

A close-up photograph of a woman in a laboratory setting. She is wearing a light blue lab coat, clear safety glasses, and blue nitrile gloves. She is looking intently at several petri dishes containing a vibrant green, textured substance, likely a microbial culture. The lighting is bright, highlighting the details of her face and the lab equipment.

ExxonMobil

# INNOVATING ENERGY SOLUTIONS

Research and development highlights



# \$16.5B

Since 2000, ExxonMobil has invested \$16.5 billion in research and development across all our business lines.

## Our commitment to energy innovation

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R&D has been part of ExxonMobil's DNA since our company began more than 135 years ago. Our innovations have helped provide the energy fundamental to modern life – from the clean, efficient fuels that power today's transportation to the natural gas that provides light and heat to homes and businesses.

Today, we are working to develop the next generation of energy solutions, including: advanced biofuels; carbon capture and storage; natural gas technologies; and new energy efficiency processes. In addition to our robust in-house capabilities, we collaborate with leading research and technology companies, national labs and universities, and others involved in breakthrough energy research.

The world faces a dual challenge: meeting growing demand for energy while also reducing environmental impacts, including the risks of climate change. While all forms of energy are needed – including natural gas and renewables such as wind and solar – new technologies will be required to meet the world's emissions-reduction goals.

ExxonMobil is committed to doing our part. This publication provides more insights and details about this important work.

**Our world faces a dual challenge: meeting growing demand for energy while reducing environmental impacts, including the risks of climate change. ExxonMobil is committed to doing our part.**

**The world needs more energy.**

By 2040, global energy demand is projected to increase more than 20%. A few key factors are contributing to this growth.

**Population growth**

The world's population will likely reach about 9.2 billion people by 2040, up from 7.6 billion today.

**Energy inequality**

Even today, nearly 1 billion people lack access to electricity, which impacts their income, education and health.

**Growing middle class**

Rising incomes, particularly in developing nations, will help create the largest expansion of the global middle class in history, from 3 billion to more than 5 billion by 2030.

**New energy consumers**

More middle-class consumers will mean increased demand for homes, cars, electricity, goods and services — and the energy to power them all.

**Lower-carbon energy**

The world is gradually shifting to lower-carbon fuels like natural gas and renewables (e.g., biofuels, wind and solar). Investments in emissions-reducing technologies such as carbon capture and storage will also be critical.

**Energy efficiency**

New technologies and products, such as modern appliances, advanced building materials and fuel-efficient vehicles, will help society use less energy.

**Society wants lower emissions.**

To meet global energy demand while also reducing energy-related emissions, society needs more access to affordable and reliable lower-carbon energy, and technologies and products that are more energy efficient.

**Making progress**

Global energy-related CO<sub>2</sub> emissions are projected to peak by 2040, even as populations and economies continue to grow. Despite this progress, breakthrough technologies are needed to meet targets set by international accords such as the Paris Agreement.

**R&D is in our DNA**

ExxonMobil is looking for affordable, scalable solutions that address the three main areas of energy use:

**transportation, power generation and manufacturing.** We are also deploying advanced technologies in these areas where applicable.

