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in partnership with ENGIE

GASIFY OR ELECTRIFY?

Pathways for the Zero-Carbone Energy Future

ÉDITO

Resilience and ENERGY DIVERSITY


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DIDIER HOLLEAUX, EXECUTIVE VICE PRESIDENT ENGIE

For years now our energy system has drawn its strength from the combination of different energy vectors, in particular electricity and gas. Why, at a time when the perspective of an energy transition based on progressively decarbonised and decentralised complementary energies is coming to the fore, would we pit electricity against gas?

Physics and chemistry have not yet provided us with any means of storing energy that is both easy to mobilise and transport and as dense in energy as molecular bonds. This explains the success of petroleum products in the last century, however their high carbon footprint means they will progressively need to be replaced by gas (first natural and then green gas). The rise of intermittent renewable energies producing green electricity accentuates the need to develop reliable and flexible solutions for the production, storage and transport of energy to meet the needs of the power grid.

If the target to be carbon neutral by 2050 naturally leads to a greater electrification of uses and if demand-side management (energy efficiency and time-based management) certainly have a role to play, we must not rule out the different low-carbon energy vectors (hydrogen, biogas, etc.), which are just as essential a part of an economic, carbon neutral energy mix. In the context of the energy transition to zero carbon, these high-performance solutions are also vital if we are to meet the needs of our customers (consumers, industry and local authorities).

The aim of this survey is to present the many and varied solutions that will make the reduction of greenhouse gas emissions a reality and ensure that achieving carbon neutrality is possible and makes the most of every available resource and energy vector. Like biodiversity, energy diversity makes our world more resilient and it must therefore be preserved. ■

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www.pourlascience.fr
170 bis boulevard du Montparnasse 75014 Paris
Tél. 01 55 42 84 00

Group POUR LA SCIENCE
Editorial staff director: Cécile Lestienne
Editor in chief: Maurice Mashaal
A special issue in partnership with ENGIE:
Loïc Mangin and Simon Thurston
Artistic direction and realisation:
Ghislaine Salmon-Legagneur
Copy editor: Maud Bruguière
Marketing & diffusion:
Charline Buché & Elena Delanne
Personnel management: Olivia Le Prévost
Fabrication: Marianne Sigogne et Zoe Farre Vilalta
Publisher and manager:
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Media and communication: Susan Mackie
susan.mackie@pourlascience.fr Tél: 01 55 42 85 05
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Why finding complementary technological solutions is indispensable

For 200 years, humanity has thrived on the availability of energy that is easy to store and transport, but because of the climate crisis we now have to decarbonise our economies and lifestyles within a time span of two generations. Every transition scenario includes a reduction in the overall volume of energy and the decarbonisation of what remains. We therefore need to consume less energy and at the same time move to greener forms of energy, which should be, as far as possible, as flexible and available as fossil fuels. This special issue of *Pour la Science* explores the wide variety of technological solutions that are essential if we are to meet the challenge of reducing energy demand, whilst providing readily available green energy. These solutions exist at every step of the value chain, from production (biogas, integrating solar panels and crops) and storage (batteries, hydrogen) to the point of consumption (new heating systems).

CONTENTS

MICHAEL E. WEBBER,
CHIEF SCIENCE & TECHNOLOGY
OFFICER, ENGIE

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Research is necessary to accelerate our transition to a zero-carbon world

By classical definition from the early industrial era, energy is the capacity to do work, however in the modern context that seems very limited compared with what energy actually offers society. Taking a broader and updated view, energy is the ability to do interesting and useful things. Energy brings illumination, information, heat, clean water, abundant food, motion, comfort and much more to our homes and factories with the the turn of a valve or the touch of a button. It is the potential to harvest a crop, refrigerate it, and fly around the world, but it also guarantees education, health and security. Our civilisation is founded on access to energy and the corollary is therefore that a lack of energy would lead to its collapse.

An absence of energy does not mean it disappears entirely: the laws of thermodynamics tell us that energy is conserved. Energy is an inherently finite resource. We cannot make more of it; we can only move it around or transform it. At its heart, our relationship with energy is about harnessing the benefits and containing the environmental impacts of those transformations. Bringing the benefits of energy to everyone without heating the atmosphere, acidifying the oceans, or denuding land will require new thinking and new solutions.

THE WORLD IS A COMPLEX PLACE

In the modern world, everyone uses energy with a mixture of elation and guilt: it's the energy-lover's dilemma. How do we get all the benefits we enjoy from consuming energy without the downside impacts of pollution, price volatility and national security risks?

The answer is to recognise that each fuel and technology has its upside benefits and downside risks. Worldwide energy use is a complex system with many parts. The energy sector is intertwined with society in many obvious and non-obvious ways.

If there is one lesson we should keep in mind for our energy challenges, it is that there are no universal, immediate solutions. We need a suite of solutions adapted to each location because no single option can get us all the way to our zero-carbon future without a critical drawback such a high cost, insufficient scale, or poor reliability.

That means we need innovative thinkers to develop more options, lower the cost of existing options and to optimise how they all fit together. The world's research ecosystem of industrial facilities, national labs, and universities in many countries must step up with high levels of internal and governmental support to accelerate the pace of our innovation and because the challenge is complex and too big for any one company or government to solve, we must collaborate across sectors, academic disciplines, and borders.

The way to solve this conundrum is not by hashing out old clichés of fossil fuels versus renewables, electricity versus gas, or other tired battles. We need a more refined view. The same thinking that got us into these problems - drill more, pave more, consume more - will not get us out of them. Tired techno-enthusiasm that just says we can use smarter gadgets won't be enough, either. Energy efficiency is one way of reducing our carbon footprint without affecting our lifestyle, but it is not enough.

The fastest, cheapest and most reliable way to reach zero-carbon energy includes a mixture of low-carbon electricity and low-carbon gases. We need cleaner forms of energy and we need to clean up conventional forms with carbon capture and scrubbers so that we can maintain and expand energy access without scorching the planet.

The areas that need rapid attention are low-carbon power generation (such as wind, solar, and geothermal energy), low-carbon gases (such as biomethane, synthetic methane, hydrogen and hydrogen carriers such as ammonia, formic acid and methanol), technologies that reverse the accumulation of CO_2 in the atmosphere (through carbon capture, direct air capture, and soil carbon sequestration), cross-cutting tools (such as drones, robots, sensors, and artificial intelligence) and smart and efficient uses of energy (including energy storage, smart appliances and user education to change our behaviours and habits).

ENGIE's corporate research program is organised around these themes and our benchmarking with the world's largest national laboratories and energy and technology companies indicates that we are not alone with our view of the future. Indeed, most of us are tackling similar problems. We just need to move more quickly collectively.

“As we are facing similar problems, couldn't we work together to find the solutions?”

Adopting a cleaner suite of options while increasing energy access and letting go of our dirtier past is our critical path forward. Change is good, so we should go for it. But change is slow, so we better get started. This is where we need research: to accelerate the transition.

TIME IS RUNNING OUT

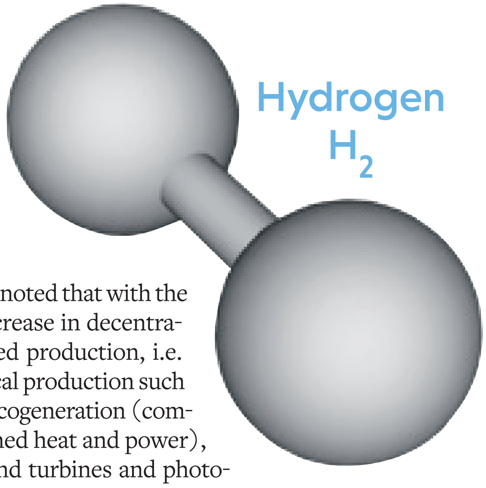
It usually takes decades or centuries to transition from one dominant fuel or technology to another. In the United States, coal became the most popular energy source in 1885 and was only surpassed 65 years later by petroleum in 1950. Petroleum still leads today, but might be overtaken by natural gas in the next decade, meaning it will have ruled for 80 years.

While natural gas provides some important environmental and performance benefits, we don't have another 80 years to wait to replace it with cleaner options such as zero-carbon electricity or other gases with lower carbon footprints. That means the race is on and our task in the research world is to increase the scale and decrease the cost of those alternatives so they can be adopted widely sooner.

The mission of our teams is now clear, we just need to pick up the pace in order to meet the energy challenges alongside out scientific and academic partners and develop the energy solutions of the future, the ones that will allow us to preserve biodiversity, the climate and social inclusion. ■

The molecules of the energy transition

Whatever the path to a zero-carbon world, electricity will not be the sole source of energy: molecules such as hydrogen, methane and ethanol will be required for a long time to come.



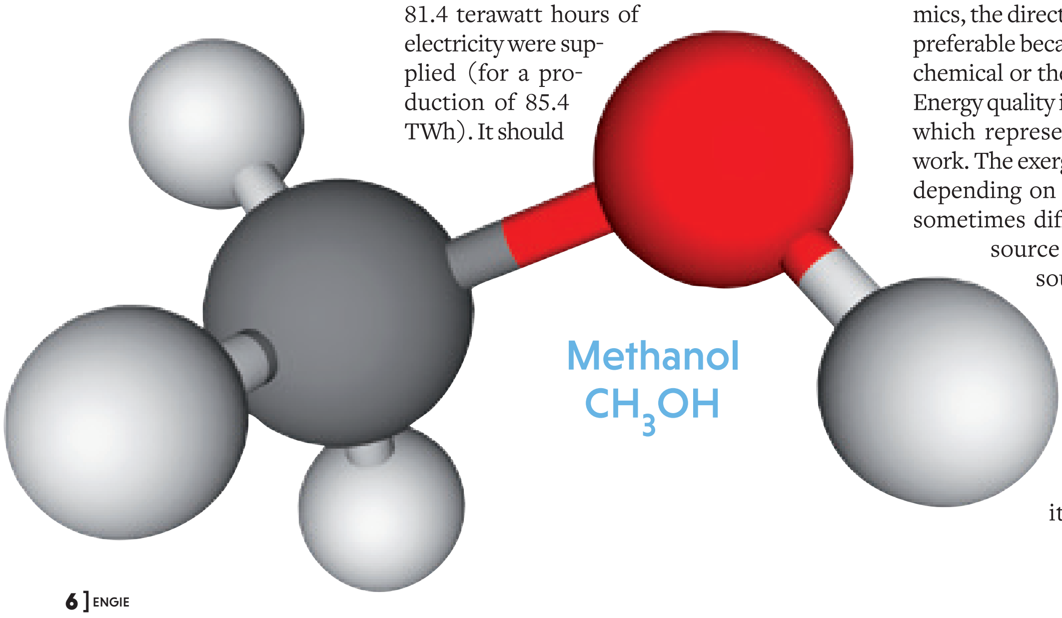
WRITTEN BY:
RONNIE BELMANS, PROFESSOR AT THE CATHOLIC UNIVERSITY OF LEUVEN, CEO ENERGYVILLE AND JAN MERTENS, PROFESSOR AT UNIVERSITY OF GENT, ENGIE CHIEF SCIENTIFIC OFFICER.

THE AUTHORS WOULD LIKE TO THANK ENGIE'S SCIENTIFIC COUNCIL FOR THE RICH AND RELEVANT DISCUSSIONS ON THE QUESTION.

For a long time, we have considered the decarbonisation of electricity as a key part of the energy transition, in particular by means of a massive increase in the use of renewable energy sources to generate electricity. Despite the intermittency of renewables, the development of information and data management technologies should ensure that the power system operates in a stable and reliable manner. Supply will have to adapt to fluctuating demand, in particular by using batteries to store surplus energy. At the end of the day, customers will be able to rely on electricity to provide the best energy services, however even if this "electric model" will certainly be at the heart of the future energy system, there are nevertheless certain questions and concerns.

WHAT SHARE FOR ELECTRICITY

First of all, a clear distinction must be made between the energy system as a whole and electricity generation, which only accounts for a small part of it. For example in Belgium in 2016, 81.4 terawatt hours of electricity were supplied (for a production of 85.4 TWh). It should be noted that with the increase in decentralised production, i.e. local production such as cogeneration (combined heat and power), wind turbines and photovoltaics, these figures are becoming less and less accurate.



The total final energy consumption (electricity, gas, oil, coal, biomass, waste) was 489 terawatt hours. In addition, primary energy consumption (which measures a country's total energy demand) was 657 terawatt hours. The difference can be explained by the energy consumed by the chemical, iron, steel and nuclear industries etc, however this figure does not include energy used by maritime transport and international aviation. At the end of the day, it is estimated that electricity accounts for 16.6% of final energy consumption in Belgium. If we consider all of Europe, this figure rises to 17.9% (3,255 terawatt hours of electricity compared to 18,154 TWh of primary energy).

According to the second law of thermodynamics, the direct use of electrical energy is always preferable because transforming electricity into chemical or thermal energy reduces its quality. Energy quality is measured in terms of its exergy, which represents its capacity to do physical work. The exergy of electricity is 100%, however depending on what services are required it is sometimes difficult to replace a given energy source by electricity from renewable sources. This is where molecules can complement or even become a substitute for the electrons. What molecules are we talking about? Hydrogen, methane, methanol, ethane and ethanol amongst others.

Whatever we use them for, it is vital that we make these

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molecules using carbon free electricity or biogas, otherwise the energy transition will fail. Only two methods are carbon neutral: using green energy to make molecules from water and CO_2 or from biomass, which we will not discuss. An alternative, or rather an intermediate solution, would be carbon capture and storage, or even reusing CO_2.

In heavy, energy-intensive industries, molecules are needed as energy carriers, but above all as raw materials. To make a molecule of methane (CH_4) or methanol (CH_3OH) from CO_2 and H_2O requires much more energy than the (reusable) energy contained in the molecule itself. Consequently, this need for molecules will greatly increase total energy demand. Certain sectors of industry that require molecules for specific applications, for example specialised chemistry, will have to be studied on a case-by-case basis.

A good example of the contribution of molecules to a successful energy transition is during the "Dunkelflaute", a German term for a long period without sun and wind when energy production is impossible. Hydrogen and "clean" molecules consisting of one (methane and methanol) or two carbon atoms (ethane C_2H_6 and ethanol C_2H_5OH) will help make up for the lack of solar and wind energy. It will then be a matter of choosing the most suitable one.

> "The virtues of each of these molecules are often the most apparent when considering the transport sector."

