

# Innovating energy solutions

Research and  
development highlights

**ExxonMobil**



# \$1B

ExxonMobil invests about \$1 billion a year in R&D across all our lines of business.

# Research and development highlights

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**ExxonMobil has remained a leader in energy technology throughout its 135-year history. With a commitment to fundamental science and innovation unmatched in our industry, we invest about \$1 billion a year in R&D.**

We continue to advance a range of technologies to help meet growing demand for energy while also reducing greenhouse gas (GHG) emissions associated with energy use. Our in-house research portfolio includes biofuels, carbon capture and storage, breakthrough energy-efficiency processes, natural gas technologies, advanced energy-saving materials and environmental life cycle assessments. We also work with leading research and technology companies, national labs and universities.

Our commitment to reducing emissions doesn't stop in the research laboratory. Since 2000, ExxonMobil has spent approximately \$8 billion to develop and deploy lower-emission energy solutions across our operations.



# Algae and other advanced biofuels

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ExxonMobil is actively researching **biofuels made from algae**. Algae naturally produce lipids that can be turned into a renewable, lower-emission fuel for transportation. The challenge is doing so economically and at scale, moving this technology from the petri dish to the fuel tank. ExxonMobil and Synthetic Genomics Inc. continue to make progress in identifying and enhancing algae strains capable of high lipid production while maintaining desirable growth rates. And because the manufacturing processes for algae biofuels and today's transportation fuels are similar, algae biofuels could be processed in existing refineries to supplement supplies of conventional gasoline, diesel and other fuels.



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Our broad portfolio of advanced biofuels research also includes biofuels derived from **cellulosic biomass**. We have an agreement with Renewable Energy Group Inc. to study the production of biodiesel by fermenting cellulosic sugars from sources such as agricultural waste.



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Advanced, or second-generation, biofuels offer the possibility of **achieving significant GHG reductions** while also minimizing the impact on land, fresh water and food supplies compared with first-generation biofuels.



# \$250M

ExxonMobil has invested more than \$250 million on biofuels research in the past decade.

# Can algae biofuels be the lower-emission fuel of tomorrow?

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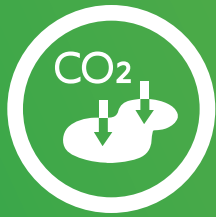
The biofuels used around the world today are largely derived from agricultural crops; sugar cane and corn are used to make ethanol, while biodiesel is made from vegetable oils like soy.

Unlike these first-generation biofuels, algae could provide a renewable fuel source that does not compete with supplies of food or fresh water. Algae also can consume carbon dioxide (CO<sub>2</sub>) and have the potential to be produced on a large scale.

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# Can algae biofuels be the lower-emission fuel of tomorrow?

From production to combustion, here are seven important reasons why we think the answer could be yes. Find out why this renewable energy source, which can be grown at scale on a limited amount of land, is so promising.



## ALGAE CONSUME CO<sub>2</sub>

In addition to producing algae, production sites could also act as carbon capture projects.



## LOWER-EMISSION FUEL

On a life cycle basis, algae biofuels emit about half as much GHGs as petroleum-derived fuel.



## HIGH YIELD

Each acre of algae yields more than 2,000 gallons (7,570 liters) of fuel. Compare that to 650 gallons (2,460 liters) per acre for palm oil and 50 gallons (190 liters) per acre for soybean oil.



### YEAR-ROUND HARVESTS

Unlike other feedstocks, such as corn, which is harvested only once a year, algae can be harvested repeatedly throughout the year.



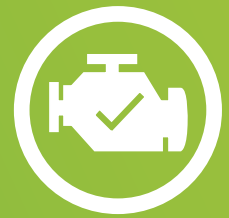
### FOOD PRODUCTION

Algae can be cultivated on land unsuitable for other purposes with water that can't be used for food production.



### WATER PURIFIER

Algae can be grown in wastewater and industrial effluent, and can actually purify polluted water while simultaneously producing energy-rich biofuels.



