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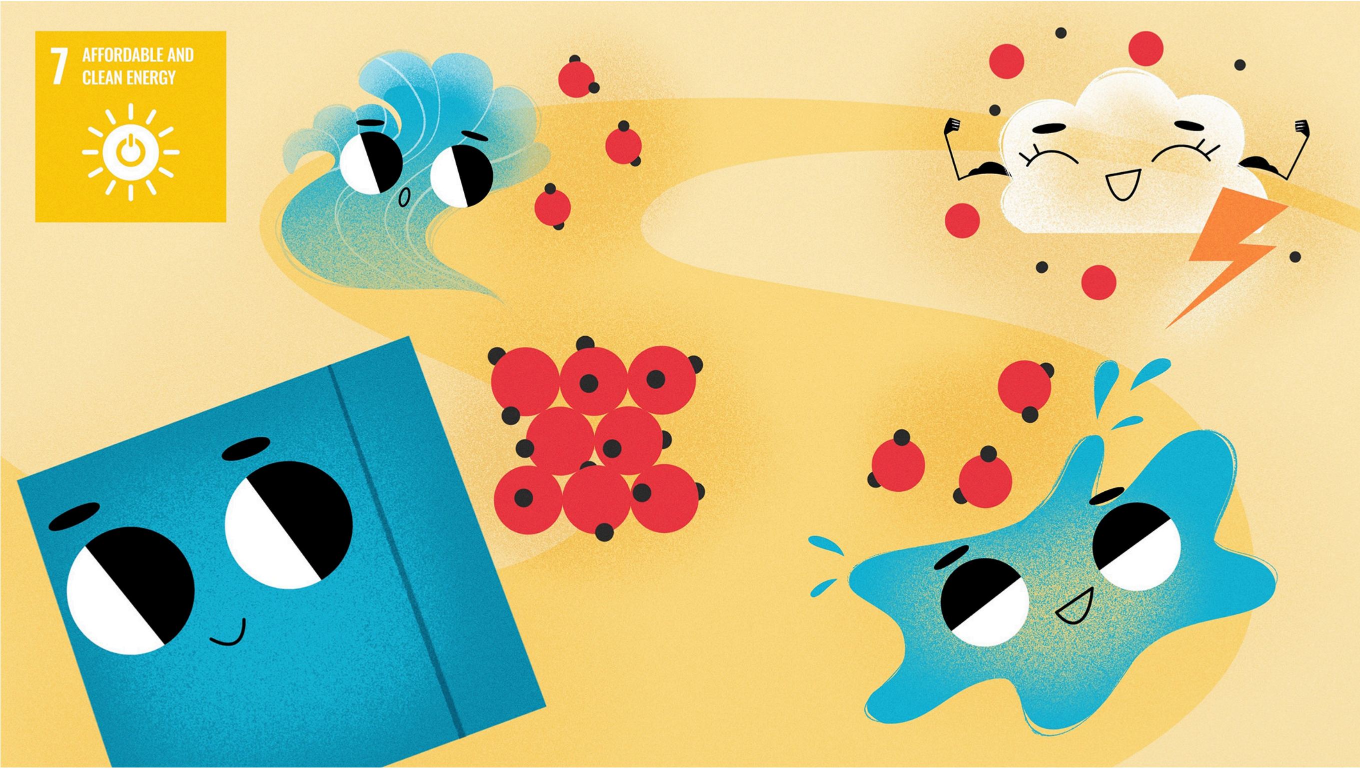

TOWARDS SDG 7: CREATING SUPER-FLAMES WITH ELECTRICITY TO POWER A SUSTAINABLE SOCIETY

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YOUNG REVIEWERS:


DEAN
AGE: 14


ISABELA
AGE: 14


ISACC
AGE: 13


PABLO
AGE: 13


XIAO NING
AGE: 15

For the past few decades, the number of people on Earth has been increasing, making it even more difficult to meet everyone's vital needs. To live our lives, we need to eat, keep warm, and move around. All these actions require energy. Many of the technologies we use nowadays require energy, too. The problem is that most of today's energy comes from burning coal, oil, and gas, which is bad for the planet. This is why the United Nations created Sustainable Development Goal 7, aimed to provide access to affordable, clean, sustainable, and modern energy for all. In this article, you will learn about plasma-assisted combustion, a new way of creating a sustainable energy source. By having better energy sources, we can help all people live better lives, while protecting our planet at the same time.