**~25%** Transportation represents about 25% of global energy-related CO<sub>2</sub> emissions.

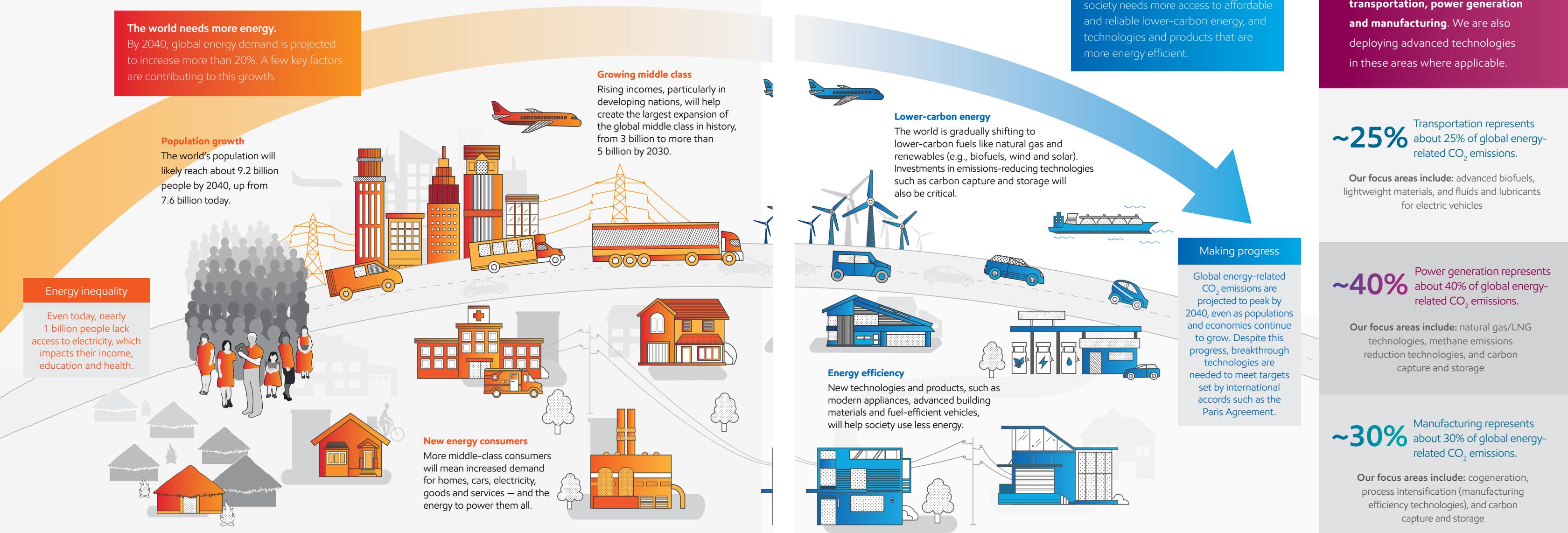
**Our focus areas include:** advanced biofuels, lightweight materials, and fluids and lubricants for electric vehicles

**~40%** Power generation represents about 40% of global energy-related CO<sub>2</sub> emissions.

**Our focus areas include:** natural gas/LNG technologies, methane emissions reduction technologies, and carbon capture and storage

**~30%** Manufacturing represents about 30% of global energy-related CO<sub>2</sub> emissions.

**Our focus areas include:** cogeneration, process intensification (manufacturing efficiency technologies), and carbon capture and storage



# Advanced biofuels

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Scientists at ExxonMobil are working to transform algae and plant waste into biofuels that could one day be used for transportation. These advanced biofuels offer the possibility of **achieving significant greenhouse gas reductions compared to today's transportation fuels**. They could also minimize impacts on land, fresh water and food supplies compared with traditional biofuels like corn or sugar cane. Algae naturally produce oils that can be turned into a renewable, lower-emission fuel. ExxonMobil and Synthetic Genomics, Inc. (SGI) are working together to identify and enhance algae strains capable of high lipid production while maintaining desirable growth rates.



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ExxonMobil is studying the production of biodiesel by fermenting cellulosic sugars in agricultural residues from places like farms and lumber mills.



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In 2018, SGI and ExxonMobil began **field testing algae** strains at the California Advanced Algal Facility. Our goal: to have the technical capability to produce 10,000 barrels a day of algae biofuels by 2025.



## \$300M

ExxonMobil has invested more than \$300 million on biofuels research in the past decade.



## Could advanced biofuels be tomorrow's lower-emission transportation fuel?

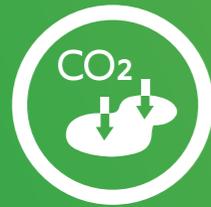
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Biofuels used today are largely derived from agricultural crops. Sugar cane and corn are used to make ethanol, while biodiesel is made from vegetable oils like soy. Biofuels made from algae and cellulosic biomass (abundant plant waste such as corn stalks and wheat straw), however, could provide a renewable fuel source that does not compete with supplies of food or fresh water. These advanced biofuels have the potential to be produced on a large scale, and are derived from sources that consume CO<sub>2</sub>.

