FUNDING FOR THIS PROGRAM IS
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Narrator: THE WORLD NEEDS
ENERGY.
AND NEARLY 80% OF IT COMES
FROM BURNING FOSSIL FUELS --
OIL, NATURAL GAS, AND COAL.
BUT BURNING THESE FUELS
EMITS CARBON DIOXIDE
A GREENHOUSE GAS THAT
CONTRIBUTES TO CLIMATE
CHANGE.
HOW CAN WE CONTINUE TO
SUPPL YOUR EVER-GROWING
NEED FOR POWER
WITHOUT DAMAGING THE
ENVIRONMENT?
ONE POSSIBILITY IS TO PUT THE
CARBON DIOXIDE
BACK WHERE IT CAME FROM -- IN
UNDERGROUND ROCK
FORMATIONS.
THE MIDWEST REGIONAL CARBON
SEQUESTRATION PARTNERSHIP
IS INVESTIGATING THIS STRATEGY
WHICH WILL HELP MITIGATE THE
EFFECTS
OF THE CONTINUED USE OF
FOSSIL FUELS FOR ENERGY.
RENEWABLE ENERGY SOURCES

ARE ANOTHER OPTION.
AND IN GOLDEN, COLORADO
THE NATURAL RENEWABLE
ENERGY LABORATORY
IS TRYING TO SCALE UP
PROCESSES FOR CREATING
BIOFUELS
FROM THE PRODUCTS OF
AMERICAN FARMS
THEIR GOAL IS TO SUPPLY
UP TO A THIRD OF THE
COUNTRY'S GASOLINE NEEDS
WITHIN 25 YEARS.

BOTH PROJECTS ARE PUSHING
THE LIMITS OF MODERN SCIENCE
IN HOPES OF LEADING THE WAY
TO A MORE SUSTAINABLE ENERGY
FUTURE.

40% OF THE WORLD'S
ELECTRICITY COMES FROM COAL.
COAL IS THE FOSSILIZED REMAINS
OF ANCIENT VEGETATION.
AND WITH GLOBAL RESERVES
THAT COULD LAST OVER 250
YEARS
IT IS THE CHEAPEST AND MOST
ABUNDANT
NON-RENEWABLE ENERGY
SOURCE AVAILABLE.
BUT BURNING COAL PRODUCES

EXHAUST PRODUCTS
INCLUDING NOT JUST WATER VAPOR
WHICH IS MOST OF WHAT WE SEE COMING OUT OF SMOKESTACKS
BUT ALSO CARBON DIOXIDE
AN INVISIBLE GREENHOUSE GAS
THAT CONTRIBUTES TO CLIMATE CHANGE.
AS THE NEED FOR ENERGY
AROUND THE WORLD
CONTINUES TO GROW
NEW COAL-FIRED POWER PLANTS
THAT WILL LAST 50 YEARS OR MORE
COME ONLINE EVERY WEEK.
COAL WILL POWER THE WORLD
FOR DECADES.
HOW CAN WE CONTINUE TO USE
THIS INEXPENSIVE AND PLENTIFUL RESOURCE
WITHOUT FURTHER DAMAGING
THE ENVIRONMENT?
Dr. Gupta: THE WAY TO TAKE CARE OF REDUCING CARBON DIOXIDE
IS YOU HAVE MULTIPLE OPTIONS.
DEFINITELY YOU NEED TO INCREASE
THE EFFICIENCY OF YOUR ENERGY USE.
YOU ALSO NEED TO LOOK AT
RENEWABLE ENERGY SOURCES

LIKE SOLAR ENERGY, WIND ENERGY.
BUT IT IS CLEARLY RECOGNIZED BY THE RESEARCH COMMUNITY THAT YOU NEED A THIRD SET OF TECHNOLOGIES
THAT CAN PROVIDE A MEANS TO KEEP USING FOSSIL FUELS ESPECIALLY COAL, WHICH IS OUR MOST ABUNDANT FOSSIL FUEL IN AN ENVIRONMENTALLY SOUND MANNER.
Narrator: NEERAJ GUPTA IS A GEOLOGIST
WITH BATTELLE MEMORIAL INSTITUTE
A SCIENCE AND TECHNOLOGY ENTERPRISE
THAT IS RESEARCHING THE FEASIBILITY AND COST
OF CAPTURING CARBON DIOXIDE FROM POWER PLANTS
AND INJECTING IT INTO UNDERGROUND ROCK FORMATIONS
A PROCESS CALLED CARBON CAPTURE AND SEQUESTRATION.
Dr. Gupta: WE CALL IT CCS.
YOU ARE PUTTING THE CO2 BACK INTO THE GROUND.
SO JUST LIKE YOU PRODUCE FOSSIL FUELS

LIKE COAL AND OIL AND GAS
FROM THE DEEP GEOLOGIC
FORMATIONS
FROM THE SEDIMENTARY LAYERS
YOU'RE USING THE SAME TYPE OF
LAYERS
AND PUTTING CO2 BACK INTO THE
GROUND WHERE IT CAME FROM.