Watch an interview with the authors of this article to learn even more! (Video 1).

ENERGY FOR ALL

The Sustainable Development Goals are a group of 17 goals created by the United Nations to make our world a **sustainable** place to live. Sustainable Development Goal 7 (SDG 7) is named "Affordable and Clean Energy" and it aims for countries to provide access to affordable, reliable, sustainable, and modern energy for all people [1]. But before exploring how we might meet this goal with the help of science, we need to define some of its complex ideas.

SUSTAINABLE

Using resources wisely to protect the planet for the future. It is about saving energy, reducing waste, and caring for nature so it lasts a long time.

First, what is energy? Energy can be defined as the amount of work that can be done by a force. The rate at which energy is used is what we call power. Energy can take many forms, like heat, light, work, and a more particular form that links matter, called chemical bonds. As living beings, we change energy from one form to another all the time. We eat food that is filled with energy, and we transform it into heat to keep our bodies warm, or to do physical tasks. When you kick a ball, you give energy from your body to the ball. But if you are not eating food, you will not have enough energy to keep playing until the end of the game! This applies to many vital actions of societies, like cooking, traveling, or heating.

One of the keywords of SDG 7 is "all". It means that energy must reach every person on the planet, to improve lives and reduce poverty. The Industrial Revolution, during which modern industry was created, is a great example of how using energy to power things like trains, cars, and stoves made life much better for lots of people. However, according to the United Nations, more than 675 million people still did not have access to electricity in 2021 [2]. So, we need to make sure we provide energy for all eight billion human beings currently on Earth, and the people who will come next.

TRANSITIONING FROM "BAD" TO "GOOD" ENERGY SOURCES

Not all energy sources are good for humans and for the planet. A "good" energy source needs to fulfill three criteria. It needs to be affordable, reliable, and sustainable. Affordable means that it must be cheap enough that everyone can afford to buy it. Reliable means that it should always be safe and accessible. Sustainable is a tricky one. On one hand, it means energy should not damage the environment, but it also means that the world should not run out of the energy source.

FOSSIL ENERGY

Energy coming from the combustion of oil, gas or coal. Often associated with large emissions of carbon dioxide.

RENEWABLE ENERGY

Energy coming from various sources such as the wind, the sunlight, the water flows and that are not directly producing carbon dioxide.

To simplify, we can say that there are two main sources of energy and three big "actions" by which people use most of the energy. The first source is **fossil energy** such as coal, oil, or gas. The second source is **renewable energy**, such as wind, solar, or tidal energy. The three actions are heat, electricity, and transport. Today, most of the world's energy comes from fossil fuels, which power 90% of our heating, 79% of our electricity, and 96% of our transport [2]. But fossil fuels do not meet two of the three criteria for a good energy source—they are not sustainable or reliable. The use of fossil fuels leads to global warming and air pollution. Fossil fuels are also finite, meaning that they will eventually run out. Renewable energies, on the other hand, use the natural power of the environment. They are sustainable but often not as affordable or reliable. For example, solar panels transform light from the sun into electricity, but they cannot work at night. Also, installing solar panels often comes with a cost that the poorest people cannot afford.

Renewable energies are promising, but they will need time to be developed. In the future, societies must be adapted around renewable energies. Actions need to be taken starting today. We must improve the use of fossil energies while we still depend on them.

HOW CAN SCIENCE HELP?