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# Could advanced biofuels be tomorrow's lower-emission transportation fuel?

From production to combustion, here are seven reasons why we think the answer could be yes. Find out why these renewable energy sources are so promising.



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

Like all plants, the sources of cellulosic biomass consume CO<sub>2</sub> from the atmosphere as they grow. Algae also consume CO<sub>2</sub> to grow, using the same process of photosynthesis.



## LOWER-EMISSION FUELS

On a life cycle basis, algae and cellulosic biofuels emit about half as many greenhouse gases as petroleum-derived fuel.



## HIGH YIELD

Based on current technology, an acre of algae could yield more than 2,000 gallons (7,570 liters) of fuel. Compare that to 650 gallons per acre for palm oil and 50 for soybean oil. We're working to make algae even more productive in the future.



## YEAR-ROUND HARVESTS

Algae can be harvested repeatedly throughout the year unlike other feedstocks, such as corn, which are harvested only once a year.



## TURNING WASTE TO FUEL

Cellulosic biomass uses waste plant materials, such as crop residue like corn stalks, sawdust and other wood waste.



## FOOD FRIENDLY

Algae can be cultivated on land unsuitable for other purposes, with water that can't be used for food production. Cellulosic biomass can be derived from agricultural waste or woody biomass, which also do not compete with food.



## ENGINE READY

Fuel derived from algae and cellulosic material can be pumped into existing diesel automobiles without making major changes to car engines and infrastructure.

# Natural gas technology

The abundance and versatility of natural gas make it a valuable energy source to meet a wide variety of needs, and help the world shift to less-carbon-intensive energy sources. Natural gas is an ideal fuel for reliable power generation, and supplements intermittent renewable sources such as solar or wind. In the United States, the power sector's shift from coal to natural gas has played a key role in bringing U.S. energy-related CO<sub>2</sub> emissions to 1990s levels despite significant growth in energy demand. Recent advances in production technologies have unlocked vast new supplies of natural gas in North America that previously were uneconomic to produce. **ExxonMobil is one of the largest natural gas producers in the United States.**



ExxonMobil is committed to **reducing emissions of methane** from our operations and encouraging others across the natural gas value chain to do the same.



ExxonMobil is a leader in **liquefied natural gas (LNG) technology** that will drive lower-emission energy solutions and help supply cleaner-burning natural gas to markets around the world.



# 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

CO<sub>2</sub> can be captured, compressed and injected underground for permanent storage. **The Intergovernmental Panel on Climate Change has recognized carbon capture as essential to meeting global emissions-reduction goals.** ExxonMobil, along with its academic and private-sector partners, is focused on new ways to capture CO<sub>2</sub> from industrial and power generation sources, as well as directly from the atmosphere. Our research portfolio spans a wide range of technologies, including novel materials and processes.



ExxonMobil is a sponsor of the **National Carbon Capture Center**, a U.S. Department of Energy research facility, and is a founding member of the **Global CCS Institute**.



In 2019, ExxonMobil and Global Thermostat signed a joint development agreement to **advance breakthrough technology** that can capture and concentrate carbon dioxide emissions from industrial sources, including power plants, and the atmosphere.



# 40%

Since 1970, ExxonMobil has cumulatively captured more CO<sub>2</sub> than any other company – accounting for more than 40% of cumulative CO<sub>2</sub> captured.



# Fuel cell technology

ExxonMobil is exploring an exciting new possibility: **using carbonate fuel cells to more economically capture CO<sub>2</sub> emissions.** This novel approach would significantly reduce the energy needed to capture CO<sub>2</sub>, is easier to operate than existing technologies, and can be deployed in a modular fashion in multiple industry settings.