TRANSPORT AND MOLECULES

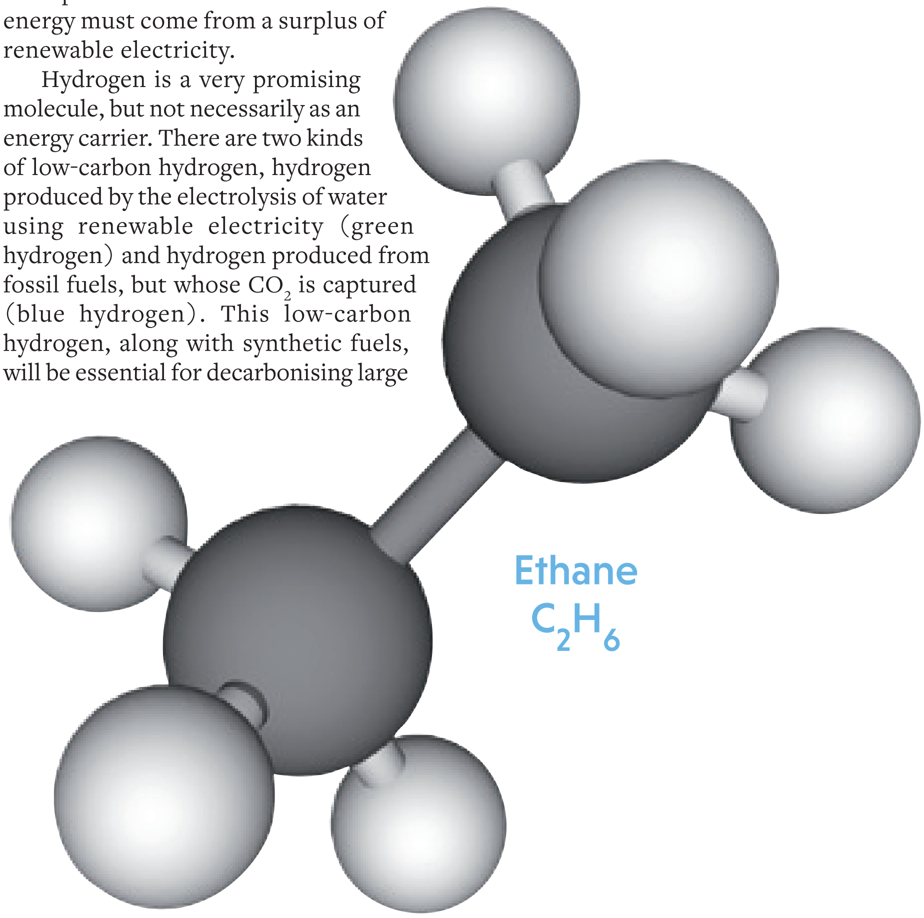
The virtues of each of these molecules are often the most apparent when considering the transport sector, although we must be careful not to generalise. Two-wheeled vehicles, from the increasingly popular electric bikes to the growing market for electric motorcycles, do not need molecules. The same goes for private electric cars. For all these vehicles, batteries are more advantageous in terms of cost than hydrogen-based solutions. They can be charged easily using the existing infrastructure and they boast much better energy efficiency compared, for example, to fuel cells.

The future of road freight transport is still unclear, although it is true that battery powered electric trucks are already on the road. Siemens is taking a different approach: it has equipped one lane of a motorway with catenaries so that hybrid trucks can run on electricity, whilst simultaneously charging their batteries, which are indispensable for the first and last kilometres of their journey after leaving the eHighway. Here again, the need for molecules will be low or even zero.

Trains, buses and local transport will increasingly be electric. Inland water transport will probably also be powered by electricity, at least for part of its activity, however we do not know yet whether the batteries' energy density will allow boats to cover long distances without them taking up too much space on board or increasing weight significantly. Molecules will certainly have a role to play in this sector, especially for maritime transport where energy needs are much greater. The same is true for aviation, although the first electric aircraft have already begun making short-range flights. As for the drones that will play such an important role in future mobility solutions (delivery services, taxis in large cities etc.), they are already electric.

Without expressing a preference, let us just note at this stage that different molecules are available. Since each has its advantages and disadvantages, it is important to take into account the energy required for their production and the fact that this energy must come from a surplus of renewable electricity.

Hydrogen is a very promising molecule, but not necessarily as an energy carrier. There are two kinds of low-carbon hydrogen, hydrogen produced by the electrolysis of water using renewable electricity (green hydrogen) and hydrogen produced from fossil fuels, but whose CO_2 is captured (blue hydrogen). This low-carbon hydrogen, along with synthetic fuels, will be essential for decarbonising large



Ethane
C_2H_6

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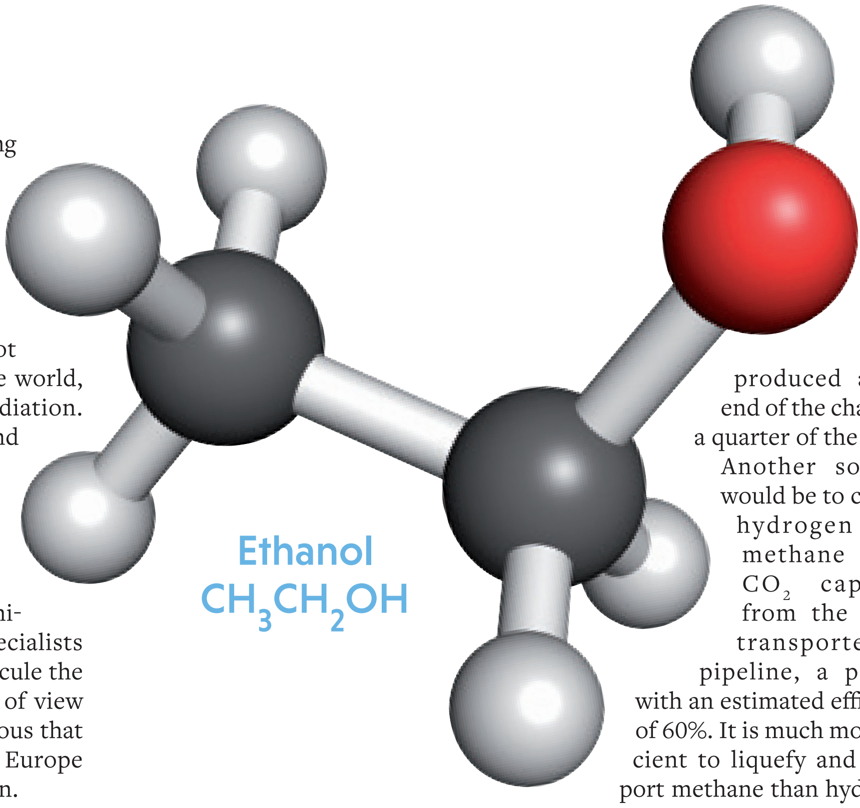

Ethanol
CH_3CH_2OH

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sectors of the world economy including the chemical, petrochemical, steel, cement and paper industries and will therefore be a valuable aid in our efforts to limit global warming to less than 2°C.

Many studies extol the merits of producing electricity in deserts. Not only do they cover large areas of the world, they are also areas of high solar radiation. Research indicates that the Sahara and Australia are both potential areas, but the question is how would we transport this energy from the Sahara to Europe for example? There are two ways: high-voltage direct current (HVDC) lines, or in the form of chemical energy, i.e. molecules. Many specialists talk about hydrogen, but is this molecule the most suitable from an energy point of view and is it the most efficient? It is obvious that the distance between Australia and Europe means that electricity is not an option.

THE ADVANTAGE OF METHANE

Let's take a closer look at the hydrogen energy chain. Hydrogen is produced by the electrolysis of water using an electrolyser, which is a device that uses electrical energy to split water (H_2O) into H_2 and O. We will assume an efficiency of 70% for this step. Finding water in the Sahara or in any other desert environment would not be easy, but let's move on.

The most efficient way of transporting hydrogen to Europe is by ship (liquid hydrogen stored in cryogenic tanks). As the boiling temperature of hydrogen is extremely low (- 252.87°C), its liquefaction is a very energy-intensive process. Different efficiency values exist in the literature, but let's take 70%.

Energy consumption for transportation, including transporting gas by pipeline to the liquefaction plant on the coast is estimated at 10%, so the efficiency of this third stage is 90%. A further 5% more energy is lost to evaporation. The overall efficiency is therefore approximately 40%. The hydrogen can then be injected directly into the natural gas distribution network and delivered to the final consumer as is.

Hydrogen can be converted into electricity at the point of consumption by a fuel cell (with an efficiency of 60%), therefore avoiding any power losses during transmission as the electricity is produced close to the end consumer. Taking all of these calculations into account, for a production of 1,000 megawatts of electrical energy, 251 megawatts are produced at the end of the chain, i.e. a quarter of the total.

Another solution would be to convert hydrogen into methane using CO_2 captured from the air or transported by pipeline, a process with an estimated efficiency of 60%. It is much more efficient to liquefy and transport methane than hydrogen, with respectively 95% efficiency and about 0.1% loss per day (i.e. 3% per trip). In terms of evaporation, we can count on an efficiency of 99%, leading to an overall efficiency at this stage of 54.7%. As far as electricity generation is concerned, a conventional high-efficiency power plant could be used (65%), however as the electricity production is centralised, we would have to take into account line losses (92%), which gives an overall efficiency of 32.7%.

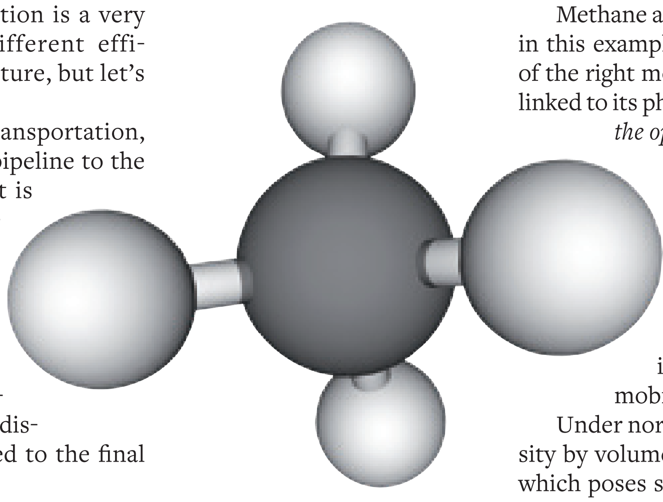
THE RIGHT MOLECULE FOR THE RIGHT USE

Methane appears to be more advantageous in this example: broadly speaking, the choice of the right molecule for a given use is closely linked to its physical properties (*see the table on the opposite page*).

The most relevant point of comparison is energy density (per unit of mass or volume). The higher the value, the more useful the energy carrier and the easier to transport and store it is, making it, in this case, more suitable for mobile applications.

Under normal conditions, the energy density by volume of hydrogen is extremely low, which poses storage and transport problems. We can alleviate these constraints in part by increasing the pressure, but its energy density will remain at best six times lower than that of gasoline, which will always be a major disadvantage in transport.

In comparison, the energy density of liquid methane (LNG) is more than twice that of liquid hydrogen. For the same volume, liquid



Methane
CH_4

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EACH ENERGY HAS SPECIFIC PROPERTIES

Energy Type	Specific energy MJ/kg	Energy density MJ/l	Specific mass kg/m^3
Residential heating oil	46,2	37,3	807,359
Natural gas	53,6	0,0364	0,679
Methanol	19,7	15,6	791,878
Methane (1.013 bar. 15°C)	55,6	0,0378	0,680
Propane (LPG)	49,6	25,3	510,081
Butane (LPG)	49,1	27,7	564,155
LNG (-160°C)	53,6	22,2	414,179
Liquid ammonia (its combustion provides N_2 and H_2O)	18,6	11,5	618,280
Kerosene	43	35	813,953
Higher heating value (HHV) liquid hydrogen	141,86	10,044	70,802
Lower heating value (LHV) liquid hydrogen	119,93	8,491	70,800
HHV hydrogen (1 atm, 15.5°C)	141,86	0,01188	0,084
LHV hydrogen (1 atm, 15.5°C)	119,93	0,01005	0,084
HHV hydrogen (690 atm, 15.5°C)	141,86	5,323	37,523
LHV hydrogen (690 atm, 15.5°C)	119,93	4,5	37,522
Gasoline (petrol)	46,4	34,2	737,069
Ethanol	30	24	800,000
Diesel	45,6	38,6	846,491
Crude oil	41,868	37	883,730
Compressed natural gas (250 bar)	53,6	9	167,910
Biodiesel oil	42,2	33	781,991

methane provides twice as much energy. Moreover, as we have seen above, the low boiling temperature of hydrogen leads to significant constraints in terms of the equipment required (tanks, pumps and compressors).

GREEN HYDROGEN… OR BLUE?

The conclusion is that there will be a massive need for hydrogen produced from renewable sources in a carbon-free society. This molecule will represent a critical intermediate step in the supply of the specific energy best suited to each need and an essential raw material for industry.

The choice between green hydrogen and its blue counterpart will obviously depend on cost and, more specifically for green hydrogen, on the availability of the renewable energy resources needed to produce it. With regard to blue hydrogen, the question of public opinion and the acceptance of CO_2 storage will need to be taken into account.

CO_2 capture and storage is best suited to large installations, for example in the chemical or steel industry, as they are already equipped with pipelines and storage facilities. The road to green hydrogen has many twists and turns. Whichever solution is chosen there is still a long way to go, even if some technologies such as electrolysers are already mature.

In any case, hydrogen or carbon-based molecules will be indispensable for a long time to come if the energy transition is to become a reality. ■

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Optimising carbon reductions

Does Europe have the technical and financial wherewithal to achieve a carbon neutral economy by 2050? As the new commission makes the Green Deal its priority, industry looks for concrete solutions.

WRITTEN BY:
HUGUES DE PEUFEILHOUX, GAUTHIER DE MAERE D'AERTRYCKE AND PIERRE-LAURENT LUCILLE, ENGIE

In December 2019, Ursula von der Leyen, President of the European Commission, officially launched the *European Green Deal* that aims to make Europe the first carbon-neutral continent by 2050. Is this a realistic goal?

"Decarbonizing Central Western Europe", an ENGIE study conducted in several countries in 2019 (see figure opposite), provides some answers to the question. It analyses the shift in energy production toward clean sources of energy from an economic viewpoint. More specifically, it aims to test the feasibility of making Western Europe's electricity, heating and transport sectors carbon neutral by 2050 and to identify the optimal path for the economy taking the advantages of each energy vector into consideration.

