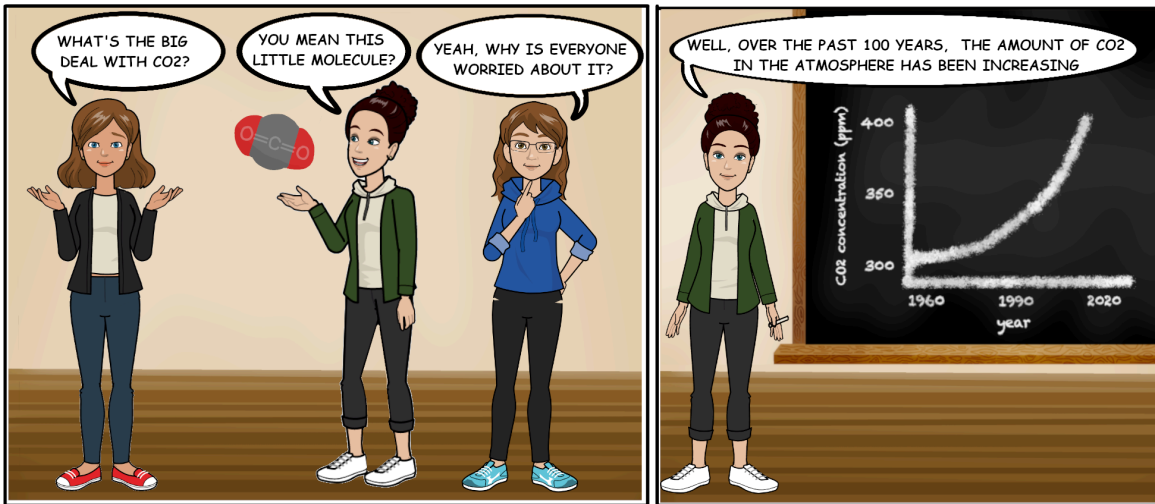
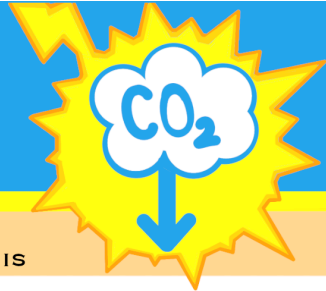
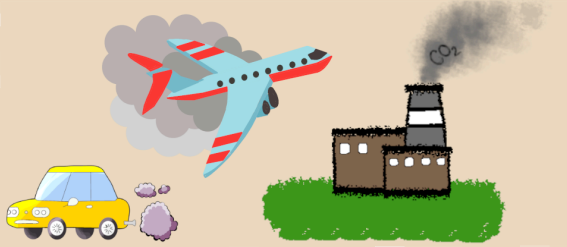


ELECTROCHEMICAL CO₂ REDUCTION

WRITTEN AND DRAWN BY
RILEIGH DiDOMENICO, KELSEY LEVINE, AND LAILA REIMANIS



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 RISING SEA LEVELS, CHANGING WEATHER PATTERNS, AND STRONGER STORMS



WHICH LEADS TO MORE DROUGHTS AND WILDFIRES



WHICH LEADS TO CHANGING PLANT LIFE CYCLES AND ANIMAL MIGRATION AND LIFE CYCLES



WHICH LEADS TO REDUCED BIODIVERSITY AND INCREASED RISK OF DISEASE



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...

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...

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

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?

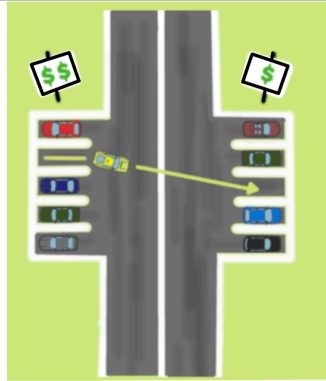
WELL, YOU KNOW HOW SOME REACTIONS ARE SPONTANEOUS AND HAPPEN ON THEIR OWN, LIKE MIXING BAKING SODA AND VINEGAR TO CREATE A VOLCANO EFFECT...

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

OR SOME REACTIONS REQUIRE SOLAR ENERGY, LIKE PHOTOSYNTHESIS

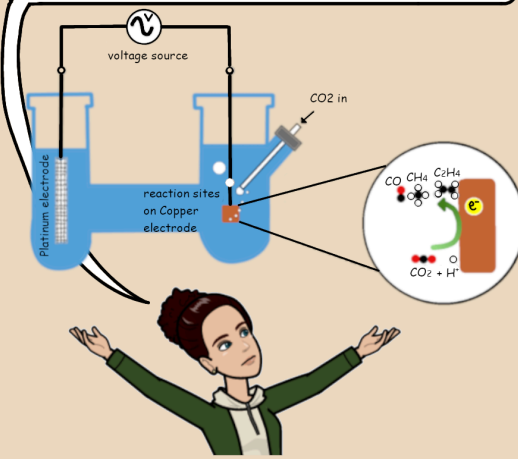
WELL, THIS REACTION REQUIRES ELECTRICAL ENERGY TO DRIVE IT FORWARD.

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 IS WHAT OUR EXPERIMENTAL SYSTEM LOOKS LIKE. WE HAVE OUR COPPER ELECTRODE IN A SALT SOLUTION WHERE THE CO₂ ATTACHES TO REACTION SITES ON THE ELECTRODE AND IS THEN CONVERTED INTO SOMETHING ELSE WHEN WE APPLY A VOLTAGE AND FORCE THE ELECTRONS TO MOVE.



THIS TECHNOLOGY SOUNDS GREAT, WHY ISN'T EVERYONE USING IT?

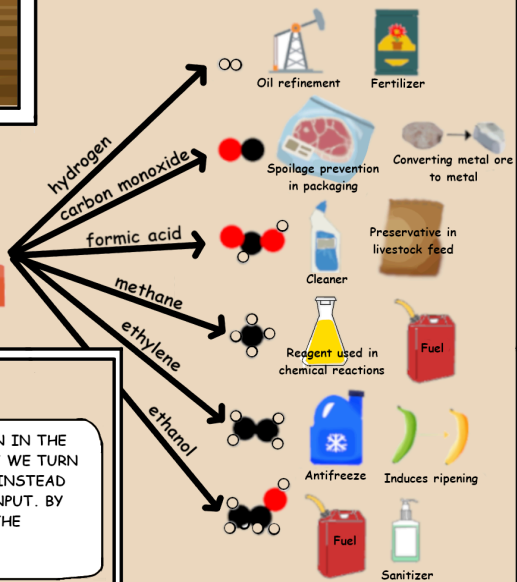
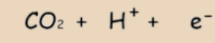
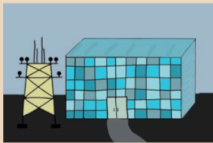
WELL, WE'VE STILL GOT SOME PROBLEMS TO ADDRESS TO MAKE THE TECHNOLOGY ECONOMICALLY VIABLE SO IT CAN COMPETE WITH THE CURRENT CHEMICAL PRODUCTION METHODS.

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

hydrogen (30%)
methane (35%)

reaction is stable for 1 hour

pulsed potential

hydrogen (30%)
methane (80%)

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.

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.

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

HELIOS



HI! OUR NAMES ARE KELSEY, RILEIGH, AND LAILA. WE ARE RESEARCHERS IN THE HANRATH ENERGY LAB IN THE SMITH SCHOOL OF CHEMICAL AND BIOMOLECULAR ENGINEERING AT CORNELL UNIVERSITY. THIS COMIC EXPLAINS 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/>