Carbonate fuel cell technology could make carbon capture **more affordable for industrial sites and power plants.**

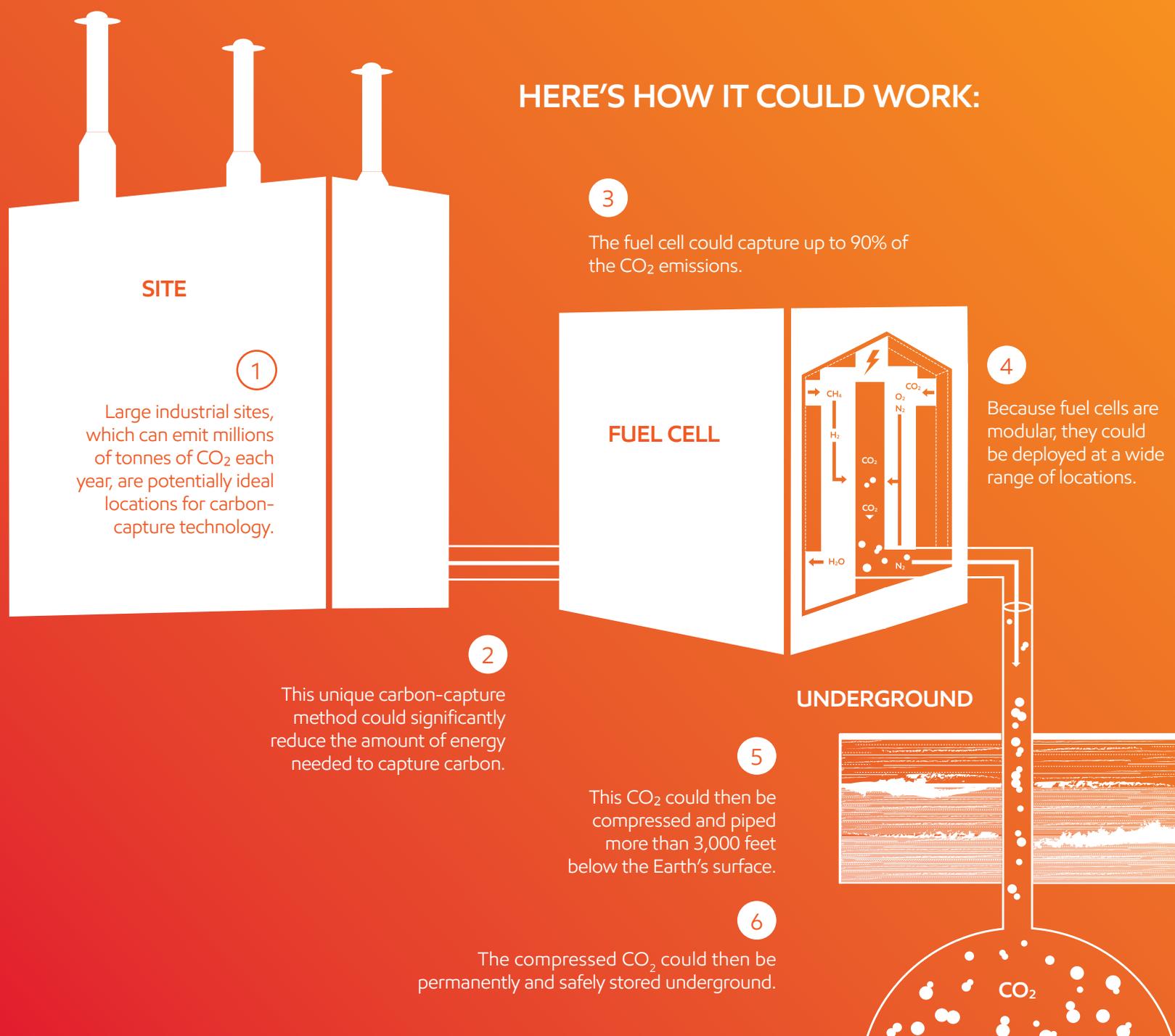


Manufacturing and power generation account for about **70%** of global energy-related greenhouse gas emissions.



# ~90%

The new fuel cell technology could capture up to 90% of the CO<sub>2</sub> from large industrial sites.



# Process intensification

ExxonMobil is looking to solve a big challenge: how to reduce emissions from manufacturing processes. One focus area is process intensification – the development of breakthrough technologies that could make manufacturing far more efficient. Our goal is to develop novel process technologies, including membranes and other **advanced separations, catalysts** and **high-efficiency reactors**, that can lower CO<sub>2</sub> emissions by 25% or greater.