In addition to the electricity sector, which is familiar territory when it comes to creating energy models, other energy uses such as industrial and residential heat production, transport and agriculture were the subject of simulations in order to work out the effects of different substitutions, which are an inherent part of climate change mitigation. The aim is to find the optimal mix of energy sources (electricity, biogas, hydrogen and biomass) in terms of usage.


Countries in the "Decarbonizing Central Western Europe" study.

For reasons of public acceptability and the question of site availability, carbon capture and storage (CCS) was not taken into account. We did however consider all the other energy technologies, including storage systems and solutions to facilitate flexibility (such as vehicle-to-grid), which contribute to meeting the goal of a zero carbon system. It is worth noting that in order to reach this objective, ambitious efforts will be required in terms of energy efficiency that will lead to a reduction in final energy demand of almost 41% by 2050.

Compared to most of the available studies that simulate annual figures, or just the final picture in 2050, or only focus on one sub-sector, this study represents a decisive step forward as it considers a combined optimal mix for all energy uses with a hourly granularity analysis. Thanks to this study, we can now see

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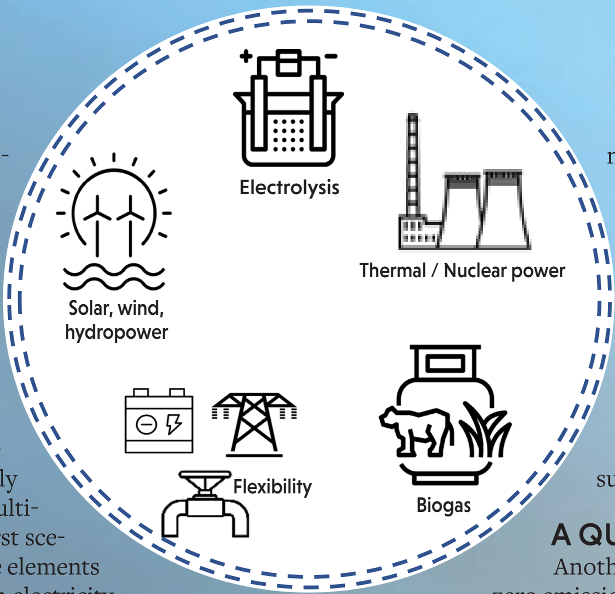


Key technologies enabling the decarbonisation.

the real impact of technical and economic constraints, such as seasonal variations in energy consumption and production, peaks in consumption and the economic interdependence of production sources.

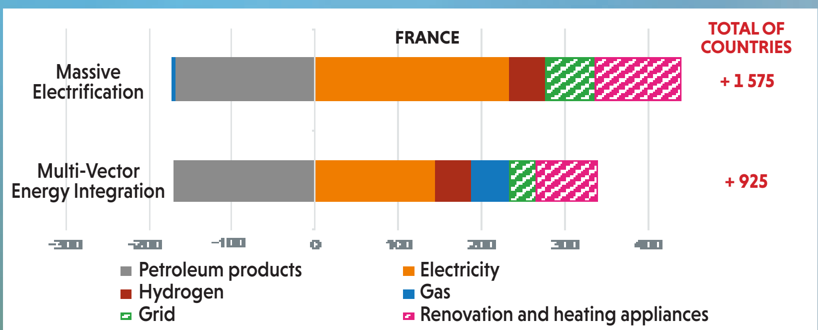
Five different scenarios were modelled. Let's take a look at the two most representative ones amongst those that ensure a successful energy transition: an early adoption of electrification and multi-vector energy integration. In the first scenario, Europe would mainly replace elements of its current energy mix with green electricity, relying solely on domestic resources to remain energy independent and rapidly and massively electrifying end-uses. This scenario implies an intense programme of electrification to meet more than 60% of energy needs, compared to just 25% today.

In the second scenario, Europe promotes the development of green electricity and green gases (biomethane, green hydrogen etc.) and imports green gas from certain trading partners as required. Even in this scenario that allows for imports, the energy independence of the zone of Europe under consideration would be much greater than today (82% in 2050 compared to 17% today).

Both scenarios analyse the flexibility of the power system that results from the optimal use of resources, from battery storage to thermal power stations fuelled by green gas. Contrary to the situation today, critical voltage is no longer the time of absolute peak demand, but the period when the difference between demand and the contribution of intermittent renewable resources is greatest, for example several consecutive days without wind during the winter. Such factors have a greater effect on the electrification scenario and, as a result, more flexibility resources need to be deployed to cope with them. What are the main results and what lessons have been learned?

First of all, the reassuring news is that several scenarios with varying amounts of electrification will allow us to achieve carbon neutrality. In every case, a successful energy transition rests on three pillars: energy efficiency, the massive development of renewable electricity and the optimised allocation of different energy vectors to meet the various uses. This last point implies the use of gas (natural and then renewable) whenever it is more competitive and harder to substitute.

Depending on the scenario (massive electrification or multi-vector energy integration), the differences in additional costs (hatched) compared to "business as usual".



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A QUESTION OF COST

Another lesson is that moving toward zero emissions in the context of a multi-vector energy scenario is less costly (see figure below) than electrification. The difference in cost based on the net present value of the entire energy system amounts to 650 billion euros. What are the reasons for this extra cost? In fact the multi-vector energy scenario does away with the need to increase power system flexibility and to dramatically increase the size of the electricity transmission and distribution network in order to cope with a more distributed power capacity in location and time.

The study also shows that European biomethane resources are used in full in every scenario, in association with 500 terawatt-hours of green hydrogen, which is slightly higher than the current French consumption of natural gas. The complement would either come from green gas imports (in the multi-vector energy scenario), or by additional hydrogen production in Europe (in the electrification scenario). In Europe, France has a competitive advantage in terms of renewable resources (wind and solar power, biomass) and will have to call upon all of them. Relying on only two of the three resources would lead to an unnecessary increase in the size of Europe's power system, in addition to the annual development needs for renewable capacities that already amount to 44 gigawatts (27 for solar and 17 for wind) over a 30-year-period, which is a major challenge both in terms of investment and acceptability.

At the end of the day switching to electricity for certain end-uses is indispensable, but if we go too far along the avenue of electrification, it could be at the risk of an excessively abrupt energy transition from a technical standpoint and one which would not be beneficial for the environment. When the effects are measured throughout the value chain - and not just in terms of energy production and consumption - making full use of the various low carbon energy vectors (including green gases) allows for a more resilient and less expensive energy transition. The European Commission should take note! ■

Princess Elisabeth Antarctica, Belgium's polar research station.

The eagerly awaited battery revolution

The rapid growth of renewable energies must go hand in hand with the wide-scale deployment of electricity storage solutions. Current technologies are efficient, but still insufficiently so: research is working fast to remedy this situation.

WRITTEN BY:
RAFAEL JAHN AND DOMINIQUE CORBISIER, ENGIE LABORELEC.
PAULO TORRES, ENGIE.

Anchored on a rocky outcrop, this Belgian polar research station is like no other: thanks to its photovoltaic and thermal panels, complemented by nine wind turbines, Princess Elisabeth Antarctica (inaugurated on February 15, 2009) runs entirely on renewable energies. Such a feat wouldn't have been possible without the batteries that enable the station to store electricity and manage the intermittent supply of power.

And it is a fact that such measures will be essential in the transition toward a carbon neutral world, a process that will see a significant increase in renewable energy sources, whose intermittent nature will exceed the limits of the power grid's current capacity to balance supply and demand, at least locally. Intermittency is a more complex characteristic to manage than we think. Today the grid's network of conventional, interconnected power plants and power reserves are largely sufficient to allow the grid operator to compensate for short periods of intermittency (from one second to a quarter of an hour). The question arises however for longer periods, such as a few hours during which clouds disrupt solar power production, at night or on days with neither wind nor strong sunshine. Increasing power reserves by keeping a higher number of conventional power plants on stand-by cannot be the only solution.

COMPENSATING FOR INTERMITTENCY

Ideally, as the world advances down the road to zero emissions, we need cheap, safe and performant storage solutions to compensate for both fast and slow fluctuations, encourage the development of local energy and microgeneration, provide non carbon-based means of grid balancing and to massively store electricity to allow the dispatchable supply of green electricity. To meet this array of needs, battery storage has an important role to play, but several obstacles remain to be overcome.

Today's battery energy storage systems are mainly based on lithium-ion technology.

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Although this technology is mature, industrial processes are perfectible, which underlines the importance of developing our practical experience of this type of battery. ENGIE works at overcoming the technological and operational obstacles that are slowing down its development. Areas of research include: battery cell ageing, how to safe the entire energy storage system, repurposing EV batteries for stationary energy storage and ways of controlling both "fleets" of batteries and single units.

For some uses however, such as mass or seasonal energy storage, lithium-ion technology will not always be the best, nor the most affordable solution. Today, providing a satisfactory amount of electrical power (measured in watts) is relatively cheap, but this is not the case for electrical energy (watt-hours). Other technologies are therefore indispensable and several are already the subject of major development efforts. In addition to performance, it is hoped to improve safety and reduce costs. Lithium-sulphur, redox flow, solid electrolyte, sodium-ion and metal-air batteries are all currently being evaluated and tested by ENGIE in the laboratory, or even as part of demonstration projects. Some of these technologies provide longer life, lower costs and a more sustainable life cycle when compared to the current technologies, which are simply paving the way. Will the road be long?

LITHIUM-ION IN THE ANTARCTIC ?

In 2008, ENGIE installed the batteries at Princess Elisabeth Antarctica. These lead-acid batteries with a gel electrolyte (instead of liquid so the batteries don't have to be kept upright) are in fact based on a century-old technology. It was no easy task to manually handle tons of material in the extreme cold, but it all worked out fine and, as soon as it was put into service, the zero-emissions base was able to count on a total energy output of 400 kilowatt hours.

At that time it was still too early to consider using lithium-ion batteries, although for Antarctica, as for space applications, price was not the major constraint. The main factor was knowledge gained from experience in terms of battery lifetime in such a harsh environment and even more so in terms of safety. Today, more than 40 years after taking their first steps, lithium-ion batteries have finally found their place in mobile and mobility applications where battery size and weight are key. For stationary applications on the other hand, these constraints are less important and it should be possible to opt for a technology that uses more common, less controversial and therefore theoretically even cheaper materials.

Will it take another four decades to replace lithium-ion? Probably not, but at least a decade will have to pass before the right substitute is discovered and improved. Circumspection will be the order of the day: seeing the sheer quantity of research in this field, the search for funding may well give rise to a good number of announcements of "sensational results", which will finally be unconfirmed and likely to sow doubt.

In the meantime and despite the imperfections of lithium-ion, efforts continue to perfect their integration with the end-user, in the grid and in areas that have not yet been electrified. An ambitious programme that is rapidly becoming a reality. ■

> **"For some uses, lithium-ion technology will not always be the best, nor the most affordable solution."**

A VICTORY IN THE SUN!

The winner of the *World Solar Challenge.*

© agoriasolarteam

Winning a race means managing your energy capital. The team that won the 2019 edition of the *World Solar Challenge* (the "Solar Vehicle World Cup") in Australia illustrated this maxim by putting their trust in ENGIE to advise them. To stand a chance of claiming victory, you need an energy efficient vehicle, good on-board solar energy production and a battery whose characteristics are well known. Next it is important to make the best use of the battery depending on the headwind, the terrain and the temperature, without running out of power in view of the finish line, but also without leaving too large a safety margin.

Thanks to ENGIE's Storage Lab, which tested the would-be cells and provided advice on their implementation, the winners were able to count on a homogeneous battery pack in which no cells were overused. Information was available at all times about the battery state of charge and they could optimise the batteries before each stage of the race. This precise energy management was decisive.

REFERENCE

The website of the winning team of the World Solar Challenge 2019: www.solarteam.be/

A marriage of reason

The boom in the use of renewable energies, in particular for electricity production, goes hand in hand with the need for large storage capacities. Amongst the various methods available, those based on renewable gases are the most promising.

WRITTEN BY:
CAROLE LE HENAFF, GRÉGOIRE HEVIN, CHRISTIAN HUE AND DELPHINE PATRIARCHE, STORENGY

Since the launch of the European Green Deal in December 2019, the European Union has been committed to a positive and forward-looking agenda with proposals that aim to make the energy transition a source of growth that will benefit its citizens and businesses.

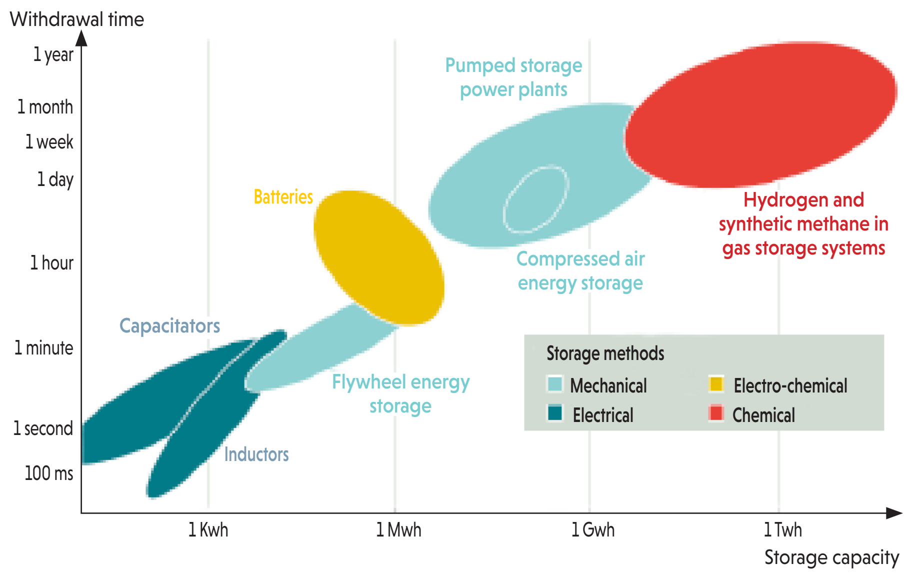
In the context of this inexorable march forward, gas and electricity networks can no longer be considered in isolation. They must, on the contrary, be considered as two inseparable elements of a much larger ensemble - the energy system. Gas storage provides the connection between the gas and electricity networks by reason of its role as the main tool for cross-sector flexibility. The connections between the two have become notably stronger in recent years.

More flexibility is required to compensate for the intermittent nature of the renewable energies that are increasingly being integrated into the electricity system. In addition, grid balancing is becoming more difficult because of the abandon of energy sources capable of maintaining the equilibrium between supply and demand (nuclear power, coal, oil, etc.). Moreover, the electrification of part of the final energy demand means that the electricity network will have to cope with much larger peaks and fluctuations in demand. The power grid has been spared this need for flexibility up until now because demand has been relatively stable. Henceforth, sufficient storage capacity will be required to provide support to the increasingly unpredictable and fluctuating production of electricity.