### ENGINE READY

Algae-derived diesel can be pumped into existing diesel automobiles without making major changes to car engines and infrastructure.

# Natural gas technology

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Natural gas emits up to 60 percent fewer GHGs than coal for power generation, and is an ideal source of reliable power while also supplementing intermittent renewable energy sources such as solar or wind. It also is an abundant and versatile fuel, capable of powering utilities, homes and transportation. Recent advances in production technologies – many developed by ExxonMobil – have unlocked vast new supplies of gas in North America that previously were uneconomic to produce. **ExxonMobil is the largest natural gas producer in the U.S.**



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Increased use of natural gas is a major reason why energy-related **CO<sub>2</sub> emissions** from the U.S. power sector are **down 15 percent since 2010**, and at levels not seen since the early 1990s.



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ExxonMobil also is a leader in liquefied natural gas (**LNG**) technology that is bringing more of this **cleaner-burning fuel** to countries that need it.



# 60%↓

Natural gas can reduce CO<sub>2</sub> emissions by up to 60% versus coal when used for power generation.



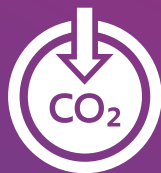


# Carbon capture and storage

Carbon capture and storage (CCS) is the process by which CO<sub>2</sub> that otherwise would be emitted into the atmosphere is captured, compressed and injected underground for permanent storage. The Intergovernmental Panel on Climate Change has recognized **CCS as essential to meeting global emissions-reduction goals.**



ExxonMobil remains a leader in CCS technology. Our capacity is among the industry's largest, with a working interest in about one-fourth of the world's CCS capacity. In 2016, we captured 6.3 million tonnes of CO<sub>2</sub> for storage – **equivalent to switching from coal to gas to meet the electricity needs of about 1 million U.S. homes.**



We are conducting proprietary, fundamental research to develop breakthrough CCS technologies, with an aim **to reduce the complexity and cost** of this important technology, while increasing its efficiency.



# 6.3M

ExxonMobil captured 6.3 million metric tonnes of CO<sub>2</sub> for storage in 2016.



# Fuel cell technology

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ExxonMobil is working with FuelCell Energy Inc. to explore an exciting new possibility: **using carbonate fuel cells to more economically capture CO<sub>2</sub>** emissions from gas-fired power plants. Existing processes for capturing CO<sub>2</sub> emissions consume energy, which increases costs; but carbonate fuel cells can produce electricity while they capture and concentrate CO<sub>2</sub> streams. As a result, these fuel cells could significantly lower the cost of CCS, thereby bringing this breakthrough technology closer to widespread use.



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Carbonate **fuel cell technology could make CCS more affordable for power plants**, which according to the U.S. Environmental Protection Agency are the single largest source of GHG emissions.



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In 2016, FuelCell Energy and ExxonMobil signed a joint agreement that will allow scientists from both companies to work collaboratively and **further develop this emissions-saving technology.**



~40%

About 40% of global energy-related CO<sub>2</sub> emissions comes from power generation.



FuelCell En

# How do fuel cells capture CO<sub>2</sub>?

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Energy innovators ExxonMobil and FuelCell Energy are collaborating on solving a big problem: how to capture CO<sub>2</sub> more efficiently on a large scale. The technology we're working on uses fuel cells to separate CO<sub>2</sub> from the exhaust stream of a power plant, making the CO<sub>2</sub> easier to capture and pipe underground. While still early in development, this process could vastly reduce the amount of CO<sub>2</sub> released into the atmosphere. It also has the potential to dramatically reduce the costs of CCS, creating a pathway for its widespread use around the world.

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## HERE'S HOW IT COULD WORK:

1

The CO<sub>2</sub> released by power plants (millions of tonnes each year) makes these locations the perfect place to apply carbon capture.

2

The unique carbon-capture method being tested by ExxonMobil and FuelCell Energy could increase the electrical output by more than 25 percent at natural gas power plants, rather than decrease electrical output like the conventional carbon-capture processes.