Narrator: IN BELMONT COUNTY,
OHIO
BATTELLE IS COLLABORATING
WITH FirstEnergy CORP.
WHO IS HOSTING THE PROJECT
AT THEIR R.E. BURGER
COAL-FIRED POWER PLANT.
STEPS AWAY FROM THE PLANT,
CREWS WORK AROUND THE
CLOCK
DRILLING A 2 1/2-KILOMETER, OR
8,000-FOOT, HOLE
SEARCHING FOR RESERVOIRS
DEEP UNDERGROUND
THAT CAN HOLD THE PLANT'S
CARBON DIOXIDE.
THIS IS ONE OF BATTELLE
MEMORIAL INSTITUTE'S
RESEARCH SITES
THAT ARE A PART
OF THE MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP

ONE OF SEVEN U.S. DEPARTMENT OF ENERGY PROGRAMS
BEING CONDUCTED ACROSS THE UNITED STATES
THAT ARE STUDYING CARBON CAPTURE AND SEQUESTRATION
AS ONE OPTION FOR MITIGATING CLIMATE CHANGE.

CO2 IS ROUTINELY SEPARATED AND CAPTURED
AS A BY PRODUCT FROM INDUSTRIAL PROCESSES.
BUT THESE CAPTURE TECHNOLOGIES
ARE NOT COST-EFFECTIVE ON THIS SCALE
AND ARE BEING FURTHER DEVELOPED.
THE OBSTACLE FOR SEQUESTRATION, HOWEVER, IS NOT COST.
FOR YEARS, CARBON DIOXIDE HAS BEEN PUMPED INTO THE GROUND
TO ENHANCE OIL RECOVERY.
THE CHALLENGE NOW IS TO TEST THIS TECHNOLOGY
FOR LONG-TERM STORAGE.
PHIL JAGUCKI IS A GEOLOGIST ON THE PROJECT.
Jagucki: CARBON DIOXIDE IS

INJECTED
INTO THE GROUND EVERY DAY.
BUT WE WANT TO PUT IT IN AND KEEP IT DOWN THERE
AND WE NEED TO FIND WAYS TO MONITOR IT
SO THAT WE CAN VERIFY THAT IT'S STAYING UNDERGROUND
THAT IT'S BEHAVING AS WE INTENDED OR AS WE HAD PLANNED.
AND SO THAT'S THE KNOWLEDGE GAP THAT WE HAVE TO FILL.
WHEN IS THE LAST SURVEY?
IF YOU THINK OF THE ANALOGY OF THE OIL AND GAS FIELDS
THAT MATERIAL HAS BEEN DOWN THERE FOR MILLIONS OF YEARS.
WHEN WE PUT CO2 IN
IT SHOULD REMAIN THERE FOR MILLIONS OF YEARS.

Narrator: THE FIRST REQUIREMENT FOR A GOOD POTENTIAL ROCK RESERVOIR IS POROSITY.
THE TARGET ROCK MUST HAVE ENOUGH TINY SPACES BETWEEN ROCK GRAINS
TO ABSORB THE CO2.
Dr. Gupta: YOU CAN IMAGINE, FOR EXAMPLE
MAYBE A SPONGE.

AND IF YOU PUT A DROP OF WATER ON SOME PIECES OF ROCK
THAT WATER IS IMMEDIATELY ABSORBED.
Narrator: NEAR THE SURFACE POROUS ROCKS LIKE THESE ACT AS AQUIFERS FOR DRINKING WATER.
BUT AS YOU GET DEEPER, THIS IS NOT THE CASE.
LAYERS OF POROUS ROCK CAN CONTAIN OIL, GAS
OR IN THIS CASE, BRINE, OR SALTY WATER.
Dr. Gupta: YOU WANT TO MAKE SURE
THAT THE CO2 THAT YOU INJECT IS DEEPER THAN ANY FRESHWATER SOURCES OF GROUNDWATER.
SO AS YOU GO DEEPER
THAT HIGH-SALINITY WATER IS NOT USEABLE NOW
OR IN THE FORESEEABLE FUTURE FOR ANY OTHER USES.
THAT'S WHY IT CAN BE USED FOR INJECTION.