The question of flexibility is becoming a key issue for the stability of the system. Every type of storage can play a role, but most are limited in terms of capacity and withdrawal time (see figure below). This is not the case for gas storage, which is set to become the main link between gas and electricity.

Flexibility today is mainly based on the storage of natural gas; tomorrow, it will have to turn to renewables, a principle that informs the "Power-to-Gas" concept. The idea is to transform renewable electricity into hydrogen by electrolysis. In this process, electricity is used to split water into hydrogen (H_2) and oxygen (O_2). The hydrogen can either be used directly or, in a second stage, be transformed into methane (CH_4) by combining it with CO_2 by means of a catalytic process.

A COMPARISON OF DIFFERENT ENERGY STORAGE TECHNOLOGIES



The various techniques for storing electricity differ in terms of storage capacity and withdrawal time. Storage in the form of gas is the best option.

Taken from: *The value of gas infrastructure in a decarbonised Europe* (Frontier, 2019).

UNDERGROUND HYDROGEN

Renewable gas will therefore be complementary to renewable electricity. ENGIE's subsidiary Storengy is investing in technologies that will enable it to adapt its existing storage assets to a zero carbon future. This will make it possible to store the massive amounts of excess renewable electricity that are currently lost or offloaded, avoid further constraints on installations and help to maintain grid balance.

These principles are at the heart of the "STOPIL H2" project, a pilot scheme for the salt cavern storage of hydrogen in Étrez (Ain, France), 20 kilometres north of Bourg-en-Bresse. Twenty-five operational salt caverns are located below the ground around the town, artificial cavities that have been made by drilling down into a 650-metre thick underground salt formation at a depth of between

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1,250 and 1,900 metres. The large quantities of gas that the cavities can contain are easily available and will make it possible to meet both basic and peak consumption needs.

This proven and highly effective technology has more than 50 years' experience with natural gas behind it and provides intrinsic environmental and safety benefits. Salt caverns have low space requirements above ground, are gas tight and are inaccessible due to their depth. In addition, there is no risk of interaction with oxygen.

The STOPIL H_2 project, funded by France's Agence Nationale de la Recherche (ANR), brings together leading French stakeholders (Storengy, Geostock, Air Liquide, BRGM, INERIS, Brouard Consulting and Armines, which represents the École des Mines de Paris and Polytechnique). It aims to rise to the specific technical challenges of hydrogen storage in salt caverns.

The first phase of the project consists in answering two questions: is a salt cavern storage facility impervious to hydrogen and can frequent, high frequency cycles of hydrogen injection and withdrawal and fast flow rates damage the mechanical stability of the cavity?

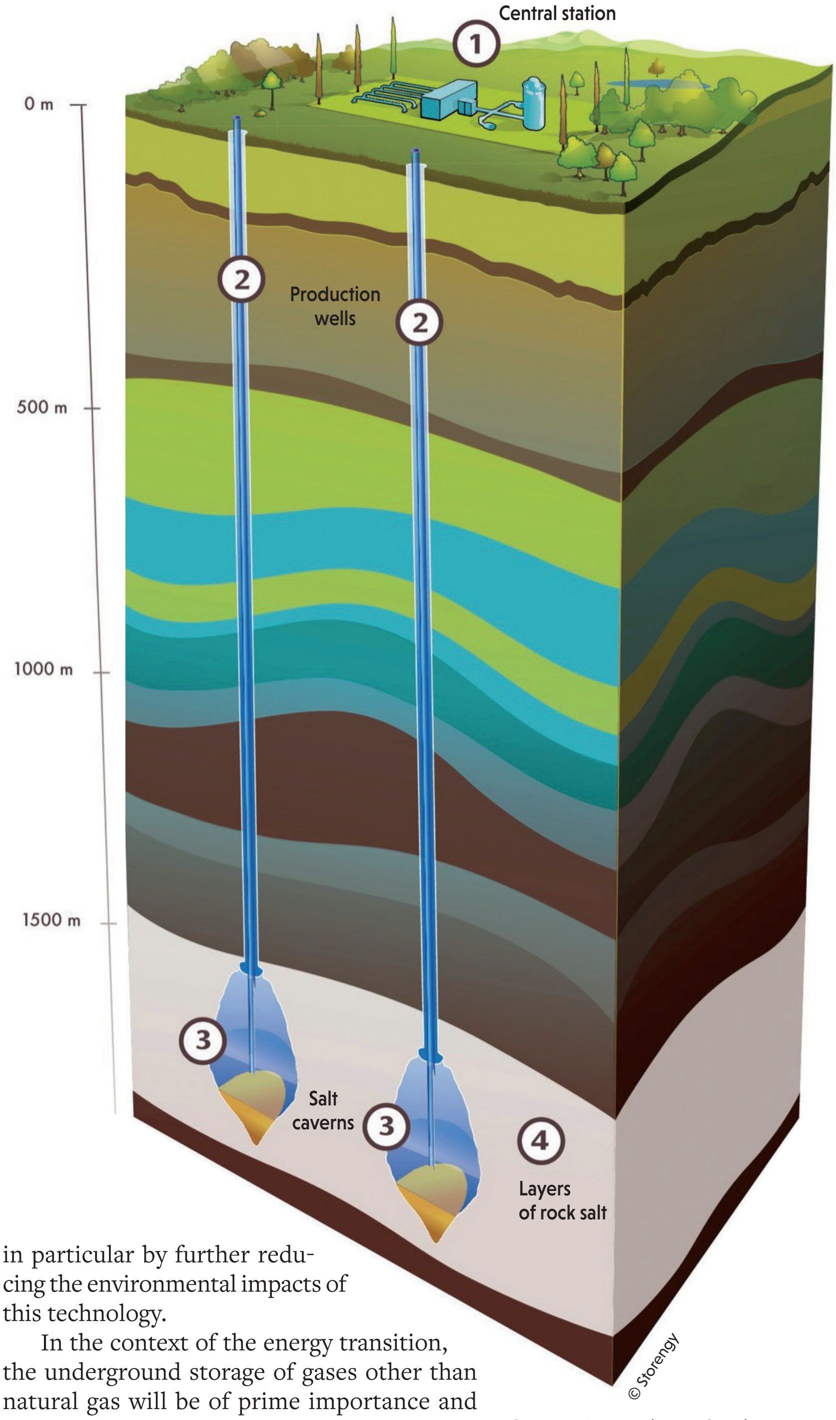
As far as the first question is concerned, the imperviousness of the cavity and well tightness is indeed a key concern from the point of view of storage safety and efficiency. The tightness of hydrocarbon storage caverns, thousands of which exist worldwide, is tested with nitrogen. Within the framework of the STOPIL H_2 project in Étrez, a hydrogen tightness test will be carried out in a cavity at a depth of approximately 1,000 metres located (see figure opposite). Its goal is to obtain information with a view to devising industrial scale tightness tests for hydrogen storage caverns in the future.

SALT CAVERN OPERATION

As for the second question, a test is planned in which the pressure of the hydrogen in the cavity will be increased to the maximum (in the range of 150 bar). The pressure will then be rapidly decreased and increased several times in succession, before finally being returned to its initial level. This test will provide the information to judge whether short and intense pressure cycles, as are currently used successfully in natural gas storage, will affect the cavern and possibly cause a significant decrease in performance. Once the concept has been validated, the cavity could eventually store up to 40 tonnes of hydrogen, i.e. around 1.5 gigawatt hours, intended in the short term for local consumption.

Once the principle has been established and supported by sound scientific studies, stakeholders will have to ensure the social acceptability of underground storage facilities, in particular by further reducing the environmental impacts of this technology.

In the context of the energy transition, the underground storage of gases other than natural gas will be of prime importance and essential to the development of new sources of electricity production and new forms of consumption. The performance of storage facilities will have to adapt to the intermittent nature of renewable sources of electricity. Programmes of technological innovation must be launched now if we are to meet future challenges, in particular to reduce the investments required and make the regulatory framework more conducive to the integration of renewable gases and their storage as part of a 100% renewable electricity mix. Only then will we be able to succeed in meeting the deadlines set by the European Union. ■



Storengy's experimental cavity in Étrez (Ain, France) will help to study the storage of hydrogen in salt caverns.

ENGIE

Dreaming of electric mobility

WRITTEN BY:
LAURENT DE VROEY,
ENGIE RESEARCH

2020 Monday morning. I wake up after a night that was far too short and listen to the traffic report. It couldn't be any worse: I'm going to be stuck in traffic jams all the way to work and what's more I need to get petrol! Crawling along the clogged roads, I am surrounded by anonymous vehicles, each with a single occupant. The clock is ticking and the engines are running, but the cars aren't moving. Once in town, the next challenge is finding somewhere to park – and to top it all off, there's the short walk to the office in the midst of noise and exhaust fumes. I can't wait to be at work!

2035. Monday morning. The night was still too short, but I got an extra hour's sleep this time. My favourite app shows me today's best mobility option: a shared electric car to the station, the train and then a self-service electric scooter. The hustle and bustle of the city hasn't changed, but it's so much quieter and the air is cleaner now towns and cities have banished the internal combustion engine!

Smart charging is vital when managing a fleet of electric cars

Multi-modal transport solutions and electric mobility have really changed the game. Why did we wait so long?

Mobility and transport are the cornerstones of modern society, whether for practical reasons or for the freedom they offer. The need to significantly reduce the transport sector's carbon emissions is inciting a growing number of public and private stakeholders to encourage the development of electric mobility, however for the sector to grow, many practical problems facing both users and society will need to be resolved. Two such issues are where to recharge electric vehicles (charging infrastructure) and the energy demand in play.

AN OPTIMIZED INFRASTRUCTURE

There are several options available to the people in charge of deploying an EV charging infrastructure capable of meeting requirements. The first parameter to take into account is the speed of charging. Charging for one hour at a simple wall socket increases the car's range

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by 10 to 15 kilometres. The same amount of time at a standard charging station will increase its range by up to 100 kilometres. A fast charging station (larger and more complex) will do the same in just 15 minutes! However, charging speed raises questions of power, which we will come back to later. Another parameter is the technology used for charging that can be either conductive or inductive (depending on whether the vehicle is plugged in or charged wirelessly). The former is more efficient, but the latter is more practical. Different charging structures are available depending on the usages including plug-in charging stations and pantograph charging (using an articulated arm that can be deployed above electric buses for example). Depending on the chosen solution, charging can take place when the vehicle is stationary or even in motion.

MATURITY AND AGING

There are a whole multitude of possibilities and so, to get a clearer idea, ENGIE is studying these different charging solutions, taking a particular interest in the maturity of their technology, their impact on vehicle aging, their interoperability and their potential to be rolled-out in the medium and long term. To this end, researchers are regularly carrying out in-depth evaluations of charging solutions and technologies, both in the laboratory, during field tests and as part of an in-depth analysis of solutions already deployed around the world.

Other tests included the impact of rapid charging on battery aging compared to normal charging and the possibility of the electric car returning energy to a building or to the grid. The ease of installation and use of different charging solutions has also been tested in real-life conditions.

The other aspect of the deployment of electric mobility concerns the amount of electricity required to supply the vehicles and its availability. This question is directly related to the number and size of the batteries in use. In Europe, an all-electric mobility and transport solution would lead to an increase in electrical energy requirements of between 15 and 20%. While this increase is significant, it would be manageable if it were spread out over time.

A NEED FOR POWER

Another essential factor to take into account is that, as we have seen, the speed of charging can cause power problems. Charging a single electric vehicle in the time it takes to fill up a traditional car with petrol would require power equal to that delivered by a wind turbine running at full speed. This is impossible in practice. In addition, and depending on the location, the capacity of the electricity network is not always sufficient to meet the demand that would be generated by the simultaneous charging of a large number of electric vehicles. In this case, smart charging will be essential.

Moreover, the way in which vehicles are charged can lead to anomalies on the electricity network (voltage drops, overloading of transformers and frequency variation, etc). After a certain point, these disruptions would require action and would lead to considerable costs. To tackle these problems, ENGIE is working with various electricity network operators to assess the qualitative and quantitative impacts of these disruptions by carrying out detailed measurements of charging cycles for different types of chargers and electric vehicles.

Finding answers to these questions is all the more important as electric mobility is widely accepted today and set to grow. Studies show that 95% of electric car users would not want to go back to an internal combustion engine.

All sorts of new opportunities are opening up. Depending on the needs, we can imagine situations in which electric vehicles could supply energy to buildings or to the grid. These new perspectives for battery use would help to maximise local consumption of intermittent renewable energy production. The same concept can be extended to local energy communities: one household's electricity production could help to charge a neighbour's vehicle and another person's vehicle could supply power to the home of a fourth person. The development of such communities would impose a real paradigm shift of which electric mobility is only a first step. By getting involved in such projects, you can make the dream of 2035 come true... and get a better night's sleep! ■

FASTER, CHEAPER AND WORRY FREE

By avoiding large investments, reducing power demand and the number of chargers required, smart charging provides users, charging stations and grid operators with a whole host of advantages. Smart charging consists in adapting vehicle charging to other consumption needs on site and maximizing the use of locally produced energy (produced for example by solar panels). A growing number of commercial solutions offer some of these functions, however all of them can be found in SMATCH, ENGIE's solution for electric vehicle charging. What's more, SMATCH takes into account the specific needs of each individual user, as well as anticipating local production, consumption and vehicle requirements. It also considers network constraints, energy market tariffs and CO_2 production depending on the energy mix, which varies over time.