Most fossil fuels are used through **combustion**. To understand how combustion works, we will compare it to cooking food using a very strict recipe. For example, to burn one cup of fuel (CH_4), you need two cups of oxygen (O_2). If you follow the recipe, you will have energy. But you will also have some waste products: carbon dioxide (CO_2) and water (H_2O). We can now write the cooking recipe in one line, called an equation:

1 cup of CH_4 + 2 cups of O_2 = Energy + Waste (1 cup of CO_2 + 2 cups of H_2O)

Combustion creates energy in the form of heat by burning fossil fuels. But there are two major problems that need fixing. The fuel CH_4 is not renewable and will be totally depleted soon. And the waste generated, CO_2, contributes to global warming. There is a need to supply the same amount of energy, but by using less fuel and generating less waste. What if we told you that we could fix the two issues with a simple trick? To do this, we need **plasma**! But what is plasma, and how does it work?

Matter is made of tiny **molecules** that store energy in the form of chemical bonds. There are three well-known states of matter: solid, liquid, and gas (Figure 1). Let us take the example of ice. When you heat (add energy to) ice, it melts into liquid water. If you continue to add energy to the liquid, you get water vapor or steam. If you add even *more* energy, you will transform the steam into plasma. Plasma is like a gas with very high-energy molecules that are perfect for combustion [3].

COMBUSTION

A process where materials like wood or fuel are burning creating heat. For example a campfire or the flame of a candle.

PLASMA

Electrified gas, in which some of the molecules have been cut into extremely energetic atoms. Plasmas transfer a lot of energy into chemical bonds very efficiently.

MOLECULES

Components of all matter, which are composed of atoms that represent different elements, like oxygen (O) or hydrogen (H).

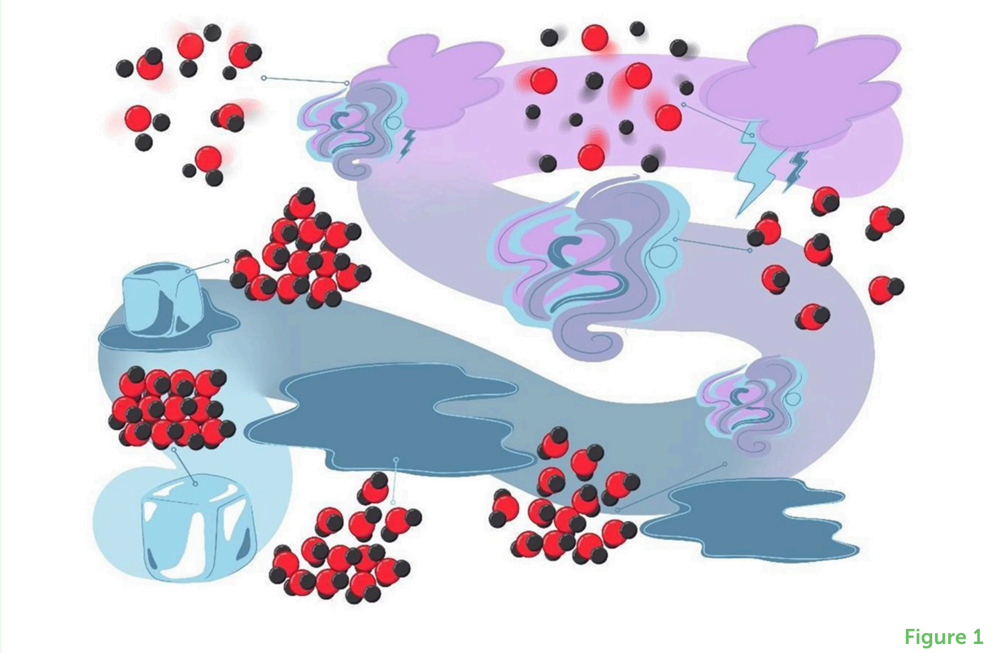

Figure 1

Figure 1

Matter can change between the states of solid, liquid, gas, and plasma as energy is added. This example shows water—H_2O. The red balls are oxygen atoms, and the black balls are hydrogen atoms. As the amount of energy added increases, the links between the atoms get weaker: the ice melts into liquid, the water evaporates into steam, and the steam becomes plasma.

It is possible to turn a gas into plasma with just a bit of electricity. Think of this as an investment. You invest a little bit of electrical energy at the start to get a lot more energy at the end. If we go back to the cooking recipe example, when we add plasma, it is like chopping the ingredients. It is easier to cook when everything is well-chopped! With this trick, we can save fuel and reduce waste!