Narrator: THESE BRINE, OR SALTY RESERVOIRS
CAN BE AN IDEAL LOCATION FOR

CARBON SEQUESTRATION.
BUT JUST AS CRITICAL AS THEIR POROSITY
IS THEIR PERMEABILITY
ALLOWING THE CARBON DIOXIDE
TO MOVE THROUGH THE ROCK'S PORES.
BUT PERMEABILITY CAN ENABLE THE CO2
TO MOVE UPWARDS AND ESCAPE TO THE SURFACE
MAKING A NONPOROUS IMPERMEABLE LAYER ABOVE THE RESERVOIR
KNOWN AS CAP ROCK
ANOTHER IMPORTANT, NECESSARY CHARACTERISTIC.

Dr. Gupta: IT WOULD BE LIKE A PIECE OF SHALE-TYPE ROCK
WHERE YOU PUT A DROP OF WATER
AND IT DOESN'T GET ABSORBED VERY QUICKLY OR NOT AT ALL.
THAT'S A CAP ROCK, AND THAT PREVENTS THE LEAKAGE OF CO2.
Narrator: WHEN SANDSTONE AND SHALE SAMPLES
ARE BOTH INJECTED WITH BLUE DYE
AND VIEWEDUNDER THE SAME MAGNIFICATION

YOU CAN SEE THE DIFFERENCE
BETWEEN AN IMPERMEABLE,
NONPOROUS ROCK
AND ONE WHICH IS POROUS AND
PERMEABLE.

THE FIRST STEP IN LOOKING
FOR POTENTIAL GEOLOGICAL
STORAGE SITES
WITH THESE CRITICAL
CHARACTERISTICS
IS A SEISMIC SURVEY OF THE
POTENTIAL AREA.
Jagucki: THE SEISMIC SURVEY
ALLOWS US TO COVER A LARGER
AREA
WITHOUT HAVING TO DRILL WELLS
EVERYWHERE.
WE CAME OUT HERE WITH
TRUCKS
THAT ARE EQUIPPED TO VIBRATE
THE GROUND.
A LOT OF PEOPLE CALL THEM
THUMPER TRUCKS.
WE HAVE A SERIES OF
MICROPHONES STUCK INTO THE
GROUND
TO MEASURE THAT SOUND
AS IT PASSES DOWN AND THEN
COMES BACK UP.
AND WE RAN ABOUT FIVE MILES
NORTH TO SOUTH

AND ABOUT FIVE MILES EAST TO WEST
SO THAT COVERS A FAIRLY LARGE AREA.

Narrator: THE PRELIMINARY IMAGES TRANSLATED FROM THE VIBRATIONS
SUGGESTED THAT THE BELMONT COUNTY SITE
WAS AN OPTIMAL, NON-FAULTED GEOLOGIC LOCATION
FOR CARBON SEQUESTRATION
SHOWING LAYERS OF POROUS SANDSTONE
CAPPED BY EVEN THICKER LAYERS OF IMPERMEABLE ROCK.
THE TWO LAYERS THEY ARE INTERESTED IN
AS POTENTIAL INJECTION ZONES
ARE THE ORISKANY LAYER
WHICH IS AROUND 1,800 METERS, OR 6,000 FEET
BELOW THE SURFACE, AND THE CLINTON LAYER
ANOTHER 600 METERS, OR 2,000 FEET, LOWER.
THE NEXT STEP IS TO DRILL A WELL
OVER 2,400 METERS, OR 8,000 FEET, DEEP
TO CONFIRM THESE FINDINGS.

TO REACH THIS DEPTH
CREWS OF FOUR WORK 24 HOURS A DAY
DRILLING AT A RATE OF ABOUT TWO MINUTES PER FOOT
BY ADDING 30-FOOT SECTIONS OF DRILL PIPE ONE AT A TIME.
Meggyesy: BASICALLY, THEY'RE GONNA PICK THOSE UP
AND THEY ARE GOING TO PUT IT DOWN IN THE HOLE
AND PICK UP ANOTHER ONE.
EVERY TIME THEY WANT TO DO SOMETHING WITH A BIT
THEY HAVE TO PULL ALL OF THAT PIPE BACK OUT
AND THEY HAVE TO PUT IT ALL BACK IN AGAIN.
Narrator: AS THEY DRILL THE HOLE
THEY CONTINUOUSLY TAKE ROCK SAMPLES
TO DETERMINE IF THE LAYERS THEY SAW ON THE SEISMIC SURVEY
ARE ACTUALLY THERE.
Meggyesy: WE HAVE A BUNCH OF VERY LARGE AIR COMPRESSORS
BIGGER THAN A PICKUP TRUCK,
THAT ARE BLOWING COMPRESSED AIR
DOWN THROUGH THE DRILL PIPE,
OUT THE BIT

AND IS PICKING UP THE DEBRIS AS WE'RE DRILLING.
IT'S LIFTING IT ALL THE WAY BACK UP OUT THE HOLE
AND IT BLOWS IT OUTAT THE BLOW PITS.

