:** Like electrons.

**ANNE CO:** And what happens is the anode gives away electrons. At the cathode, you introduce oxygen. Reaction occurs, and the only byproduct is water. And at the same time, you produce an electrical current. And this electrical current will allow you to power your car.

**GABRIELA HOPPER:** So the ingredients you need to make power, hydrogen and oxygen, are everywhere.

**MOLLY BLOOM:** You can get the hydrogen from water, which is composed of a hydrogen atom and two oxygen atoms. That's why water is sometimes called H2O. H is for Hydrogen and O is for Oxygen.

**GABRIELA HOPPER:** You can break out hydrogen atoms through something called an electrolysis cell.

**MOLLY BLOOM:** This electrolysis cell also needs electricity to work.

**ANNE CO:** The idea here is that in the future, we can couple in renewable sources of electrical energy. For example, we can have an electrolysis cell that is being powered by wind or by the sun to actually form our hydrogen.

**MOLLY BLOOM:** That would mean the process creating this hydrogen wouldn't pump any carbon dioxide into the atmosphere.

**ANNE CO:** And then you would then take this hydrogen, put it in a fuel cell car to run your car. And with the byproduct being water. That makes it a closed loop.

**MOLLY BLOOM:** By closed loop, she means the source for the fuel is also the byproduct of the reaction that creates the energy. You get the hydrogen from water. Hydrogen goes into the fuel cell. And energy and water are produced. A closed loop. The other thing you need in order for the fuel cell to produce power is oxygen.

**ANNE CO:** So where you get the oxygen, that's easy. It comes from the air. Our air is composed of 20% oxygen.

**MOLLY BLOOM:** But the oxygen gas in the air is two oxygen atoms bonded together to form a molecule. And that bond needs to be broken.

**ANNE CO:** But it's very difficult to break that oxygen-oxygen bond.

**GABRIELA HOPPER:** And the most efficient way to break that bond is to use platinum as a catalyst. It causes the chemical reaction.

**ANNE CO:** A lot of the efforts in my laboratory are to develop fuel cell catalysts that essentially dilutes the amount of platinum that we need.

**MOLLY BLOOM:** Platinum is expensive, which makes hydrogen powered cars more expensive. That's why you don't see many on the road.

**GABRIELA HOPPER:** But Anne and her team are working to change that.

**ANNE CO:** Looking forward in the future, we're also looking at different ways to make catalysts that are efficient and durable, but does not contain any platinum group metals.

**GABRIELA HOPPER:** If you look on the road today, cars with electric engines account for only 5% of sales. But by 2025, that number is expected to grow to 25%.

**MOLLY BLOOM:** Between fuel cells and other higher performance batteries she works on, scientists like Anne think the future of cars will be electrified.

[MUSIC PLAYING]

Internal combustion engines are the most common engines on the road today.

**GABRIELA HOPPER:** And a byproduct of combustion is carbon dioxide.

**MOLLY BLOOM:** Carbon dioxide keeps our planet warm.

**GABRIELA HOPPER:** But burning carbon based fuel is producing too much carbon dioxide and causing the planet to warm a little too much.

**MOLLY BLOOM:** To replace these internal combustion engines, scientists are working on making electric cars that are cheaper and more convenient to use. That's it for this episode of *Brains On.*

**GABRIELA HOPPER:** Hey, we should probably stop and refuel. Want to do the Honor Roll while we're waiting?

**MOLLY BLOOM:** I'm on it.

[LISTING HONOR ROLL]

**AUDIO TRACK:** Brains Honor Roll. High fives.

**GABRIELA HOPPER:** All right. Let's get back on the road. We have a lot more ground to cover.

**MOLLY BLOOM:** Let's go.

**GABRIELA HOPPER:** *Brains On* is produced by Marc Sanchez, Sanden Totten, and Molly Bloom.

**MOLLY BLOOM:** Many thanks this week to engineers Roger Smith, Joe Camoriano, Steve Griffith, and Eric Stromstead, Carolyn Hopper, John Fielka, Loren Dee, Courtney Kennedy, Kenny Blumenfeld.

**GABRIELA HOPPER:** You can keep up with us on Instagram and Twitter. We're at @brains_on.

**MOLLY BLOOM:** And we're on Facebook, too.

**GABRIELA HOPPER:** And email your questions, ideas, mystery sounds, and drawings to us any time.

**MOLLY BLOOM:** We're at hello@brainson.org. Or you can find our mailing address if you want to send us physical mail. That address can be found on our website, brainson.org.

**GABRIELA HOPPER:** Thanks for listening!