MAKING MORE ENERGY WITH SUPER-FLAMES

So how can we use plasma to improve regular combustion? We can create super-flames! Super flames, or plasma-assisted flames, are powerful types of fires that use a bit of electricity to create plasma, making the flames burn much hotter and more efficiently than regular flames. One of the best types of super-flames is called a **detonation**. A detonation is a very strong and fast flame, moving faster than the speed of sound! Detonations are more energetic than normal flames for the same amount of fuel. This is great, but tricky, because it is very hard to create and control a detonation. To start a detonation, plasma can be used on a flame (Figure 2). When plasma is added, the flame quickly accelerates and becomes a detonation [4]. The detonation generates a very large amount of useful energy because the particles are compressed in a small region called the shockwave. Close to this region, the temperature and the pressure are so high that the combustion process is stronger than in a normal flame.

DETONATION

A flame that spreads at speeds faster than the speed of sound. Detonations are powerful and very effective at generating energy.

USING LESS FUEL WITH SUPER-FLAMES

Another way to improve the combustion process is to simply use less fuel. But what happens if not enough fuel is provided to a flame? It

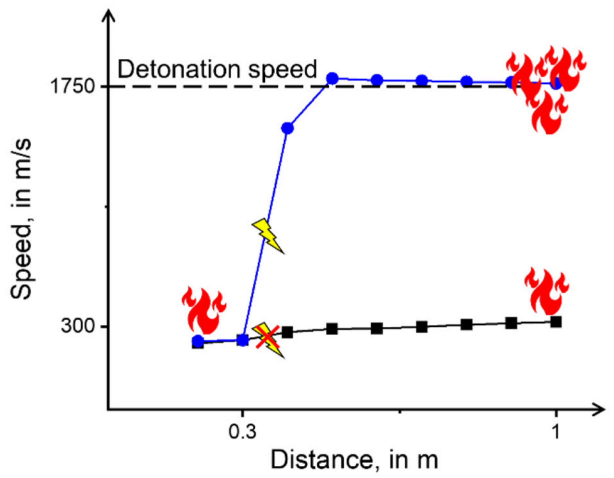

Figure 2

Figure 2

A comparison between a regular flame and a super-flame. The *X*-axis represents the traveled distance by the flames in meters. The *Y*-axis represents the speed in meters per second. The blue curve is the speed of a flame assisted by plasma, and the black curve is the speed of a flame without plasma. The plasma-assisted flame quickly increases in speed and becomes a detonation or super-flame that travels above the detonation speed of 1,750 meters per second (or 6,300 kilometers per hour). The flame without plasma does not increase in speed.

becomes lean. A **lean flame** becomes more and more unstable until it disappears, or blows out. However, if we use plasma, we can force the flame to stabilize and be sustained for longer, even if we use a very small amount of fuel. This is called extending the blow-off limits of lean flames (Figure 3). By using plasma on a lean flame, it is possible to save a lot of fuel and produce less waste [5].

LEAN FLAMES

Flames that are very unstable and can vanish easily due to lack of fuel. A lean flame can be stabilized by plasma addition.