Jagucki: AS THAT FLUID COMES OUT
WE CAN LITERALLY HOLD A BUCKET UNDER THE END OF IT
AND WE GET SOME WATER AND CUTTINGS IN IT.
AND THEN WE GIVE THAT SAMPLE TO OUR MUD LOGGER
AND THE MUD LOGGER LOOKS AT THE CUTTINGS.
HE CAN TELL WHAT TYPE OF ROCK WE'RE IN.
Narrator: AT APPROXIMATELY 1.8 KILOMETERS
OR 5,800 FEET, DOWN
THE TEAM EXPECTS TO FIND THE SANDSTONE
THAT IS PART OF THE ORISKANY ROCK LAYER
ONE OF THE POTENTIAL INJECTION ZONES.
BUT SO FAR, THERE IS NO SIGN OF THAT LAYER.
Jagucki: WE LOGGED ANOTHER WELL

ABOUT 30 MILES NORTH OF HERE, AND THAT SANDSTONE WAS PRESENT.
SOME OF OUR OTHER REGIONAL DATA TELLS US THAT IT'S HERE. BUT IT'S AT THIS PARTICULAR LOCATION.
THAT'S WHY IT'S SO IMPORTANT TO GET SITE-SPECIFIC INFORMATION
BECAUSE NO MATTER HOW GOOD YOUR REGIONAL INFORMATION IS UNTIL YOU VERIFY IT ON-SITE, YOU JUST DON'T KNOW.
Narrator: AT ABOUT 5,900 FEET THE SAND GRAINS FROM THE ORISKANY LAYER START TO APPEAR.
Jagucki: WE WERE GLAD WHEN WE FOUND THE ORISKANY SANDSTONE.
THAT PROVIDES A GOOD POTENTIAL TARGET
FOR US TO DO OUR EXPERIMENT.
AND IT'S DEEP BELOW GROUND SURFACE.
IT'S OVER A MILE DOWN. IT'S WELL CONTAINED.
IT'S GOT THOUSANDS OF FEET OF SHALE ABOVE IT
THAT FORM A VERY GOOD CONTAINMENT LAYER.

Narrator: ADDITIONAL TESTS ARE DONE.
WELL LOGGING MEASURES FLUID LEVELS
THAT ACT AS A PROXY OF POROSITY IN THE ROCK
INDICATING LAYERS OF POROUS SANDSTONE
AND NONPOROUS SHALE.
AND CORE SAMPLES ARE COMPARED TO PREVIOUS EXAMPLES
TAKEN OVER DECADES FROM OHIO GEOLOGICAL SURVEYS LAB.

THIS DATA WILL PROVIDE THE EXACT DEPTH AND CHARACTERISTICS
OF THE ROCK LAYERS.
ONCE THESE EVALUATIONS ARE COMPLETE
THE ROCK WILL BE TESTED
BY INJECTING ABOUT TWO DAYS' WORTH OF PLANT CO2 EMISSIONS
AND MONITORING WHETHER ANY OF IT IS LEAKING UP TO THE SURFACE.

IF THIS TECHNOLOGY PROVES FEASIBLE
AND ECONOMICALLY VIABLE

THEN CARBON SEQUESTRATION
HOLDS GREAT PROMISE
AS BEING PART OF THE SOLUTION
TO CONTINUE TO PROVIDE
AFFORDABLE ENERGY
WITHOUT CONTRIBUTING TO
CLIMATE CHANGE.
Dr. Gupta: WE HAVE TO CLEARLY
RECOGNIZE
THAT THIS IS ONE OF SEVERAL
OPTIONS THAT WE HAVE TO
DEPLOY.
IT IS NOT THE ONLY OPTION.
BUT THIS OPTION, IF IT CAN BE
USED
LIKE WE ARE TRYING TO SHOW
WITH OUR RESEARCH
WOULD BE A SIGNIFICANT PART
OF THE PORTFOLIO OF
TECHNOLOGIES
FOR REDUCING CO2 EMISSIONS.

Narrator: CARBON CAPTURE AND
SEQUESTRATION
IS JUST ONE PART OF THE
EFFORT
IN PROVIDING A SUSTAINABLE
ENERGY FUTURE.

RENEWABLE FORMS OF ENERGY,
SUCH AS SOLAR AND WIND
ALONG WITH ENERGY EFFICIENCY

ARE ALSO VITAL COMPONENTS TO THIS STRATEGY
HOLDING PROMISE THAT WE WILL BE ABLE TO MEET THE CHALLENGE
OF POWERING OUR HOMES AND OUR BUSINESSES
IN A LESS DAMAGING WAY.