5

Compressed CO<sub>2</sub> is safely piped more than 3,000 feet underground.

6

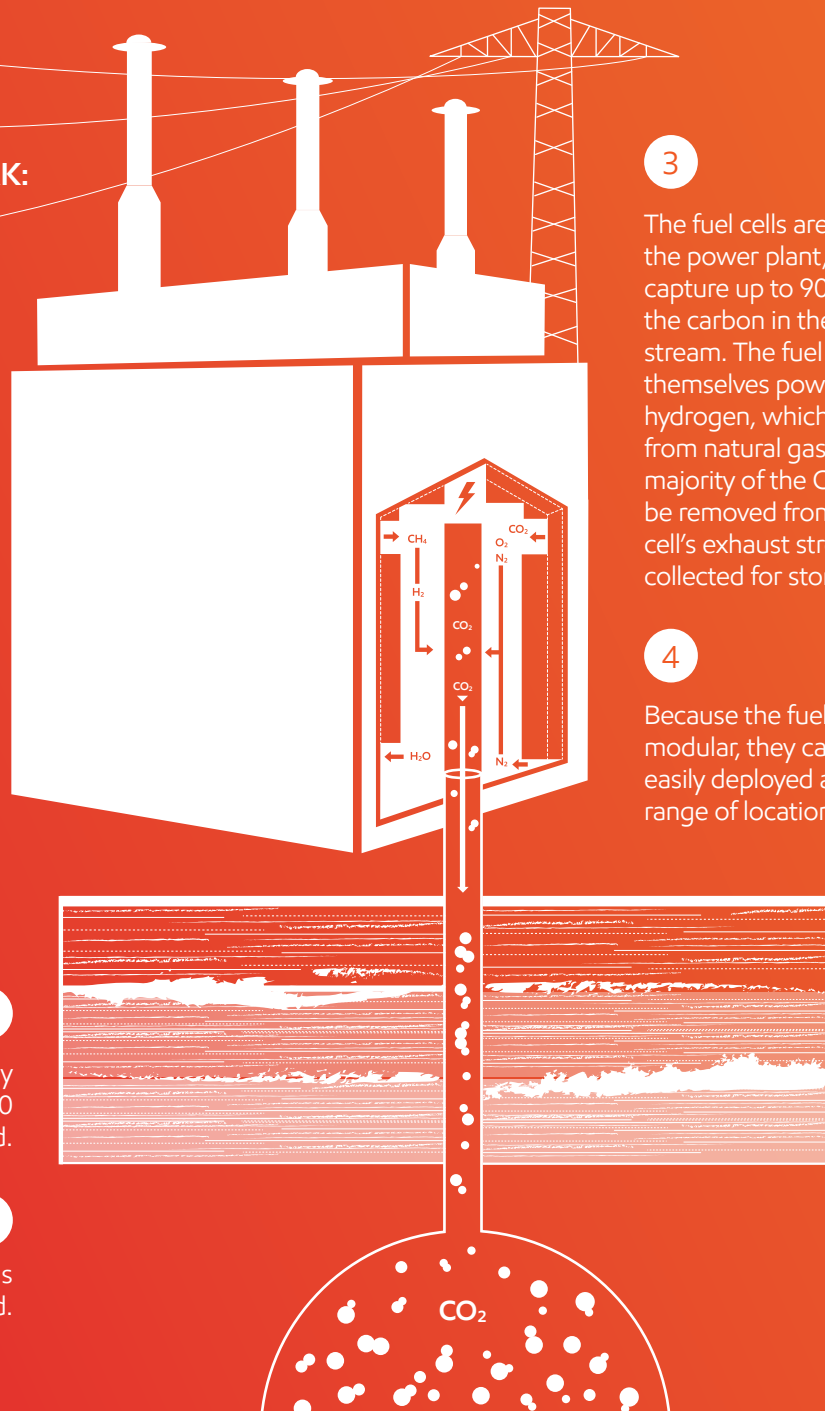
The compressed CO<sub>2</sub> is permanently stored underground.