SMATCH

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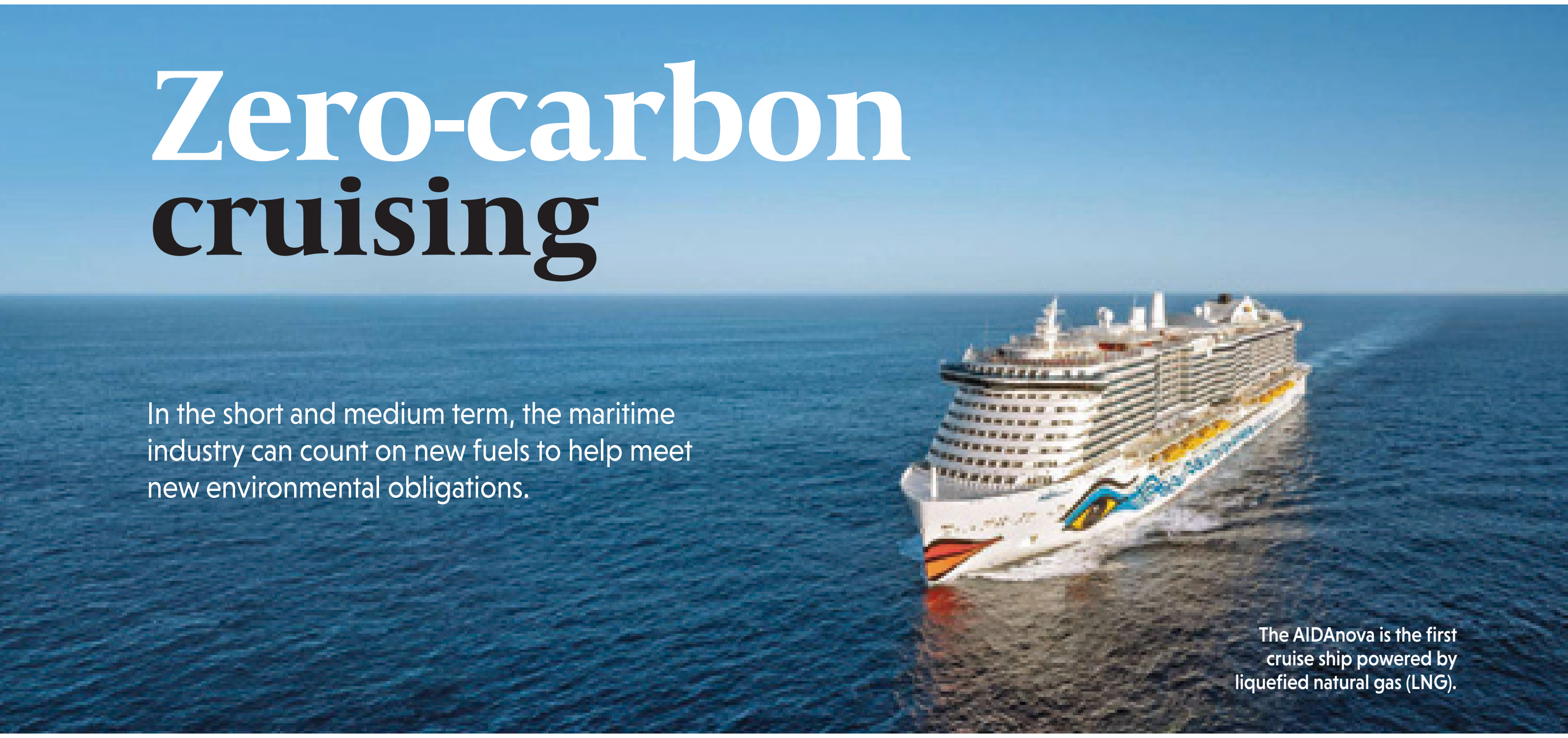
Zero-carbon cruising

In the short and medium term, the maritime industry can count on new fuels to help meet new environmental obligations.



The AIDAnova is the first cruise ship powered by liquefied natural gas (LNG).

WRITTEN BY:
FRÉDÉRIC LEGRAND AND GABRIELLE MENARD, ENGIE LAB CRIGEN

Aida Cruises launched the *AIDAnova* in 2018. Built by the Meyer Werft shipyards, it was the world's first cruise ship to run on liquefied natural gas (LNG) and, as such, illustrates the shipping industry's commitment to reducing its carbon footprint. Although the road will be long, the trend is irreversible.

Historically shipping has used heavy fuel oil (HFO) for propulsion, which is a heavy fraction distilled from crude oil. As this so-called "bunker fuel" is made from petroleum refining residues, it contains compounds, in particular sulphur, which make it more polluting. The combustion of heavy fuel oils results in emissions of CO2, sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter. Maritime transport represented just under 3% of global CO2 emissions in 2018, the equivalent of Germany's annual emissions.

The International Maritime Organization has decided to react and has set ambitious targets to curb greenhouse gas emissions (at least 50 % below 2008 levels by 2050). Since 2015, the IMO has also imposed a progressive reduction in the maximum permitted sulphur content (from 3.5 % in 2015 to 0.5 % in 2020) in the bunker fuels of some 50,000 ships in circulation worldwide. In the *Sulfur Emission Control Areas* (SECA), which include the North American coasts and the seas of Northern Europe, even stricter limits apply with a maximum sulphur content of 0.1% as of 2015.

Different solutions are available to shipowners to help them comply with requirements. The first consists in replacing heavy fuel oils with marine diesel or low sulphur fuel oils, which requires some minor modifications to the ship's engines to make them compatible. However this option involves significant additional operational costs (low-sulphur alternatives are much more expensive). Price and availability are key issues and the former will rise as demand increases, however this will initially be the most widely adopted solution as it does not require large investments.

CHOOSE YOUR WEAPONS

Another avenue is to continue burning high sulphur fuels, but to reduce pollution levels by installing exhaust gas cleaning systems, also called "scrubbers", which remove and collect sulphur. However this solution is not necessarily suitable for all ships. More importantly, it only eliminates sulphur emissions (and not NOx and other pollutants) and so it only addresses part of the problem. In terms of cost, this solution offers the best return on investment, but it is not without risk as it raises the question of how to dispose of the sulphur residues. In addition, the carbon footprint of exhaust gas cleaning systems is disappointing; in fact operating this equipment increases the ship's overall fuel consumption and therefore its greenhouse gas emissions. On 1 May 2019, less than 2,400 ships were equipped with exhaust gas cleaning systems.

The last option is to change over to an entirely new fuel, which for shipowners with a long-term strategy usually involves investing in a new

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vessel. Today, heavy fuel oils are being replaced by LNG and even, and we will come back to this later, by bio-LNG or hydrogen. As demonstrated by the *AIDAnova,* LNG is currently the most widely used new fuel source. Indeed, LNG complies with all environmental requirements as it has zero sulphur and particulate matter emissions, reduces NOx emissions by 80% and CO_2 emissions by 20%. LNG is also available in large quantities and LNG engines for ships of various tonnages are available, however constraints exist because the logistics of LNG distribution are not adapted to this usage yet and the return on investment is also longer.

With fewer than 400 ships powered by LNG in service or on order, this can still be considered to be a niche market, but some studies predict an annual potential for LNG-fuelled ships of 35 million tonnes by 2035, in other words a market share of approximately 10%. In 2017, ENGIE joined forces with Mitsubishi, NYK line and Fluxys to launch the outfitting of the *ENGIE Zeebrugge* bunkering vessel (see opposite). With a capacity of 5,000 m3, it will be able to supply LNG to ships of any type operating in Northern Europe from its base in the port of Zeebrugge (Belgium), which it will do from 2020 under the brand name "*Gas4Sea*".

“Maritime transport is well on the way to zero carbon”

BETTER THAN LNG

To address this new market, ENGIE has launched several ambitious research programmes that focus on the production of green gases and their use in the maritime transport sector. One of them addresses the fact that the thermodynamic behaviour of LNG is completely different to that of other fuels because LNG is a cryogenic liquid whose chemical composition changes as it evaporates into natural gas, which is then burned by the engines.

The changes that take place during the voyage are reflected in the evolution of parameters that are essential for the operation of the engines, including the methane number (a number linked to the composition of the gas that reflects combustion quality). A gas chromatograph could be installed to continuously monitor LNG composition, but such a device is expensive. Other solutions now exist: ENGIE Lab CRIGEN has developed *Smart gauge*, an algorithm that calculates the composition of the LNG in the ship's storage tanks throughout the route based on real-time pressure and temperature measurements and the initial composition of the LNG.

Despite its low environmental impact, LNG does not completely eliminate CO_2 and NOx emissions, however two new fuels could provide the solution. The first is bio-LNG (or liquid biomethane) i.e. liquefied biogas, which reduces CO_2 emissions by 90% compared to heavy fuel oil and does not require any additional investment for LNG-powered ships. The development of bio-LNG is however hindered by its higher production costs. Building on more than 60 years' experience in the field, ENGIE Lab CRIGEN has launched a research program aimed at using innovative processes to reduce the cost of the liquefaction of biogas by 40%. In 2020, tests will be carried out at the CRIGEN site in Stains and then at the LNG terminal in Montoir-de-Bretagne to validate the new technology. The objective for 2021 is to install the solution at the site of an ENGIE partner. Bio-LNG could replace LNG by 2030.

In the longer term, liquid hydrogen could be a suitable fuel source for maritime transport. In fact, as long as it is produced from renewable sources, it does not generate any greenhouse gases, nor does it emit NOx, SOx or particulate matter. Today available solutions for producing, storing and transporting liquid hydrogen are limited. ENGIE has launched a research program that aims to halve the costs of producing and transporting hydrogen by developing new liquefaction processes. Projects are also underway in South America to provide industry with hydrogen-based maritime transport solutions.

Contrary to its reputation as a rather conservative industry, maritime transport is well on the way to becoming carbon neutral. Several solutions are available and ENGIE is supporting the key players to help them reduce the industry's carbon footprint. One day soon, we will be able to cruise with a clear conscience. ■

© ENGIE

ENGIE Zeebrugge **can supply LNG to any type of LNG-powered vessel.**

Toward a net zero carbon industry

Energy-intensive industries were amongst the first at working on improvements of the energy efficiency of their processes. While good progresses are made, indeed, several technological breakthroughs are needed now.

WRITTEN BY:
LUDOVIC FERRAND, PHILIPPE BUCHET AND JEAN-PIERRE KEUSTERMANS, ENGIE

If you live in a city you can't help noticing that certain materials such as steel, cement and glass dominate the urban landscape. These ubiquitous materials are produced by so-called energy-intensive industries (EIIs), which are responsible for a high-level of greenhouse gas emissions because their activity revolves around numerous energy-intensive processes. Demand can exceed 200 megawatts for a single installation, in other words the equivalent of one hundred football fields equipped with solar panels! In total, the steel, cement and chemical industries alone account for 5.4 gigatons of CO_2, or more than 15% of global anthropogenic emissions. In this context, how can carbon neutrality be achieved by 2050?

A RACE AGAINST THE CLOCK

We are now at a tipping point. If we want to achieve carbon neutrality by 2050 and win the race against the clock, we need to implement solutions that go far beyond the best today's technology has to offer. Considering all that needs to be done to make the necessary changes time is definitely running out. Just one example: plant lifetimes in the cement and steel sectors often exceed 40 years and so research and development has a major role to play in several key areas.

One such area is material efficiency. This involves rethinking materials to improve their energy performance, for example by finding a breakthrough in lightweight steel to make lighter vehicles with a lower fuel consumption.

Another direction is intensification, which strives to use the "minimum required energy" (MER) for transforming a given material (heating, melting, evaporation). ENGIE is working alongside industry to further this approach, for example in the field of high-performance burners, which is a mature technology capable of an efficiency of more than 90% thanks to a better relation between the combustion system and the combustion chamber.

Electrifying industry is another interesting avenue to explore. The major industrialised countries are currently transforming their power systems in order to achieve carbon neutrality: as a result, infrastructures are becoming more complex with the diversification and decentralisation of energy sources.

The first advantage of switching to electricity is that green energy (solar, wind and marine power etc) can be used directly. In

EMISSIONS-FREE CEMENT


Pilot plant LEILAC1

© CALIX

The cement and concrete industry is one of the largest emitters of CO_2 accounting for almost 5% of global emissions. Driven by population growth and urbanisation, demand for cement has rocketed over the last ten years and this trend seems set to continue. Implementing a carbon-free solution for this industry is however complex. Even if 30 to 40% of its CO_2 emissions result from the combustion of fossil fuels (which can be replaced by carbon free alternatives), 60 to 70% of emissions are produced by the calcination of limestone ($CaCO_3$), meaning it is necessary to find a breakthrough technology to replace this process. Other avenues of research do exist indeed such as developing alternative cements and materials, as well as carbon capture and storage. For the latter, we can considerably reduce the energy costs associated with capture by separating the combustion and calcination processes that are usually combined in the lime kiln. Such an approach has been developed as part of LEILAC, a collaborative project led by Heidelberg Cement and Calix. The second stage of the project, LEILAC2, has already been announced and, from 2020 to 2025, ENGIE will be part of the project team looking at the electrification of this innovative process, as well studying how to reuse the flow of CO_2.

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FROM VINE TO GLASS

© Gabard

Mature vine shoots can be used to produce biomethane for the glass industry.

If it is easy to recycle (50% of glass packaging is made from recycled glass), the high temperatures required to manufacture glass require a lot of energy. So how can we reduce the glass industry's large carbon footprint? Three possible solutions exist, the first of which is to convert the production process to use electricity and notably renewable electricity. The second requires converting the furnaces (in particular the glass melting furnaces), so that they can use renewable fuels as an energy source. The third involves rethinking and intensifying production processes in terms of energy.

Together with a consortium of companies that includes Xilowatt and glassmaker Verallia, ENGIE has decided to explore the second solution. BioVive is a joint project that aims to design a hollow glass melting furnace capable of burning syngas (CO, H_2, CH_4, etc.) produced by biomass gasification. A pilot scheme has demonstrated the feasibility of this carbon-free solution.

ENGIE is also continuing to work along these lines with the implementation of a decentralized biomethane production process (the Gaya project), which uses vineyard prunings to produce a renewable natural gas made from lignocellulosic biomass. Other solutions based on locally produced green hydrogen are being studied.

addition, EIIs have an obvious role to play in balancing the distribution network.

Electrification does not have to be direct however, depending on the material it allows for a wide variety of different applications, such as radiant heating using the joule effect, infrared and induction. ENGIE is taking part in the European research project DESTINY, whose objective is to develop a new microwave energy-based solution for firing granular feedstock for use in the ceramics, cement and steel sectors.

HYDROGEN, BIOMASS...

Indirect electrification refers to solutions in which electricity is transformed into an intermediate vector for an end use such as high temperature heating (eg Power to Hydrogen). As part of France's National Hydrogen Action Plan, ENGIE has taken part in feasibility tests in industry. Other initiatives, such as the European Hybrit project, aim to use hydrogen instead of coke in steel mills.

Biomass fuels also have a role to play in the energy transition, in fact some steel blast furnaces are already powered by eucalyptus charcoal instead of coke. Although this principle is hard to replicate in every context, it remains an active field of research and in this respect the BioVive project led by ENGIE is emblematic (*see box above*).