BUT WE STILL NEED TO GET AROUND.
350 MILLION GALLONS OF PETROLEUM
IS BURNED EVERY DAY IN THE UNITED STATES
MOST OF IT FOR TRANSPORTATION
EMITTING APPROXIMATELY 700 MILLION METRIC TONS
OF CARBON DIOXIDE A YEAR.
AND THE WORLDWIDE DEMAND FOR FUEL IS ONLY GOING UP
CREATING A PRESSING NEED FOR NEW RENEWABLE FUELS.
Douglas: THE URGENCY TO FIND RENEWABLE TRANSPORTATION FUELS IS AT LEAST TWOFOLD.
ONE IS ENERGY SECURITY.
OUR NATION IS ALMOST WHOLLY DEPENDENT
FOR TRANSPORTATION FUELS ON PETROLEUM PRODUCTS.

AND MOST OF THAT PETROLEUM
COMES FROM OVERSEAS.
AND IT IS BECOMING MORE AND
MORE SCARCE
AND HARDER AND HARDER TO
FIND.
IN ADDITION TO THAT
BURNING OF PETROLEUM IN
CARS, BUSES, PLANES
HAS BEEN IDENTIFIED AS A
PRIMARY CONTRIBUTOR
TO THE AMOUNT OF CARBON
DIOXIDE
THAT'S GOING INTO THE
ATMOSPHERE
WHICH COULD CONTRIBUTE TO
CLIMATE CHANGE.
AND SO THERE'S AN
ENVIRONMENTAL BENEFIT
TO FINDING A RENEWABLE
RESOURCE.

Narrator: AT THE NATIONAL
RENEWABLE ENERGY
LABORATORY
OR NREL, IN GOLDEN, COLORADO
SCIENTISTS AND ENGINEERS
WORKING FOR NREL's BIOMASS
PROGRAM
ARE DEVELOPING NEW WAYS TO
GET FUEL FROM PLANTS.

THEIR GOAL IS TO REPLACE
A THIRD OF THE UNITED STATES'
GASOLINE CONSUMPTION
WITH PLANT-BASED BIOFUELS, OR
ETHANOL, BY THE YEAR 2030.
Douglas: WHEN YOU BURN FOSSIL
FUELS
YOU'RE RELEASING CARBON
DIOXIDE
THAT WAS FIXED IN THE EARTH
MILLIONS OF YEARS AGO
WHEN THOSE ANCIENT PLANTS
DIED.
BUT WHEN YOU'RE USING A
BIO-BASED FUEL LIKE ETHANOL
YOU'RE ACTUALLY ONLY
RELEASING CARBON DIOXIDE
THAT WAS ONLY RECENTLY FIXED
BY THE PLANTS
AND THEN THE PLANTS THAT
YOU'RE GROWING FOR NEXT
YEAR'S CROP
WILL THEN FIX THAT CARBON
BACK AGAIN.
SO THE CARBON CYCLE IS
NEARLY 100% COMPLETE.

Narrator: TODAY, MOST OF THE
ETHANOL
PRODUCED IN THE UNITED
STATES COMES FROM CORN.
THE PROCESS IS NOT MUCH

DIFFERENT
FROM THAT OF MAKING WINE OR BREWING BEER.

IN LARGE-SCALE PLANTS ALL OVER THE MIDWEST
THE STARCH IN CORN KERNELS IS CONVERTED TO SUGARS
WHICH ARE THEN FERMENTED WITH YEAST.
THE END PRODUCT OF THIS FERMENTATION
IS THEN DISTILLED TO SEPARATE THE ETHANOL.
BUT THERE ARE LIMITATIONS
TO INCREASING THE PRODUCTION OF CORN ETHANOL.
CORN IS ALREADY A VALUABLE COMMODITY.
IT IS AN INGREDIENT IN MANY OF THE FOODS WE EAT
AND ALSO USED AS FEED FOR LIVESTOCK.
Douglas: WE THINK WE CAN GO
TO ABOUT 15 BILLION GALLONS OF ETHANOL A YEAR
FROM CORN KERNELS.
BUT ANYTHING BEYOND THAT
THE COMPETITION BETWEEN FUEL AND FOOD
STARTS TO TAKE PLACE.
AND SO TO GET MORE