3

The fuel cells are deployed at the power plant, where they capture up to 90 percent of the carbon in the exhaust stream. The fuel cells are themselves powered by hydrogen, which is derived from natural gas. The majority of the CO<sub>2</sub> will be removed from the fuel cell's exhaust stream and collected for storage.

4

Because the fuel cells are modular, they can be more easily deployed at a wide range of locations.





# Could fuel cells be carbon-capture game changers?

HERE ARE FOUR REASONS WHY:



## CONCENTRATES CO<sub>2</sub>

Carbonate fuel cells can concentrate up to 90 percent of CO<sub>2</sub> emissions that come out of power plants – concentrated emissions can be more easily captured and stored deep underground.



## CLEANER AIR

When carbonate fuel cells take CO<sub>2</sub> from the power plant, they eliminate a majority of smog-producing emissions.



## GENERATES POWER

Carbon capture using fuel cells generates power, which is critical to lowering the cost of carbon capture.



## CUSTOMIZABLE

Fuel cells are modular solutions, allowing for gradual investments that help utilities meet carbon-capture targets over time.

# Chemicals process breakthrough

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ExxonMobil and Georgia Tech have developed a potentially revolutionary “reverse osmosis” technology that could significantly **reduce GHGs associated with plastics manufacturing** by using a molecular filter – rather than energy and heat – to perform a key step in the plastic-making process. If brought to an industrial scale, this breakthrough could reduce the industry’s global annual CO<sub>2</sub> emissions by up to 45 million tonnes.



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**Demand for auto parts, housing materials, electronics and other products** made from plastics and other petrochemicals continues to grow. Rising U.S. natural gas production has boosted supplies of ethane, a natural gas liquid raw material used to make plastics, enabling investment in U.S. chemical manufacturing and exports.



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**Improving industrial energy efficiency** and reducing emissions are part of ExxonMobil’s mission to meet the world’s needs while minimizing environmental impacts.



# 45M

A new ExxonMobil technology has the potential to reduce the plastic industry’s global annual CO<sub>2</sub> emissions by up to 45 million tonnes.



