ELECTROCHEMICAL CO2 REDUCTION

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What’s the big deal with CO2?

You mean this little molecule?

Yeah, why is everyone worried about it?

Well, over the past 100 years, the amount of CO2 in the atmosphere has been increasing.

Fossil fuels (like coal, gas, and oil) have led to so many great developments, but now we realize there are some unintended consequences to using them.

Every time we burn fossil fuels, we produce CO2. Some of the sun’s energy hitting the earth is reflected, but some is trapped by the CO2 which acts like the glass roof in a greenhouse to keep heat from escaping. This makes the earth hotter overall.

But aren’t higher temperatures a good thing? Don’t people love to vacation in warmer climates?

Yes, but it’s more than that...

Warmer temperatures lead to more heat waves, warmer oceans, and damaged coral.

Which leads to less snow and ice and thawing permafrost.

Which leads to changing plant life cycles and animal migration and life cycles.

Which leads to reduced biodiversity and increased risk of disease.

Which leads to rising sea levels, changing weather patterns, and stronger storms.

Which leads to more droughts and wildfires.
SO WHAT DO WE DO WITH ALL OF THIS CO2? HOW DO WE STOP MAKING IT?

IN AN IDEAL WORLD, WE WOULD INSTANTLY STOP BURNING FOSSIL FUELS, BUT THAT'S NOT PRACTICAL.

CAN YOU IMAGINE IF TOMORROW THERE WAS NO MORE GAS, OIL, OR COAL TO SUPPLY ENERGY FOR TRANSPORTATION, MANUFACTURING, AND SHIPPING?

SO WHAT WE NEED IS SOME WAY TO DEAL WITH THE CO2 WHILE WE TRANSITION TO CLEANER ENERGIES, LIKE CAPTURING AND STORING IT, OR USING IT TO MAKE SOMETHING ELSE...

EXACTLY AND THAT'S WHAT WE STUDY - HOW TO MAKE USE OF ALL OF THIS EXTRA CO2. WE ARE TRYING TO USE RENEWABLE ENERGY LIKE SOLAR, HYDRO, OR WIND POWER TO CONVERT THE CO2 TAKEN OUT OF THE ATMOSPHERE INTO USEFUL CHEMICALS.

HOW DOES USING ELECTRICITY CONVERT CO2 INTO SOMETHING ELSE?

WELL, YOU KNOW HOW SOME REACTIONS ARE SPONTANEOUS AND HAPPEN ON THEIR OWN, LIKE MIXING BAKING SODA AND VINEGAR TO CREATE A VOLCANO EFFECT...

SOME REACTIONS REQUIRE EXTERNAL ENERGY IN THE FORM OF HEAT, LIKE BAKING BREAD.

OR SOME REACTIONS REQUIRE SOLAR ENERGY, LIKE PHOTOSYNTHESIS.

WELL, THIS REACTION REQUIRES ELECTRICAL ENERGY TO DRIVE IT FORWARD.
Imagine you always park your car in the lot on the left side of the street because it is cheaper than parking on the right. Every month, the price to park on the left increases until it is actually more expensive to save money. You decide to switch lots and park on the right side.

We do the same thing in our system. Except the price is energy. The cars are electrons. The left parking lot is the metal electrode, and the right parking lot is the CO2. By increasing the voltage (energy), we can raise the energy of the electrons. If we raise the energy high enough, the electrons will find an empty space with a lower energy in the CO2 and transfer there. Adding electrons to the CO2 forms new products like methane or ethanol (fuel), ethylene (used to make plastics), and more.

This technology sounds great. Why isn’t everyone using it?

Well, we’ve still got some problems to address to make the technology economically viable so it can compete with the current chemical production methods.

First, we need to make sure that the system can run stably over thousands of hours so it needs less frequent maintenance and repairs which brings down the cost.

Second, we need to improve product selectivity because it is cheaper to make a lot of one chemical instead of a little of lots of different chemicals. That way we don’t spend lots of money on separating everything later.