ExxonMobil is a member of the **Rapid Advancement in Process Intensification Deployment (RAPID) Institute**, a public-private partnership sponsored by the U.S. Department of Energy focused on significantly reducing the energy intensity of petroleum and chemical industry operations.

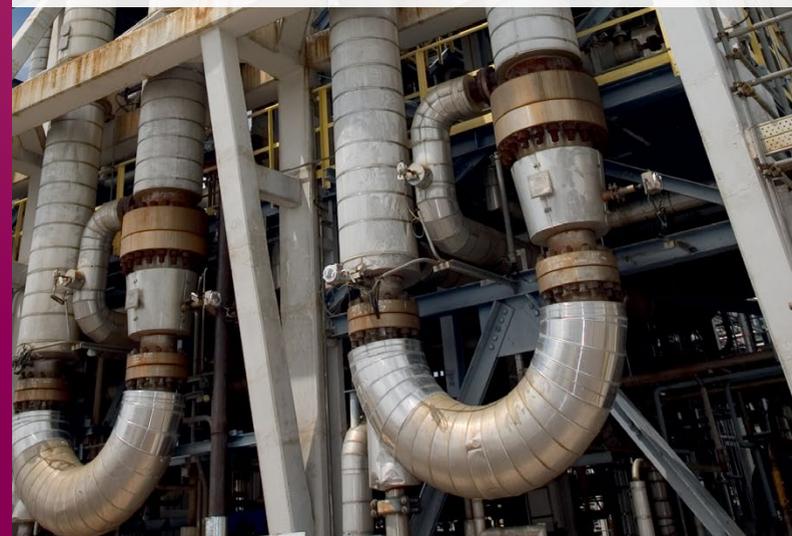


Since 2000, ExxonMobil has spent more than **\$2 billion** to make our downstream facilities more energy efficient, resulting in a 10% improvement in energy intensity.



# 25%

ExxonMobil is seeking to develop novel process technologies that can lower CO<sub>2</sub> emissions from manufacturing by 25% or greater.



## How can we reduce emissions from industry?

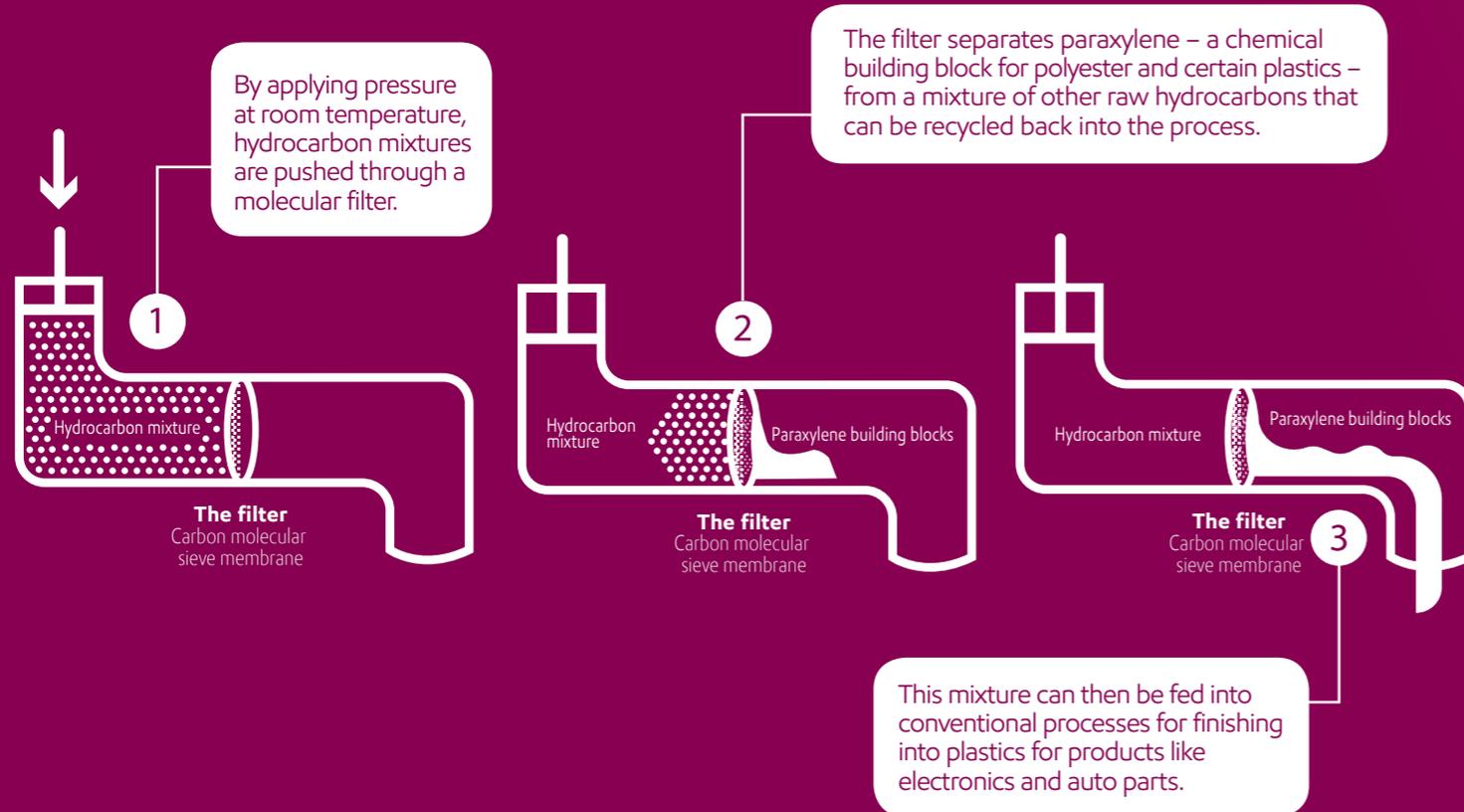
The industrial sector, which produces everything from steel to cellphones, accounts for about one-third of global energy-related CO<sub>2</sub> emissions. ExxonMobil is researching a range of process-intensification technologies that could significantly reduce emissions associated with manufacturing.