# How does this breakthrough work?

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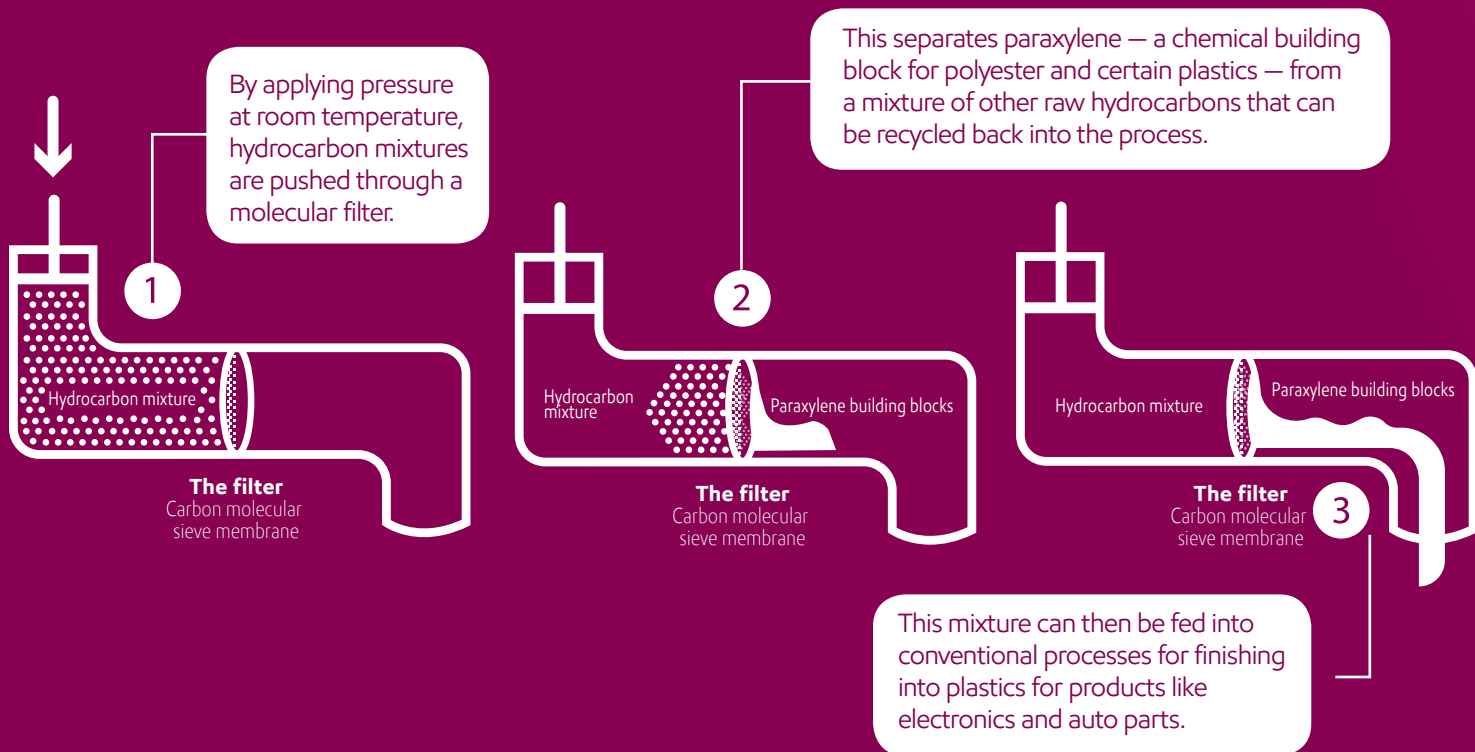
Reverse osmosis has the potential to dramatically reduce the amount of energy required in plastics manufacturing. The technology employs a molecular-level filter – the molecules needed to produce plastics pass through; the others are recycled back into the process. This separation of molecules is a critical step in the production of plastics, but one that currently requires a lot of thermal energy. Because reverse osmosis works at room temperature, it may one day replace existing separation technology with a much less energy-intensive option.

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# How does reverse osmosis work?

Organic solvent reverse osmosis is a manufacturing process that could replace energy-intensive technology at chemical plants.

## HERE'S HOW IT WORKS:





# If we used reverse osmosis to help make certain plastics, it could:



Cut energy costs by **\$2 billion annually**



Reduce industry's annual global carbon emissions by **45 million tonnes**



Even more responsibly **meet demand** for plastics



Lower manufacturing costs can help keep products affordable for consumers.



Same carbon footprint as 5 million U.S. homes.



In products like water bottles, electronics and auto parts.

# Advanced products

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ExxonMobil develops and produces a range of **advanced products that reduce GHG emissions and improve sustainability.** These include resilient, lightweight automotive plastics that reduce overall vehicle weight and advanced tire technologies that help maintain optimal tire pressure – both of which make vehicles more fuel-efficient.



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ExxonMobil also produces lightweight packaging materials for everything from food to electronics. **Lighter packaging means less transportation-related energy use and GHGs.** Plastic packaging also helps extend the shelf life of fresh food by days or even weeks, improving safety and reducing food waste.

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Our high-performance lubricants – used not just in cars and trucks, but in more than **40,000 wind turbines worldwide** – improve sustainability because they need replacing less frequently, reducing the volume of used oil that needs to be disposed of or recycled.



# 10%↓

A 10% reduction in vehicle weight can improve fuel economy by as much as 7%.



# Life cycle assessments

A product's environmental impact extends beyond its manufacturing and use; it also includes the acquisition of raw materials used to make the product, as well as its transport and disposal. In other words, a product's estimated environmental impact should reflect its entire life cycle. ExxonMobil uses in-house experts and tools to conduct **environmental life cycle assessments** of emerging products and activities. In doing so, we are able to assess which technologies have the potential to deliver the game-changing results required to transition the energy system to lower-emission solutions.