And third, we need to be able to convert lots of CO2 at once to keep up with commercial supply and demand.

So what are people doing to fix these problems?

There’s a lot of exciting research going on in the field. In our lab, we study what happens if we turn on and off the energy input like a switch instead of applying a constant electrical energy input. By doing this, we can control the energy of the electrode to put it in different states.
WE ARE ALSO TRYING TO APPLY THIS METHOD TO GAS-FED DEVICES.

IMAGINE AN EXTREMELY BUSY HIGHWAY, WHERE YOU EXPERIENCE STOP AND GO TRAFFIC AND IT TAKES HOURS TO REACH YOUR DESTINATION. THIS IS LIKE OUR CURRENT SYSTEM WHERE WE BUBBLE CO2 THROUGH THE LIQUID SALT SOLUTION. THE CO2 HAS TO TRAVEL LONG DISTANCES FROM THE INLET TO THE REACTION SITE AND IT HAS TO INTERACT WITH MANY MOLECULES ON THE WAY, WHICH SLOWS IT DOWN.

USING A GAS-FED DEVICE IS LIKE ADDING AN EXPRESS LANE ON THE HIGHWAY FOR CO2 CARS ONLY, AND NOW INSTEAD OF BEING STUCK BEHIND ALL OF THESE OTHER CARS IN TRAFFIC, THE CO2 CAR CAN SPEED BY TO THE DESTINATION. INSTEAD OF BUBBLING THE CO2 THROUGH THE LIQUID AND WAITING FOR IT TO TRAVEL TO THE REACTION SITE, WE CAN JUST FLOW CO2 DIRECTLY BEHIND THE POROUS ELECTRODE SO IT HAS A MUCH SMALLER DISTANCE TO TRAVEL AND A MUCH EASIER TIME GETTING TO THE REACTION SITE.

SO FAR, WE HAVE FOUND THAT PULSING THE ELECTRODE POTENTIAL REDUCES THE AMOUNT OF HYDROGEN WE MAKE AND CAN INCREASE THE AMOUNT OF CARBON PRODUCTS WE MAKE. HYDROGEN IS AN UNWANTED PRODUCT FROM A SIDE REACTION, SO STOPPING THAT REACTION MEANS WE CAN ENHANCE THE OTHER REACTIONS WE DO WANT TO HAPPEN - LIKE CONVERTING CO2 INTO METHANE OR ETHYLENE.

constant potential

pulsed potential

hydrogen (30%)

methane (35%)

reaction is stable for 1 hour

reaction is stable for over 24 hours

WE HAVE ALSO FOUND THAT PULSING THE ELECTRODE ALLOWS US TO CONVERT CO2 TO OTHER CARBON PRODUCTS FOR OVER 24 HOURS. WHEN WE DON’T PULSE THE ELECTRODE, THE CO2 CONVERSION REACTION ONLY RUNS STABLY FOR ABOUT AN HOUR BEFORE THE REACTION RATES START DECREASING.

THE INSPIRATION FOR THIS WORK CAME FROM THE COMICS BY DR. LUCAS LANDHORST. AVATARS WERE MADE WITH FXTON AND ALL OTHER IMAGES WERE CREATED IN GIMP.

SO WHAT DOES IT MATTER?

IF WE CAN USE RENEWABLE ENERGY TO TURN CO2 INTO A SINGLE, USEFUL, VALUABLE PRODUCT, THEN WE CAN REDUCE THE AMOUNT OF ATMOSPHERIC CO2 AND PREVENT SOME CONSEQUENCES OF CLIMATE CHANGE.
Hi! Our names are Kelsey, Raleigh, and Laila. We are researchers in the Hanrath Energy Lab in the Smith School of Chemical and Biomolecular Engineering at Cornell University. This comic explaining our research on pulsed electrochemical CO₂ reduction. For more information on our work or on our lab, check out https://hanrath.group.cbe.cornell.edu/research/electrocatalysis/