THAN 15 BILLION GALLONS OF ETHANOL A YEAR
WE NEED TO GO TO OTHER METHODS.
AND THAT'S WHY WE'RE INTERESTED IN TRYING TO LEARN HOW TO ECONOMICALLY MAKE ETHANOL FROM THE CELLULOSIC MATERIALS --
THAT IS, THE STALKS, STEMS, LEAVES --
THE NONEDIBLE PARTS OF THE PLANT.
Narrator: CELLULOSIC MATERIAL, OR BIOMASS
IS BASICALLY THE FIBROUS, WOODY
AND GENERALLY INEDIBLE PORTIONS OF PLANTS.
AND IT IS THE MOST PLENTIFUL BIOLOGICAL MATERIAL ON EARTH.
THE CHALLENGE FOR NREL SCIENTISTS AND ENGINEERS LIKE ANDY ADEN
IS TO DESIGN COST-EFFECTIVE CONVERSION PLANTS
THAT CAN CREATE FUEL FROM MANY DIFFERENT TYPES OF BIOMASS.
Aden: THERE ARE LOTS OF DIFFERENT TYPES OF BIOMASS.
THERE ARE AGRICULTURAL

RESIDUES, LIKE CORN STOVER OR WHEAT STRAW
THINGS THAT ARE CURRENTLY LEFT IN THE FIELD
AFTER THE GRAIN HAS BEEN HARVESTED.
THERE ARE WOOD TYPES OF FEED STOCKS THAT ARE BIOMASS --
WOOD CHIPS LIKE POPLAR, FOR EXAMPLE.
IT'S A VERY FAST-GROWING TREE AND YOU CAN POTENTIALLY HAVE PLANTATIONS OF THIS MATERIAL THAT CAN PRODUCE LARGE AMOUNTS OF BIOMASS FOR FUEL ALL THE WAY EVEN TO A PRAIRIE GRASS LIKE SWITCH GRASS.
THE BENEFITS OF THIS MATERIAL IS IT'S VERY DROUGHT-TOLERANT AND YOU CAN GET A LOT MORE TONNAGE OF THIS MATERIAL OFF OF AN ACRE OF LAND.
SO THERE ARE A LOT OF REASONS AND A LOT OF ADDITIONAL BENEFITS FOR USING BIOMASS AS A SOURCE OF ETHANOL
AS OPPOSED TO JUST CORN GRAIN
ONE OF WHICH IS THERE'S A LOT MORE OF IT OUT THERE

THE SECOND OF WHICH IS YOU AVOID THE FOOD-VERSUS-FUEL ISSUES.
THE THIRD POTENTIAL BENEFIT IS TO FARMERS IN RURAL AMERICA BECAUSE IT ADDS ADDITIONAL MARKETS
FOR THEM TO SELL MATERIALS INTO.

Narrator: BUT THERE ARE MANY OBSTACLES
IN CREATING ETHANOL FROM CELLULOSIC MATERIAL.
THROUGH PHOTOSYNTHESIS PLANTS MAKE SUGARS THAT THEY USE FOR ENERGY TO GROW.
SOME OF THOSE SUGARS ARE BONDED TOGETHER AND STORED CREATING STARCHES, LIKE THE STARCH IN A CORN KERNEL
THAT CAN BE USED LATER FOR ENERGY.
THESE STARCHES ARE EASILY BROKEN DOWN
MAKING THEM AN ATTRACTIVE SOURCE FOR ETHANOL CONVERSION.
BUT SOME SUGARS ARE BONDED DIFFERENTLY, INTO LONG CHAINS LIKE STEEL GIRDERS WITHIN

PLANT CELL WALLS.
SPECIFICALLY, THERE ARE THREE PRIMARY COMPONENTS OF BIOMASS --
CELLULOSE, HEMICELLULOSE, AND THE POLYMER LIGNIN
WHICH FILLS THE REMAINING SPACES IN THE PLANT CELL WALL.
PLANTS EVOLVED SO THAT THESE MATERIALS WOULD LAST A LONG TIME
AND BE CHEMICALLY DIFFICULT TO BREAK DOWN
MAKING THE BIOMASS CONVERSION PROCESS CHALLENGING.
NREL HAS CREATED A PILOT PLANT
TO TEST WAYSTO IMPROVE THE PROCESS
OF BREAKING DOWN THE CELLULOSIC MATERIAL
AND MAKE THE SUGARS AVAILABLE FOR FERMENTATION.
THE FIRST STEP IN THE PROCESSIS PRETREATMENT.
Aden: NATURE HAS REALLY MADE THESE MATERIALS
TO BE RESISTANT TO BEING BROKEN DOWN.
SO THAT'S WHY WE HAVE TO DO SOME PREPROCESSING