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# Chemicals process breakthrough

ExxonMobil and Georgia Tech have developed a potentially revolutionary technology that could significantly **reduce greenhouse gas emissions associated with plastics manufacturing** by using a molecular filter – rather than energy and heat – to perform a key step in the process. It could be 50 times more efficient than today's separation techniques.

## HERE'S HOW IT WORKS:



## Other technologies that can reduce industry-related emissions include:



**Low-energy separations:** Separating molecules is a key part of making energy and chemicals. ExxonMobil is looking for ways to do so using less energy. **ITQ-55** is an ultra-narrow-pore zeolite that can separate ethylene from ethane – a key step in petrochemicals production – by acting as a “molecular sieve” rather than via cryogenic distillation. Developed with Spain’s Instituto de Tecnologia Quimica, it could reduce the energy used to purify ethylene by up to 25%. We also have developed a new gas-treating technology called **RapAdsorb™**, which significantly reduces the infrastructure and energy needed to remove water and CO<sub>2</sub> from natural gas.



**High-efficiency reactors:** ExxonMobil is working to reduce the energy needed to transform hydrocarbons into other useful products. We focus on thermal efficiency, modern reactor design and process miniaturization.



ExxonMobil has developed a range of **high-efficiency catalysts** that help refiners make cleaner, high-quality transportation fuels more efficiently. Our latest is Celestia, a bulk metal hydroprocessing catalyst that is twice as active as the most advanced catalyst in use today.

## Advanced products

ExxonMobil develops and produces a range of petroleum-based **products that help our customers reduce their greenhouse gas emissions and improve efficiency.** These include resilient, lightweight automotive plastics that reduce overall vehicle weight, as well as advanced tire materials and transportation fuels and lubricants – all of which can **enable cars and trucks to go even farther between fill-ups.**



Our advanced products include **packaging solutions** that save fuel and avoid food waste, and **building materials** that make homes and offices more energy efficient.



Our high-performance lubricants – used 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 potential 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 to a lower-carbon energy system.



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



ExxonMobil develops **technologies that reduce carbon emissions** over a product's life cycle. For example, we make a range of advanced products – such as materials for lightweight plastic packaging – that help manufacturers reduce transportation energy use, emissions and waste.