Industrial symbiosis can also be a means to achieving carbon neutrality. It consists in converting the waste or by-products (material or energy) of one industry or process into the resources needed by another. This concept seems to be difficult to roll out on a large scale, although there have been some resounding successes. Thanks to its part in the Be-Circle project, ENGIE is contributing to the research effort to remove barriers and unlock the potential of the circular economy within a given geographic area.

Finally, EIIs are particularly well suited to carbon capture solutions because their source of carbon emissions is centralised at a single location. More research is being carried out and an increasing number of pilot experiments are taking shape. The goal is twofold: to determine the most efficient carbon capture processes and to identify ways of reusing the CO_2 to avoid it being released into the atmosphere.

Although this overview is far from exhaustive, it shows the wide variety of current approaches. It also illustrates the current and actual ambition to go beyond energy efficiency and move resolutely toward carbon neutrality. The challenges are still immense, but there are many promising avenues to explore. So that, one day, we will have a different perspective on the materials around us. ■

The future of heat pumps

By providing low and medium-temperature heat for industrial uses, innovative heat pumps will help to meet the targets imposed by the energy transition.

WRITTEN BY:
AKIM RIDA AND
JEAN-YVES DRUILLENNEC,
ENGIE

In 2019, the French Ministry of the Environment (Ministère de la transition écologique) launched its "Coup de Pouce Chauffage" scheme that provides financial assistance to households to help them replace their old heating system with more energy efficient equipment, in particular heat pumps. But what about businesses?

Companies have also got the measure of environmental concerns and are looking to reduce their carbon footprint. One way of doing this is to find low or zero carbon solutions for producing heat. There is a lot at stake because 32% of the final energy consumption worldwide (total energy consumed by end users) goes to industry, with three-quarters of it being used to produce heat. Half of this amount corresponds to low (under 100°C) and medium (under 400°C) temperatures, meaning this is an important lever of action that can contribute to reducing the carbon footprint of the industrial sector.

Two key methods involve improving energy efficiency and employing biomass (wood, green waste and agricultural residues etc) including the greening of natural gas networks. Other avenues, notably those in connection with industrial symbiosis (when the waste or by-products of one industrial process provide the raw materials needed by another) or other innovative processes are the subject of careful studies at the present time.

Above and beyond these methods, many scenarios envisage the deployment of either electric or hybrid boilers and, above all, heat pumps - which are expected to become much more efficient - more or less in line with the current trend in private households. Development of equipment capable of providing temperatures between 120°C and 200°C is ongoing.

HEAT PUMPS TODAY

A heat pump is a device that transfers heat from a colder heat source, such as the air, soil, groundwater to a heat sink. In industry the source is often waste heat that would otherwise have been lost. A working fluid or refrigerant circulates through the device and undergoes a series of transformations, absorbing heat in the evaporator, heating up in the compressor and releasing heat in the condenser. The other component of the system is an expansion valve.

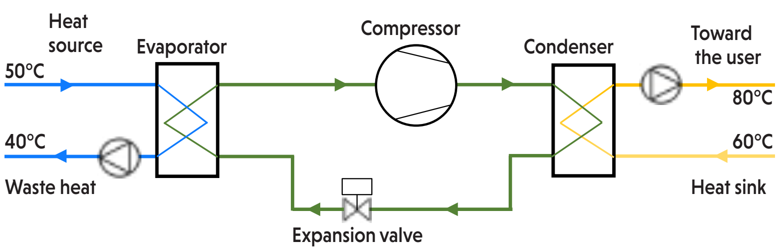
The coefficient of performance (COP) is a measure of heat pump efficiency. It corresponds to the ratio of the heat supplied by the heat pump to the energy (often electricity) consumed by the compressor.

In commercially available heat pumps, the system typically contains either a mechanical compressor or an absorption system. In an absorption heat pump, the vapour is absorbed into a liquid. This solution is then pumped to a higher pressure, which requires much less energy than using a compressor. To start the cycle again, the refrigerant is removed from the liquid by evaporation (desorption), for which a reliable source of heat is required. Hybrid compression/absorption heat pumps exist which combine both technologies.

Amongst the many available heat pumps using either or both of these technologies, several solutions are emerging that are now capable of providing heat at a temperature over 110°C. Operating with a heat source between 8°C and 40°C, ENGIE's Thermeco2 heat pump can raise the temperature of a fluid up to 110°C. It uses CO_2 as a working fluid, which has the advantage of being non-toxic, non-flammable and cheap. In addition, it has no impact on the ozone layer and a global warming potential (GWP) very low compared to most refrigerants used today. Its so-called "transcritical" cycle is original because it takes place in part in the supercritical phase: at the compressor outlet, the pressure of the working fluid is higher than its critical pressure, a point beyond which, in practice, the CO_2 can be cooled without condensing. For this reason, the conventional condenser is therefore replaced by a gas cooler.

Another example of high temperature heat pumps is the Hybrid Heat Pump, first developed

INSIDE A HEAT PUMP



A heat pump transfers thermal energy from a lower-temperature location called the source (blue) to a higher-temperature location called the heat sink (yellow).

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At the beginning of 2018, the Hybrid Heat Pump was installed at the Compagnie des Fromages & RichesMonts in Vire (France). By exploiting waste heat rejected by the refrigeration units, it supplies seven gigawatt hours of hot water at 85°C per year that can be used for cleaning, sterilization and production. The CO_2 emissions resulting from the production of heat have fallen by 90%.

> **"The decarbonisation of low and medium temperature heat in industry is now at a crossroads"**

in Norway by the Institute for Energy Technology (IFE) and then by Hybrid Energy. Following a partnership agreement signed in 2015, ENGIE Solutions assembles these customised systems in Montauban-de-Bretagne in the department of Ile-et-Vilaine (France). This heat pump combines the principles of absorption and compression and works with a natural refrigerant based on a mixture of water and ammonia. This fluid is zeotropic, which means that the phase change occurs within a range of temperatures rather than at a constant temperature. Compared to a conventional heat pump, heat exchange performance at the condenser and evaporator is improved thanks to this property, leading to a better COP. This heat pump is therefore capable of heating water up to 120°C at a low operational pressure (below 25 bar). A traditional heat pump using pure ammonia could not exceed 50°C at this pressure. Operating at 40°C/100°C, this heat pump's COP is 4.5.

Producing and distributing heat in the form of hot water in processes where steam is often the preferred energy carrier holds back the deployment of these new technologies because significant changes to the process are required such as the integration of a new exchanger. Heat pumps capable of generating steam between 150°C and 200°C would provide many opportunities. Current developments in heat pump technology are aimed at improving COP and increasing temperatures to 200°C. The lack of low environmental impact refrigerants is the main obstacle.

TOMORROW'S HEAT PUMPS

A direct application of very high temperature heat pumps consists in exploiting low temperature-waste, renewable heat sources (solar, geothermal, free heat) to produce steam in parallel with an existing boiler. A heat pump generating steam would at least double the efficiency of an electric boiler and the use of green electricity would make this system carbon neutral. It is this principle that is behind a steam generating heat pump commercialised by Kobe Steel, which enables a modest steam temperature of 120°C. The SGH120 has a COP of 3.5 with a heat source at 65°C. Kobe Steel proposes to go one step further with the SGH120, adding a steam compressor unit to reach a steam temperature of 165°C (with a COP above 2).

The decarbonisation of low and medium-temperature heat in industry is now at a crossroads. There is no universal solution, the reason being that heat comes in many forms and that increasing temperature comes at a cost. Given the different situations encountered, the idea of a mix of solutions seems to be the most suitable. Energy efficiency is one such solution and perhaps the only certainty today. ■

HOT OR COLD, SAME DIFFERENCE!

Ambitious objectives have been fixed for the reduction of greenhouse gas emissions in the residential and commercial building sector (-17% in France). Meeting these objectives will be challenging because of the low renewal rate of buildings, the tens of millions of owners and other stakeholders involved and the way these buildings are grouped together in villages, neighbourhoods and towns. Nevertheless solutions do exist and, whether they are for heating (see below), or on the contrary for air conditioning (*see page XXVI*), surprisingly they have a lot in common, especially when it comes to managing daily and seasonal peaks in demand. In fact, they all require reducing demand, using renewable resources and providing innovative technical, organisational and financial solutions. The convergence of electricity, gas, heating and cooling networks will also be a key success factor.

Staying warm without warming the planet!

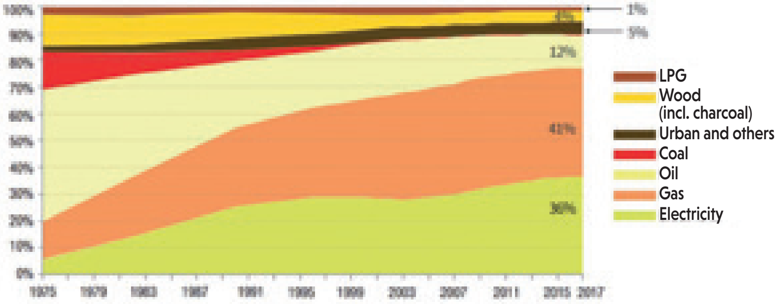
When it comes to heating, the only sure way of reducing the carbon footprint of heat generation is by combining electricity and gas rather than by pitting them against each other.

Whether it's "The battle of the radiator" or "Things are getting heated", the press are striving to outdo each other when it comes to finding the wittiest headlines as they report on the negotiations that are going on behind the scenes as France attempts to draw up its new environmental building regulations. The regulations in question, RE 2020, will notably define the prescribed method of heating for new builds. Debate is raging between the proponents of an all-electric solution and those who swear by gas, each side hoping to influence the final decision in its favour. But what exactly are the ins and outs of the matter at hand?

Over the last 30 years, heating performance has improved significantly as oil and coal have gradually been replaced by natural gas and electricity, as well as with the shift to producing electricity using nuclear energy, hydroelectric power and natural gas. According to the Ademe, emissions from heating have been divided by three since 1975 for an equivalent area, but at 400 terawatts-hour, heating still accounts for a quarter of France's final energy consumption. It is therefore a key sector for achieving carbon neutrality.

Today natural gas and electricity are by far the main energies used for heating (*see graph below*), however electricity is not a primary energy, which means it is not directly available in nature. As electricity is an energy vector that results from the transformation of primary energies (natural gas, uranium, wind, solar radiation, etc), studying the primary energy sources used to provide electricity for heating shows a completely different picture. Although nuclear energy is predominant accounting for almost 50%, there is still a considerable part of fossil fuels in the mix.

BREAKDOWN OF HEATING BY ENERGY TYPE



Natural gas and electricity largely dominate the energy sources used for heating. Electricity predominates in new builds, except in multi-family residential housing, which is mainly heated by natural gas.

© CEREN, adapted by ADEME. Key figures for 2018

A QUESTION OF BALANCE

The place of the various energies in tomorrow's energy mix is therefore not so much a question of either natural gas or electricity, but rather a question of balancing different primary energies. Some renewable resources can, by nature, only be converted into electricity (wind, photovoltaic), whereas others, such as renewable gases and solar thermal energy (STE), can be used directly for heating.

Electric energy does however have its limits when it comes to coping with daily and especially seasonal variations in demand. The difficulty for the electrical system is to be able to start up electricity generation plants usually intended for use in winter and to ensure that the size of the network is sufficient to respond to short peaks in demand.

Let's do a little maths. In 2019, the peak energy demand of buildings was estimated at

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Which type of heating is best? Gas or electric?

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280 gigawatts (85 GW of which were supplied by the electricity grid) and their lowest energy demand was 80 gigawatts. If we were to imagine a hypothetical situation in which every building used electric heating, 200 gigawatts would have had to be kept in reserve in 2019 and used solely to respond to winter peak demand. This amount is the equivalent of 120 EPRs or 250 state-of-the-art gas-fired power stations, which would then have to be shut down during the summer.

In the light of this, what route seems the most advantageous if we are to achieve carbon neutrality by 2050? We must begin by attacking the root of the problem, which is the level of winter peak demand, starting by rapidly and drastically reducing the energy demand of buildings. The fight to reduce heat leakage has been ongoing for several years but it is time to step up our efforts.

The second line of attack focuses on heat generation systems. If the latter rely on controllable resources - whether these resources are renewable (biomass, renewable gases) or low carbon such as an EPR nuclear plant – they must be as efficient as possible. In addition, solar, wind and hydropower will need to be backed up by sufficient storage capacity. Less controllable means of production are of little use in responding to changes in demand, in particular winter peak demand. The different storage solutions (each of which has its advantages and disadvantages) include batteries (whose environmental performance may be questionable), mechanical storage, thermal energy storage (in water or other more complex materials), and storage in the form of hydrogen, which is considered to be a renewable gas if generated with renewables.

The next question is the share of each of these controllable resources in the future energy mix, which is where the real debate on the place of electricity and gas in heating lies. The question can be rephrased as follows: "What are the most appropriate means of heat production to respond to winter peak demand and where are they situated? We need to decide between controllable, centralised means of electricity production and more decentralised ones that are closer to the end-user and which make the most of short, circular cycles (electric heat pumps coupled with a system using renewable gas, solar energy coupled with thermal energy storage, the use of waste heat, etc.). This can be on a regional level with energy communities based on existing networks, or on the scale of one or several buildings with hybrid systems that call upon controllable, carbon neutral means of production to provide extra energy as necessary.

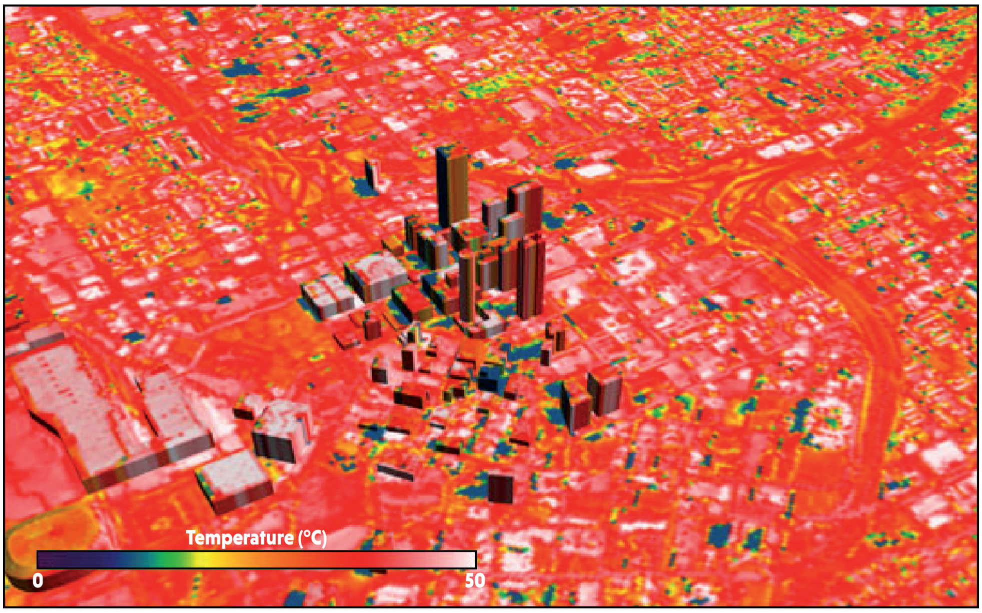
WRITTEN BY:
BENJAMIN HAAS, ENGIE LAB CRIGEN AND MURES ZAREA, ENGIE RESEARCH.