ExxonMobil also **collaborates with researchers at universities** to advance the science of life cycle assessments. Additionally, in recent years, we have developed new approaches to quantifying environmental impacts associated with energy systems and published our findings in prestigious peer-reviewed journals.



ExxonMobil continues to develop **technologies that reduce carbon emissions**. For example, we produce a range of advanced products – such as lightweight packaging materials – that help manufacturers reduce energy use, emissions and waste.



# 19K

ExxonMobil employs 19,000 scientists and engineers, including more than 2,200 with Ph.D.s.

# How is ExxonMobil fueling future energy discoveries?

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Every day, ExxonMobil works with academic institutions around the world to research and develop new solutions to the world's energy challenges. Our work includes everything from researching advances in materials science and carbon storage to understanding wind and solar energy. These collaborative relationships with colleges and universities fuel new discoveries and empower advanced energy research both in focused, short-term projects and multiyear programs.

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# University research collaborations

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Beijing University of  
Chemical Technology

California Institute of Technology

Carnegie Mellon University

Case Western Reserve University

Changchun Institute of  
Applied Chemistry

City College of New York

College of William and Mary

Colorado School of Mines

Cornell University

Delft University of Technology

Drexel University

Duke University

Dutch Polymer Institute

Florida State University

George Mason University

Georgia Institute of Technology

Heriot-Watt University

Imperial College London

Jacobs University Bremen

Jiangsu University

Joseph Fourier University

Louisiana State University

Massachusetts Institute  
of Technology

Michigan State University

Montana State University

Moscow State University

Nanyang Technological University

New York University Abu Dhabi

Newcastle University

North Carolina State University

Norwegian University of  
Science and Technology

Pohang University of  
Science and Technology

Princeton University

Purdue University

Qatar University

Rice University

Sichuan University

South China Institute  
of Technology

Stanford University

Texas A&M University

Texas A&M University  
at Galveston

Tsinghua University

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University College Dublin

University of Alberta

University of Bristol

University of British Columbia

University of Calgary

University of California, Berkeley

University of California, Irvine

University of California, Riverside

University of California, San Diego

University of California, Santa Barbara

University of Cambridge

University of Delaware

University of Florida

University of Hawaii

University of Houston

University of Illinois at Chicago

University of Illinois at  
Urbana-Champaign

University of Leeds

University of Massachusetts  
Amherst

University of Miami

University of Michigan

University of Minnesota

University of Mons

University of North Texas

University of Notre Dame

University of Oklahoma

University of St. Thomas

University of Southern Mississippi

University of Stockholm

University of Strasbourg

University of Texas at Austin

University of Texas at El Paso

University of Tulsa

University of Vermont

University of Washington

University of Wisconsin

University of Wyoming

Utrecht University

Virginia Polytechnic Institute  
and State University

Vrije Universiteit Brussel

Western Michigan University

As of 2017

# University research collaborations

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In addition to in-house research, ExxonMobil works with approximately **80 universities globally to explore next-generation energy technologies**. We are a member of the MIT Energy Initiative, which supports advanced energy research. We have a collaboration with Princeton University in fields including solar and battery technology, and an agreement with the University of Texas to study carbon storage and other technologies.



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ExxonMobil was a founding member of the Global Climate and Energy Project at Stanford University, which seeks to develop **game-changing breakthroughs** that could lead to lower GHG emissions and a less carbon-intensive global energy system.



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Other collaborations range from understanding the impacts of black carbon and aerosols (University of California, Riverside) to the conversion of cellulosic sugars to fuels (University of Wisconsin).



# \$145M

ExxonMobil has committed \$145 million to fund breakthrough energy research at MIT, Princeton, the University of Texas and Stanford.



Learn more at  
[exxonmobil.com/technology](https://www.exxonmobil.com/technology)

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