TO BREAK APART THE CELLULOSE
AND THE HEMICELLULOSE
FROM THE LIGNIN.
AND THAT'S WHAT HAPPENS
IN THE PRETREATMENT PART OF
THE PROCESS.
WE START TO USE ACID AS A
CHEMICAL HYDROLYSIS AGENT --
HYDROLYSIS REALLY MEANS
ADDING WATER TO A REACTION --
TO BEGIN TO BREAK DOWN THE
BIOMASS
INTO ITS INDIVIDUAL PIECES
AND GET SOME OF THE THOSE
SUGARS INTO SOLUTION.
Narrator: THIS PRETREATMENT
PROCESS
RELEASES THE SUGARS IN THE
HEMICELLULOSE.
BUT THE CELLULOSE REMAINS
SOMEWHAT INTACT
LEADING TO THE NEXT STEP
IN BREAKING DOWN THE
CELLULOSIC MATERIAL.
Aden: ONCE WE'VE PRETREATED
THE BIOMASS
WE BRING THAT PRETREATED
BIOMASS, IN A SLURRY OR A
PASTE
INTO OUR FERMENTERS HERE.
AND THIS IS WHERE WE ADD OUR
CELLULASE ENZYME

INTO THE PROCESS.
CELLULASE ENZYME IS SIMPLY A NATURAL PROTEIN
THAT ACTS AS A CATALYST TO BREAK DOWN THE CELLULOSE INTO ITS INDIVIDUAL SUGAR UNITS.
ONCE WE HAVE THAT MIXTURE OF SUGARS
THAT HAS COME FROM THE PRETREATMENT
AND FROM USING THE ENZYMES
WE CAN FERMENT THAT MIXTURE OF SUGARS THEN
INTO FUEL ETHANOL.

Narrator: THE ENZYMES USED
TO BREAK DOWN THE CELLULOSIC MATERIAL
ARE AN EXPENSIVE PART OF THIS PROCESS.
NREL's EXTENSIVE BIOCHEMICAL LABORATORIES
ALONG WITH INDUSTRY PARTNERS, HAVE BROUGHT THE COST DOWN
FROM $5 PER GALLON OF ETHANOL PRODUCED
TO ABOUT 20 CENTS PER GALLON.
BUT THIS COST HAS TO BE REDUCED EVEN FURTHER
TO COMPETE WITH CORN

ETHANOL AND TRADITIONAL PETROLEUM.
BILL ADNEY IS RESEARCHING NEW WAYS
TO IMPROVE THESE ENZYMES USING BIOTECHNOLOGY.
Dr. Adney: ENZYMES ARE IMPORTANT IN NATURE
IN THE BREAKDOWN OF BIOMASS.
THEY'RE FOUND ALL OVER THE PLACE, WHEN YOU THINK ABOUT IT.
COMPOST PILES WOULD BE ONE EXAMPLE OF A PLACE
WHERE YOU WOULD FIND CELLULOSE-DEGRADING ENZYMES.
AND WE'VE LOOKED ALL SORTS OF PLACES.
Narrator: ONE PLACE THEY LOOKED WAS YELLOWSTONE NATIONAL PARK.
Dr. Adney: WE WERE LOOKING FOR ENZYMES
THAT COULD SURVIVE AT HIGH TEMPERATURE.
SO WE LOOKED AT SOME OF THE BIOMASS
THAT'S DECAYING IN THE HOT SPRINGS.
Narrator: WHAT THEY FOUND WAS A BACTERIUM

THAT FEEDS ON THE ORGANIC DEBRIST HAT FALLS INTO HOT SPRINGS.
THE ENZYME THEY ISOLATED FROM THE BACTERIUM
ATTACHES ITSELF TO THE CHAIN OF SUGARS IN CELLULOSE
AND BREAKS IT APART.
Dr. Adney: THIS PARTICULAR ENZYME
WE'VE DONE SOME ENGINEERING ON
AND HAVE BEEN ABLE TO IMPROVE THE ACTIVITY
BY ABOUT 12% TO 15%.

Narrator: WHILE THIS ENZYME BREAKS THE CHAIN
IT DOES NOT RELEASE THE SUGARS.
THAT IS THE JOB OF ANOTHER ENZYME
ONE THAT WAS DISCOVERED NEARLY 50 YEARS AGO.
Dr. Adney: IN THE LATE '50s, EARLY '60s
IT WAS AN ISSUE WITH THE ARMY UNIFORMS IN THE TROPIC AREAS.
THEY FOUND THAT THEY WERE DEGRADING RAPIDLY.
SO THE ARMY BEGAN TO INVESTIGATE WHY THIS WAS

OCCURRING.
AND ONE OF THE FIRST THINGS
THEY ISOLATED WAS A FUNGUS
THAT PRODUCED ENZYMES THAT
BROKE DOWN THE COTTON
MATERIAL
FOUND IN THE SOLDERS'
UNIFORMS.
THESE ENZYMES ARE VERY
UNIQUE.
THEY ARE TERMED PROCESSIVE
ENZYMES.
SO ONCE THEY ATTACH TO A
CHAIN, THEY MOVE
PROCESSIVELY DOWN
RELEASING THE SUGAR AS THEY
MOVE ALONG.
THIS PARTICULAR ENZYME
IS PROBABLY THE SINGLE MOST
IMPORTANT ENZYME
IN BIOMASS CONVERSION AT THIS
TIME.
YET WE DON'T KNOW HOW IT
REALLY WORKS.
Narrator: BY GAINING A BETTER
UNDERSTANDING
OF HOW THESE ENZYMES WORK
AND ENGINEERING THEM TO
FUNCTION MORE EFFECTIVELY
RESEARCHERS AT NREL WILL
IMPROVE THE
BIOMASS-CONVERSION PROCESS