THREE LEVELS

Each of these levels (centralised, regional and building) has its advantages and disadvantages which can be summed up as follows: the more powerful (and therefore the more centralised) production is, the easier it is to control and manage from a technical standpoint. On the other hand, it is less energy efficient because of the losses during the transformation of one form of energy into another. Arbitrating between the relative roles of each level is complex and, while it is a burning issue of current interest, it is essential not to lose sight of the fact that putting all one's eggs in one basket (often all-electric) without allowing for resilience and evolution, means risking failure. In order to reach zero carbon, it is vital we keep all our options open, work at every level, not hide carbon emissions in centralised electricity production, and finally, aim to achieve energy efficiency as well as economic efficiency. This is what the teams at ENGIE are working toward. Can you see the headline - "An alliance for virtuous heating"? ■

A carbon-free, air-conditioned world…

If we want to effectively combat global warming, we will have to overcome some sizeable challenges in the building sector, especially in terms of air-conditioning and refrigeration. But they are not insurmountable!



Heat islands (here in Atlanta) are characterised by much warmer temperatures (in white) than the surrounding areas.

© Nasa

The figures are revealing: in the United States, more electricity is used for air conditioning than the total energy consumption of Africa! And there's no sign of it decreasing soon. In fact, air conditioning units for residential and commercial properties have a bright future, mainly because of a desire to improve the comfort of occupants in the summers that are getting hotter and hotter. What can we do about the inevitable increase in the demand for "cold"?

A wide range of equipment (air conditioners, reversible heat pumps, water chillers etc) is available; most of the machines on the market use electric compressors, although a few do run on gas. Some machines are energy efficient and have reduced their impact on the environment, for example by running solely on renewable energy, adding a heat recovery system or using either natural refrigerants or refrigerants with a low global warming potential (GWP), such as carbon dioxide, ammonia, propane or hydrofluoroolefins etc.

There is no doubt that air conditioning manufacturers will continue their efforts, in particular to comply with regulatory deadlines in terms of greenhouse gas emissions. The Kigali Amendment to the Montreal Protocol provides for a phase down in the production and consumption of HFC (hydrofluorocarbon) refrigerants, which have a much higher GWP than the above-mentioned refrigerant gases. Another objective is to improve the seasonal performance factor for this equipment. In addition to these measures, it is essential to reduce the need for "cold" as much as possible by favouring bioclimatic buildings, which we shall address later.

THE CHALLENGES AHEAD

In terms of product development, it is fundamental to innovate by improving the overall performance of existing systems, as well as providing new features and breakthrough technologies. Some examples are advanced vapour compression systems and emerging non-vapour compression systems (evaporation, absorption), active gases with good heat transfer capacities and water-based evaporative air conditioners, as well as thermoacoustic (that use sound waves to carry heat away from the environment to be cooled) and thermoelectric devices.

The wide power range of most of these technologies makes them suitable for different types of buildings as they can be used for individual or collective cooling needs and integrated into heating networks. If it becomes possible to recover a sufficient amount of the

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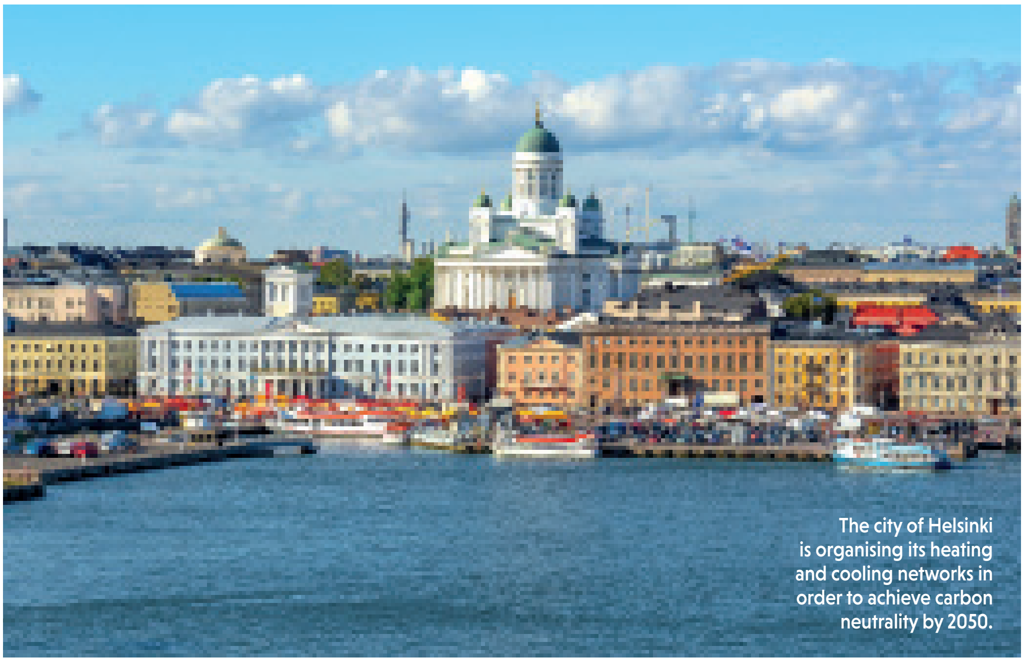
energy lost during the production of cold, thermofrigorific systems (producing heat and cold) integrated into heating networks probably have a bright future ahead of them. All the more so as the heat losses from air conditioning units contribute to the severity of urban heat islands (*see figure on the opposite page*).



The city of Helsinki is organising its heating and cooling networks in order to achieve carbon neutrality by 2050.

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It is important to underline that paying attention to the way in which we use these systems is essential if we are to obtain the expected results: storage, the careful management of production and consumption levels and a smart communications network (as used in smart grids) are all important factors.

Another challenge is to encourage the use of clean energy instead of traditional energies such as fossil fuels and nuclear power. Among the energy sources that can be used for refrigeration systems are underground water, solar energy (because its production is in phase with the need for air conditioning), biomass and hydrogen, amongst others. Denmark's energy policy is a good example of this transition because it aims to be renewable energy self-reliant by 2050. This is also the case for Helsinki in Finland (*see figure below*).

The development of a cloud infrastructure and the smart management of air conditioning equipment are also key areas of research. Companies in charge of operating and maintaining space cooling systems are likely to switch to a decentralised network for processing and analysing operational data. Cross-referencing this information with other information of a technical or administrative nature will help to improve the quality of the services on offer.

The very idea of a building is to create an "interior", a space where the occupants have control over the atmosphere: as they manage the relationship between this interior and the exterior climate, the building envelope and the air treatment system both have a key role to play in terms of energy efficiency. The current approach consists basically in insulating the interior of the building from its immediate environment, however the ground, the air, the sun, the sky and the wind are all potential sources of energy, both in winter and summer. Can we make use of these potential energy sources by allowing them into buildings?

Making use of these potential energy sources is the idea behind bioclimatic design, which aims to reduce a building's heating - and especially cooling - needs. Residential and commercial buildings could dramatically reduce their use of air conditioning and refrigeration systems by making use of available sources of cold.

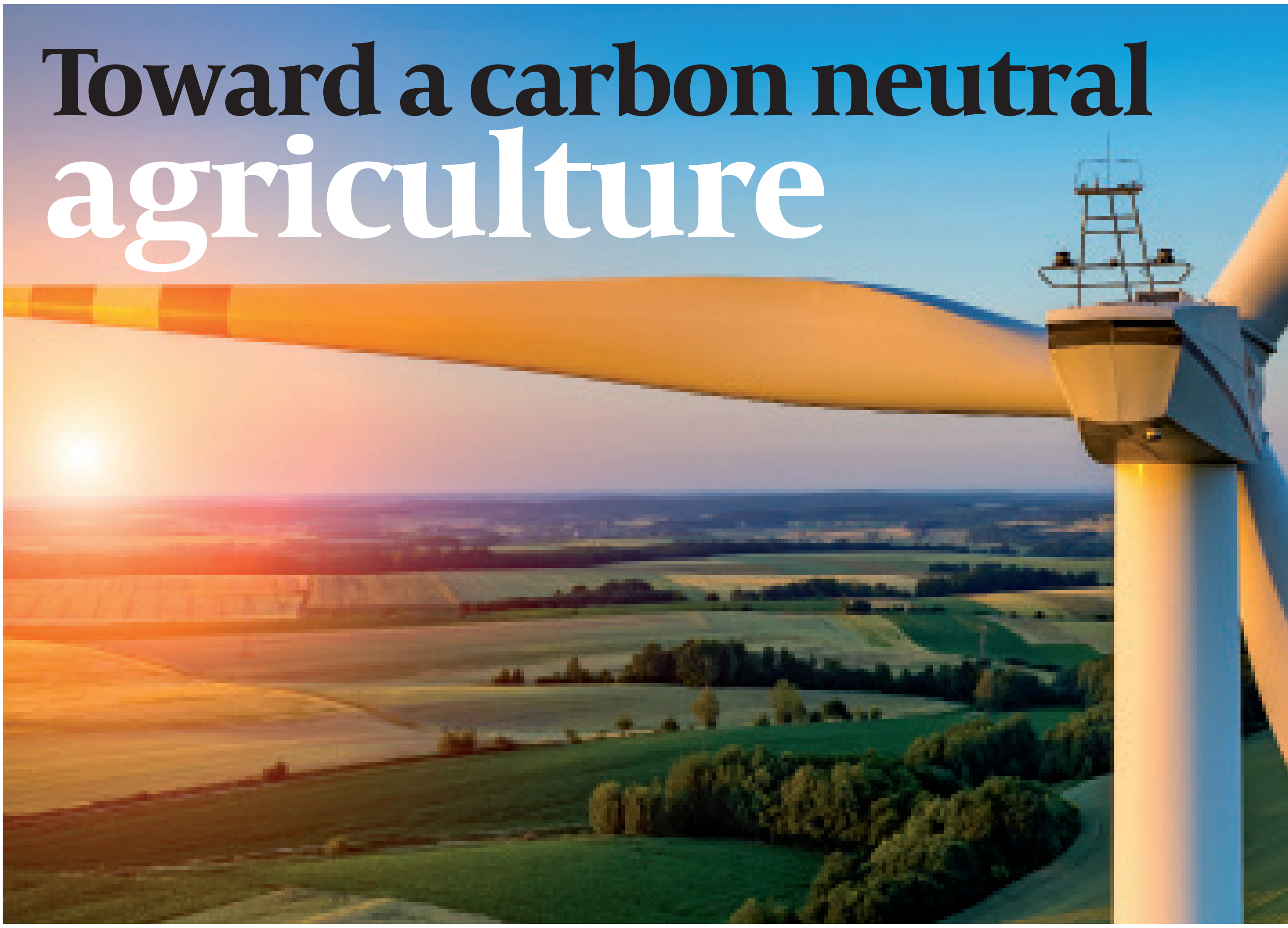
BIOCLIMATIC DESIGN

ENGIE Research teams are exploring many of the most promising bioclimatic solutions, such as coatings with specific properties that can reduce solar gain by reflecting sunlight, whilst continuing to increase the building's heat loss by ejecting heat, even during the day, as thermal radiation in a mid-infrared wavelength range (sky cooling). Another solution is to increase a building's thermal inertia by integrating phase change materials into its envelope: in this way, units of cold accumulated overnight can be used during the day.

Other solutions such as free cooling make use of the various sources of cold available, such as deep sea or lake water, cold air currents, mountain snow, cold nights and days and underground water.

The building sector now seems to be sufficiently well structured to meet the challenge of the energy transition. As far as space cooling is concerned, the technological progress in building techniques, as well as in the manufacturing of air conditioning and refrigeration systems, is continuing apace, even if the associated economic model may prove to be complex depending on the regulatory framework of the country in question. At the end of the day, the United States may well be able to stay cool without warming the planet. ■

WRITTEN BY:
RODOLPHE DESBOIS AND CRISTIAN MURESAN, ENGIE



Toward a carbon neutral agriculture

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WRITTEN BY:
ELODIE LE CADRE LORET AND BÉRENGÈRE GENOUVILLE, ENGIE RESEARCH.

According to the United Nations Department of Economic and Social Affairs, by 2050 more than 66% of the 9 billion people on earth will live in cities, up from 43% today. That's nearly 3 billion more city dwellers than in 2020. This growing urban population will mean that more food will have to be produced as close to cities as possible and with cleaner and cleaner energy. Energy consumption in the food industry already accounts for more than 30% of global primary energy consumption and more than 20% of greenhouse gas emissions.

Trying to provide sufficient quantities of good quality food and water is a challenge for all of us, as farmers, food processors, transport companies, distributors or consumers. On our planet, land use, biodiversity and resources are already suffering from climate change. In one part of the world, periods without rain are getting longer and droughts more intense, whereas elsewhere spring comes earlier and earlier, but late frosts persist. Under these conditions, how can we produce more and better while respecting the planet's limits and reducing the competition between agriculture and energy production, for example when solar panels cover large areas of land? ENGIE takes a close interest in these issues, but why exactly?

The answer is because ENGIE is by the energy consumer's side on a day-to-day basis, providing them with greener and more efficient energy wherever they live. And of course farmers and the food industry need a lot of energy, such as for agricultural machinery, heat for drying crops before storage, cold to preserve raw or processed foodstuffs, electricity for irrigation or organic matter to produce biogas etc. ENGIE provides for integrated solutions that supply green energy and improve the energy efficiency of the entire food production chain, even contributing to making fertilisers greener.