# 2:1

For every one unit of greenhouse gases associated with manufacturing lightweight plastics and other chemical products, more than two units are saved by society through the use of these products (McKinsey & Co.).

# Corporate collaborations

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In our search for energy and environmental solutions, ExxonMobil partners with companies whose expertise in certain areas complements our own. We also work directly with the users of our energy and chemical products – including automakers and packaging companies – to develop new products that reduce energy use and emissions.



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ExxonMobil and IBM are jointly researching the use of **quantum computing** to develop next-generation energy and manufacturing technologies.



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ExxonMobil scientists work directly with a range of automakers to develop fluids and lubricants specifically made to meet the unique needs of **electric vehicles**.



## IBM Q

ExxonMobil was the first energy company to join **IBM's Q Network**, a worldwide community exploring quantum computing applications across industrial sectors and science.



## How is ExxonMobil fueling future energy discoveries?

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No single company or entity is capable of developing the breakthroughs needed to meet the world's energy and environmental challenges. That's why ExxonMobil casts a wide net in the search for new energy technologies – collaborating with universities, national labs, and other companies and innovators around the world.

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## In-house research capabilities

ExxonMobil's R&D program spans a wide range of focus areas, including catalysts and other advanced materials, computational modeling, and process engineering. ExxonMobil also has been a leader in climate research for more than four decades. Our findings are consistently published in peer-reviewed publications.



ExxonMobil has **research and technology labs** around the world, including our main R&D facilities in New Jersey and Texas, and others in Belgium, Canada, China, Malaysia, India and Qatar.



ExxonMobil's world-class computing and data analytics capabilities enable our innovations. We are a founding member of the **U.S. Oil and Gas Blockchain Consortium**, which explores how blockchain technologies can be applied in the oil and gas industry.



# 20K

ExxonMobil employs 20,000 scientists and engineers, including more than 2,200 with Ph.D.s.



## Universities and labs

ExxonMobil works with about **80 universities** around the world to explore next-generation energy and environmental solutions. The centerpiece is our investment in **five global energy centers**: the MIT Energy Initiative; Princeton E-filiates Partnership; Stanford Strategic Energy Alliance; The University of Texas Institute; and the Singapore Energy Center led by the Nanyang Technological University and National University of Singapore. ExxonMobil has committed \$175 million to fund breakthrough energy research at these centers.

In 2019, ExxonMobil formed a partnership with the U.S. Department of Energy's **National Renewable Energy Laboratory** and **National Energy Technology Laboratory**, to jointly research and develop lower-carbon energy systems and technologies. This unique collaboration will focus on next-generation biofuels, carbon capture, life cycle assessment and other promising areas.



# \$100M

ExxonMobil will invest up to \$100 million over 10 years in its research partnership with U.S. national labs.



## Beyond R&D: policy and actions

Meeting the dual challenge is a global issue that requires the collaboration of governments, industries, consumers and other stakeholders. ExxonMobil has been vocal in our support of an economy-wide price on CO<sub>2</sub> emissions. We are a member of the **Climate Leadership Council**, which promotes a carbon fee with the revenues returned to Americans. In 2018, we joined the **Oil and Gas Climate Initiative**, a voluntary initiative representing more than a dozen of the world's largest oil and gas producers working collaboratively toward solutions to mitigate the risks of climate change. We continue to **support the Paris Agreement** as an important framework for addressing climate-change risks.



ExxonMobil has an agreement with Orsted A/S to buy 500 megawatts of **wind and solar power** for our operations in West Texas, making us one of the top 10 corporate wind and solar buyers in 2018.



ExxonMobil is a founding member of the **Alliance to End Plastic Waste**, a collaboration of nearly 30 global companies across the plastics value chain seeking to develop effective ways to minimize and manage plastic waste and promote solutions for used plastics.



# 15%

ExxonMobil is taking steps to reduce methane emissions from our operations by 15%, and flaring by 25%, by 2020 versus 2016.



# \$9B+

Since 2000, ExxonMobil invested more than \$9 billion in R&D of lower-emission solutions.

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

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