EVEN FURTHER.
ONCE THE ENZYMES HAVE
BROKEN DOWN THE SUGAR
CHAINS
FERMENTATION ORGANISMS ARE
ADDED
TO TURN THOSE SUGARS INTO
ETHANOL.
IN THIS PART OF THE PROCESS,
TOO, PROGRESS NEEDS TO BE
MADE.

Aden: IN THE CURRENT
CORN-ETHANOL INDUSTRY
THE YEAST THEY USE TO
FERMENT THE GLUCOSE INTO
ETHANOL
IS VERY GOOD AT WHAT IT DOES.
IN THIS PROCESS, WE HAVE A
MIXTURE OF SUGARS --
GLUCOSE, XYLOSE, MANNOSE,
AND OTHER SUGARS.
WE HAVE ORGANISMS
ENGINEERED
TO BE ABLE TO FERMENT SOME
OF THOSE SUGARS
PRIMARILY GLUCOSE AND
XYLOSE, AT THE SAME TIME
BUT THEY DON'T DO IT AS
EFFICIENTLY AS THEY NEED TO
AND WE'D LIKE TO ENGINEER
THEM TO DO OTHER SUGARS AS

WELL
TO MAKE THIS A MORE EFFICIENT PROCESS
AND GET MORE ETHANOL
FOR EVERY POUND OF BIOMASS
THAT WE BRING IN.
Narrator: AT NREL
THEY ARE CONTINUALLY
ENGINEERING THESE ORGANISMS
TO BECOME MORE EFFICIENT
IN HOPES OF ONE DAY
PRODUCING A SINGLE
FERMENTING ORGANISM
THAT CAN TOLERATE HIGH
CONCENTRATIONS OF ETHANOL
AND WORK ON ALL SUGARS AT ONCE.

BUT ALL OF THESE PROCESSES
TAKE A LOT OF ENERGY.
AND HERE IN THE PILOT PLANT
THEY ARE WORKING ON A
SOLUTION TO THAT AS WELL
BY USING THE LAST REMAINING PIECE
OF THE CELLULOSIC MATERIAL,
THE LIGNIN.
Aden: THAT LIGNIN PLAYS A VERY IMPORTANT PART
IN THE ENERGY PICTURE OF THIS PROCESS.
BECAUSE CELLULOSIC BIOMASS

HAS THIS LIGNIN COMPONENT
THAT CAN BE USED FOR A
FUEL,YOU DON'T HAVE TO BUY
COAL.
YOU DON'T HAVE TO BUY
NATURAL GAS.
YOU CAN BE A SELF-SUSTAINING
ENERGY PLANT LIKE THIS
BY BURNING THIS LIGNIN
RESIDUE.
YOU COULD NOT ONLY PROVIDE
ALL OF THE ENERGY NEEDS
FOR A PROCESSING PLANT SUCH
AS THIS
YOU COULD ALSO POTENTIALLY
SELL A GREEN ENERGY
BYPRODUCT
TO THE LOCAL POWER GRID.

Narrator: BY MAXIMIZING THE
ENERGY POTENTIAL
OF CELLULOSIC MATERIAL
NREL's BIOMASS PROGRAMIS
HELPING TO PAVE THE WAY
TO A NEW ENERGY FUTURE.
Douglas: WITH ADDED
EFFICIENCIES
WE THINK WE COULD VERY
EASILY GET TO THE POINT
WHERE HALF OR MORE OF THE
LIQUID FUELS USED IN THE U.S.
COULD BE GROWN HERE IN THE

U.S. ON AN ANNUAL AND CYCLICAL BASIS.
SO WE WOULD BE GROWING OUR OWN TRANSPORTATION FUEL.
Narrator: BIOMASS FUELS
ALONG WITH OTHER RENEWABLE ENERGY SOURCES
CARBON SEQUESTRATION
NUCLEAR ENERGY, AND NEW EFFICIENCIES
WILL ALL CONTRIBUTE TO PROVIDING AFFORDABLE ENERGY FOR OUR RAPIDLY INCREASING GLOBAL POPULATION
AND REDUCE THE IMPACT
OF CLIMATE-CHANGING GREENHOUSE GASES.

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