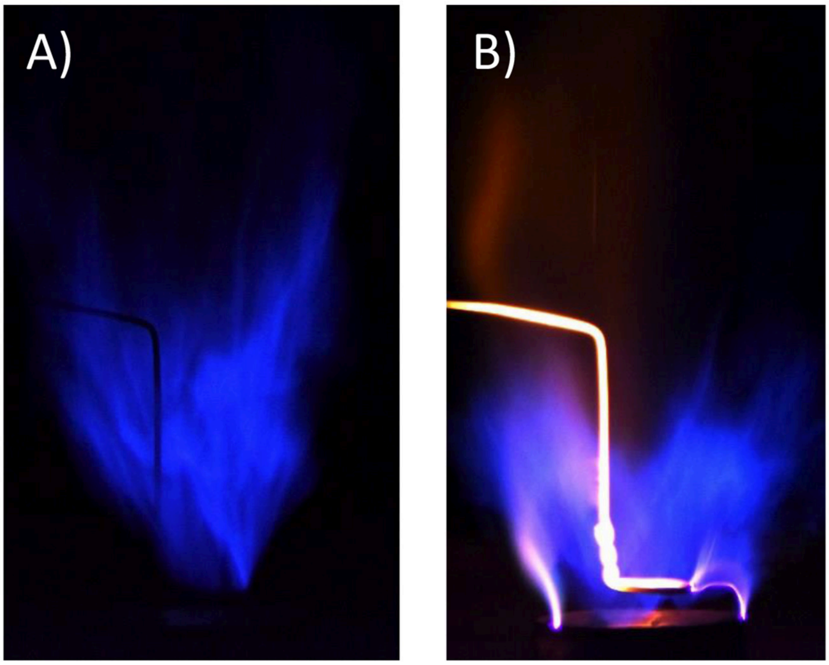

Figure 3

Figure 3

How plasma helps lean flames. **(A)** A weak flame, in the absence of plasma, is close to blowing off because the amount of fuel is small. **(B)** The same flame is helped by plasma (pink at bottom). You can see that this super-flame is more compact, brighter, and hotter (the flame is reddish and the piece of metal glows), just by the addition of plasma to its base.

WHAT IS LEFT TO DO?

Plasma-assisted combustion is a very recent area of research. There is still a lot to do! The number of people looking at the interaction between flames and plasmas is growing. But there are questions that still need to be solved. For example, what is the best way to use plasma technology in modern engines? Or why does plasma work so well for some conditions but not so well for others? How can we make plasma-assisted combustion safe for global use?

Despite these questions, we now know that super-flames may be a reliable way of generating large amounts of energy with the least amount of fuel consumption and waste generation. This is important for SDG 7, as it may be a quick solution to the sustainability issues of classical combustion of fossil fuels. It will help us make better use of fossil fuels while we transition to more sustainable energy sources. Finally, plasma technology is not limited to traditional fossil fuels, it can also enhance the combustion of alternative and more sustainable fuel sources. These might include hydrogen, biofuels, or synthetic fuels made from renewable resources. The more we know about these new fuels, the faster we can achieve SDG 7.

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YOUNG REVIEWERS

DEAN, AGE: 14

Hi, my name is Dean, and I am a student in The KAUST School, in 8th Grade. I enjoy reading a book, watching TV, studying, and playing with my cat. I enjoy being creative and I am a visual learner.

ISABELA, AGE: 14

Hi, my name is Isabela, and I am currently an eighth grader in TKS. I am a visual learner who enjoys hands-on activities such as rock climbing, painting, and gymnastics.

ISACC, AGE: 13

My name is Isacc. I reviewed this paper through a Club at my school. My hobbies include: reading, robotics, basketball, and running. I have gone to many different schools across Europe and Saudi Arabia is the first country I have lived in outside of Europe. I really enjoy school here, but not the weather. I have enjoyed reviewing this paper and hope I can review more.

PABLO, AGE: 13

My name is Pablo. I am 13 years old and a student at The KAUST School. My hobbies include swimming, 3-D modeling and printing. I also enjoy learning and science.

XIAO NING, AGE: 15

Hi, I am Xiao Ning. Ever since I was young, I have been intrigued by the many aspects of nature and science. This interest has bloomed and continues to grow even now, as in my middle to high school career I have participated in many science-related activities and excelled in my science studies. For instance, I have participated in WEP week, a science-circulated event. Overall, my love for science drives my motivation to become a young reviewer.

AUTHORS

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Deanna Lacoste graduated with a Ph.D. in combustion science from the University of Poitiers, France, in 2002. She started to work on plasma physics and on plasma assisted combustion in 2003, at Ecole Centrale Paris (now CentraleSupelec). After 11 years with the French CNRS, in 2014 she joined the King Abdullah University of Science and Technology (KAUST), in Saudi Arabia. Since 2021, she is an associate professor of mechanical engineering affiliated with the Clean Energy Research Platform, KAUST. Her research mainly focusses on plasma-assisted combustion, non-equilibrium plasma discharges at atmospheric pressure, control of flame dynamics, and detonation. *deanna.lacoste@kaust.edu.sa

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