However each region is different and technologies need to be adapted to different agricultural sectors, geographical areas and parts of the agri-food chain. To meet the wide variety of different situations, ENGIE implements field projects in partnership with farmers and

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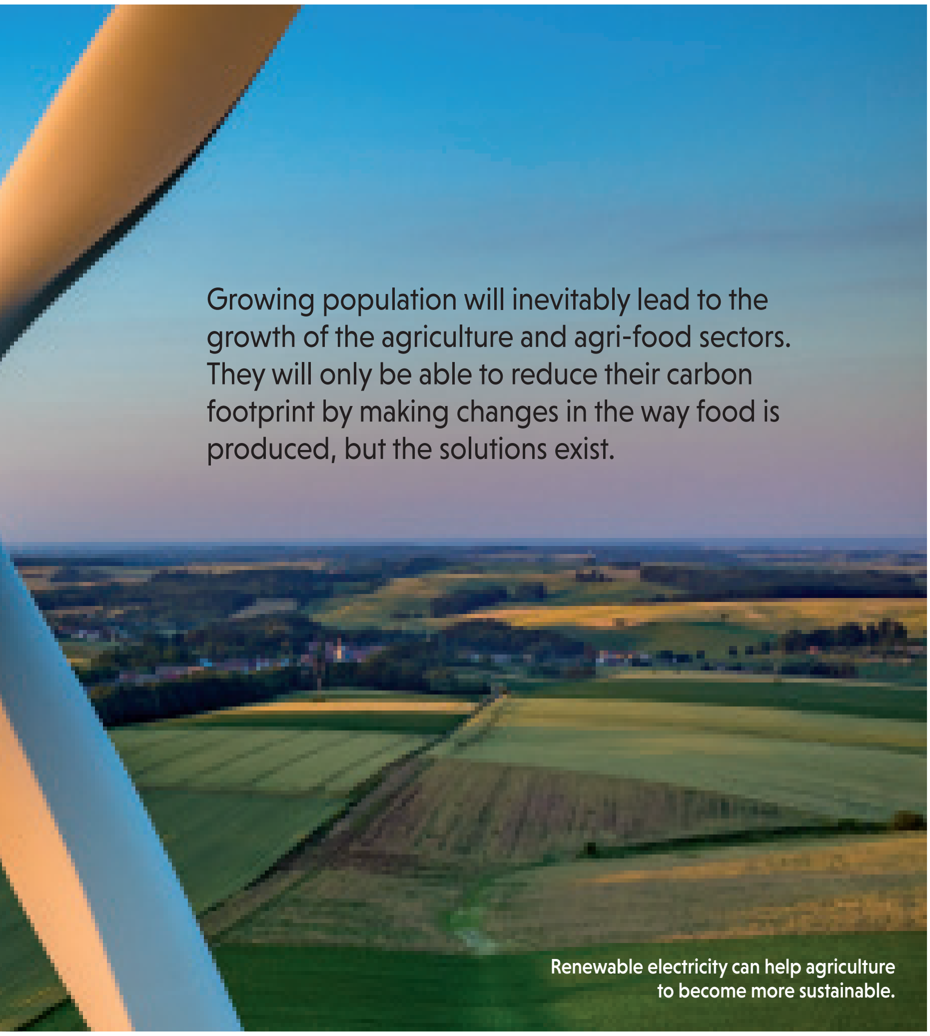


Renewable electricity can help agriculture to become more sustainable.

agronomists, which endeavour to meet their needs as closely as possible.

If we take a few examples of our pilot projects, we will see that we can significantly reduce the carbon impact of the food we eat. These projects aim to answer three questions: What technologies are the most promising? How will our food change? Will we pollute less by eating products made using local energy?

FROM FIELD TO GREENHOUSE

The first project deals with competition for land by studying how best to combine food and solar energy production on the same area of land. It analyses the best combinations of PV panels (of different types) and food crops that grow better in the shade, taking into account different climates.

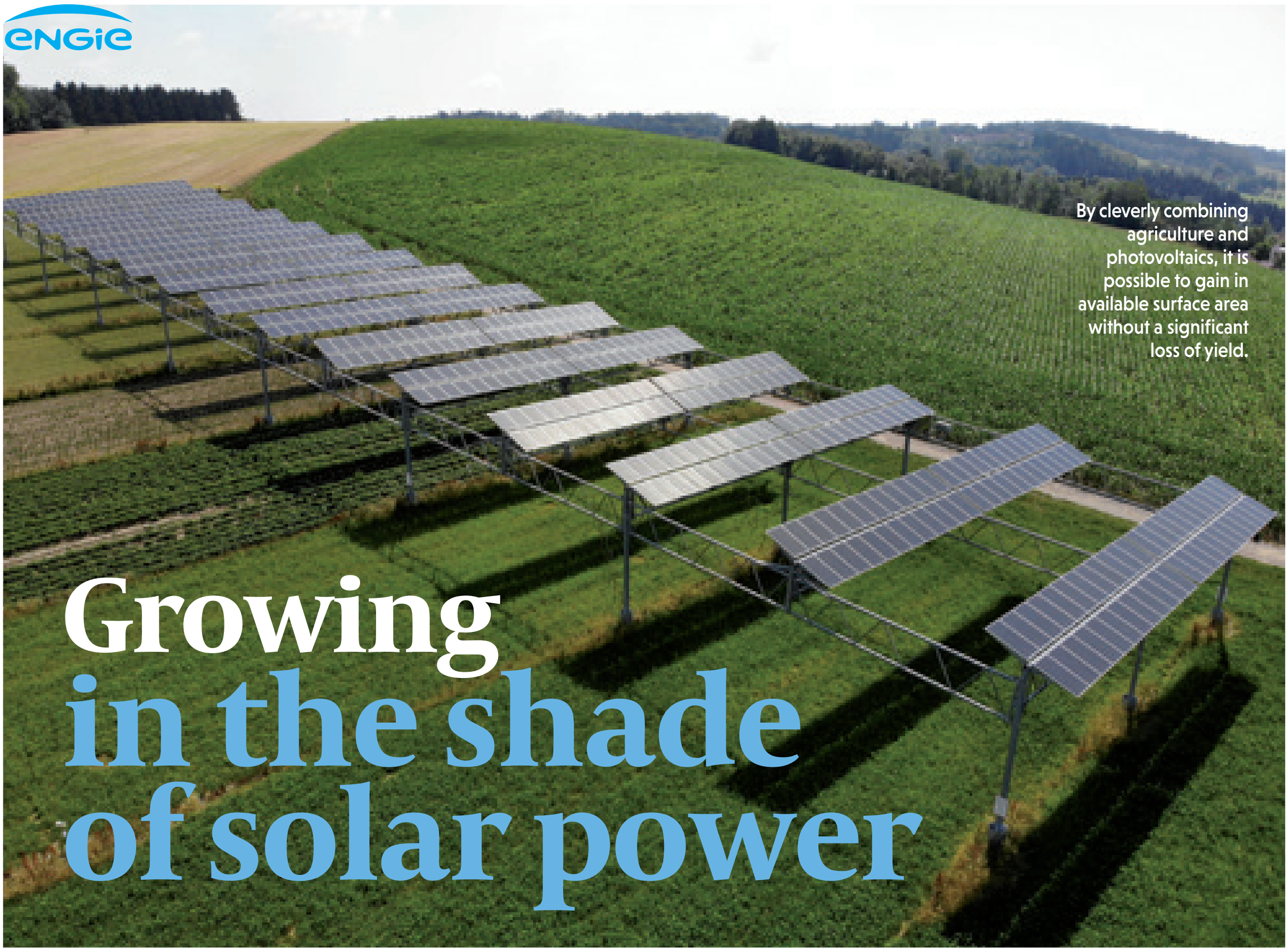
The second pilot project aims to reduce emissions from greenhouse crops. Greenhouses cover an area of about 10,000 hectares in France, two thirds of which are used for vegetables. The aim is to improve energy efficiency to the point where such crops become carbon neutral, bearing in mind that, according to the Ademe, depending on the region they currently consume between 270 and 330 kilowatt-hours per square metre. On average, this energy represents 22% of the direct production costs of greenhouse farming. For this project, ENGIE established a partnership with Wageningen University & Research in the Netherlands to design a greenhouse that is autonomous, notably in terms of energy. The test greenhouse has been equipped with water, soil moisture, light, oxygen and CO_2 sensors, amongst others, in order to obtain optimal growing conditions, whilst limiting carbon emissions and energy consumption.

USE OF GREEN HYDROGEN

The third project addresses the production of sustainable fertilisers. Crops need water and CO_2, but they also need nutrients such as nitrogen, phosphorus and potassium. Nitrogen is provided by various synthetic compounds made from ammonia using the Haber Bosch process (the catalytic hydrogenation of atmospheric nitrogen), however the hydrogen gas used as a catalyst is often fossil fuel-based. ENGIE is developing new processes to produce green hydrogen by using surplus green electricity for the electrolysis of water. Today this process, which would help produce more sustainable fertilisers, is centralised in very large-capacity plants. One of the challenges of the research programme is to study the technical and economic interests of relocating this production as close as possible to the site of consumption. Not only would this limit soil pollution, but reducing the transport of fertilisers would also lessen air pollution. These solutions deployed alone or in combination will not affect food quality, but they will reduce its carbon footprint.

These initiatives are not isolated. They complement an array of high-tech (precision agriculture, urban agriculture, etc.) and low-tech (no-till farming, etc.) solutions. They will develop in parallel across cities around the world depending on farm size and the capacity of farmers to adopt these new technologies. In the medium term, the most affordable and mature technologies, such as the use of new sensors to optimise production and processes, will become widespread. At the same time, consumers will need to mobilise and lobby producers in order to limit carbon emissions caused by food transport, reduce food waste and improve traceability.

According to the latest overview of emerging technologies by DNV GL, city dwellers will move toward sharing local resources. This will take the form of food cooperatives based around local, low-carbon food production. In this way, we can reduce the carbon footprint of food from farm to fork to the minimum. ■



By cleverly combining agriculture and photovoltaics, it is possible to gain in available surface area without a significant loss of yield.

© Fraunhofer ISE

Growing in the shade of solar power

Whether it's in temperate climates or more arid regions, co-locating crops and solar panels is a win-win solution.

WRITTEN BY:
JÖRAN BEEKKERK VAN RUTH, STIJN SCHEERLINCK, ENGIE LABORELEC, ROB KURSTEN, ENGIE BENELUX AND CLAIRE DU COLOMBIER, ENGIE SOLAR

All around the world, photovoltaic systems have become a key element in the energy transition and yet some highly urbanised countries, such as Belgium and the Netherlands, lack the necessary space to install large solar power plants. In this context, wouldn't it make sense to use the land more wisely?

One solution would be to combine agricultural activity and solar power production on the same plot of land, a concept known as agrivoltaics (a word coined by combining agriculture and photovoltaics). ENGIE BENELUX has taken up the challenge and is implementing a large-scale project of this type in the Netherlands that aims is to install a 45-megawatt solar farm combined with a crop-growing activity by 2021.

CELERY OR RASPBERRIES?

The first phase of the project consists of a one-hectare field trial to test different options and gain the necessary experience that will enable the deployment of the demonstrator over 50 hectares. Several questions need to be answered, such as what to plant. What's best, celery or raspberries? The crop must be marketable, but be able to grow in the shade. Another question involves choosing between classic or bifacial solar panels and deciding on their configuration, i.e. what is the optimal density of PV panels to produce enough electricity, without blocking too much sun from the underlying ground? To answer these questions, ENGIE is working with a local partner, Green Meteor, which originally specialised in building structures to protect crops against the hail or the sun. This partnership is also beneficial in that it forges links with the horticultural sector, which is vital for the proper conduct of the project.

THE GLOBAL HISTORY OF AGRIVOLTAICS

The idea of co-locating photovoltaics and agriculture was first suggested in 1981 by Adolf Goetzberger and Armin Zastrow and it has progressed in Japan since 2004 under the impetus of Akira Nagashima. Many types of crops such as citrus fruits, cucumbers, rice and vines can benefit. The technique has now spread to various countries around the world: China, India, Malaysia, Austria and Chile etc. In 2017 in Vietnam, the Fraunhofer Institute ISE deployed a pilot agrivoltaic system on a shrimp farm in the Mekong Delta.

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ENGIE is envisaging the development of an agrivoltaic project in Chile's Arica Province (photo of Lluta Valley),

Do the PV arrays affect yields? The findings of the APV-RESOLA project, conducted in Germany by the Fraunhofer Institute ISE in 2018 show that agrivoltaic installations are capable of achieving satisfactory agricultural production. Some crops are quite tolerant to shade and can adapt to a reduction in photosynthetically active radiation (the amount of light available for photosynthesis, i.e. situated in a range of wavelengths between 400 and 700 nanometres) without significant yield loss. The results therefore vary depending on the amount of shadow caused by the solar panels.

As part of the APV-RESOLA project, an experimental field planted with potatoes (*see figure on opposite page*) was partially covered with solar panels, resulting in a 30% decrease in the annual amount of sunlight received. As a result, potato yield increased by 3%! The overall result can be expressed as a land equivalent ratio, in this case the LER is 186%, i.e. 103% potato efficiency compared to the reference yield for the same area and 83% relative photovoltaic production efficiency.

Whereas potatoes seem to benefit from shade, this is not the case for all plants. In the same conditions, clover production decreased by 8% illustrating that the choice of crop type is crucial!

ENCOURAGING BIODIVERSITY

The synergies between agriculture and photovoltaics go far beyond crops and energy efficiency. Solar farms can benefit local biodiversity, whilst creating a habitat that is vital to the survival of pollinators. In the United States for example, ENGIE NORAM has planted local plant species on its solar farms and joined forces with various stakeholders, such as the National Renewable Energy Laboratory (NREL) in Colorado and the University of Minnesota Bee Lab, to create habitats for pollinators including bees, as well as to support biodiversity on a national level. One particular example is the InSPIRE project through which the NREL is trying to quantify the environmental and economic benefits of planting native and other beneficial vegetation at solar sites.

Another example is a project under development in Hawaii in which ENGIE has joined forces with Agicon LLC to identify possible synergies between photovoltaics and agriculture. One of its recommendations is to use an indigenous native shrub, the *Psydrax odorata* as a windbreak.

In France, ENGIE Green has also developed five solar projects that integrate beehives and flowering plants as a way of supporting biodiversity.

Can agrivoltaics be useful elsewhere than in temperate regions? To answer this question, let's head off to the Atacama Desert in Chile, which is difficult to beat as far as sunshine and heat are concerned! High solar irradiance is of course good news for PV power production, although excessive temperatures and dust can negatively affect performance. Heat and lack of water are however not usually ideal conditions for crop growth.

GROWING IN THE DESERT

But that's exactly where agrivoltaics comes in: the shade provided by solar PV arrays allows crops to thrive in favourable microclimatic conditions (higher soil moisture and lower ambient temperatures). If a source of water is available, water can be pumped to irrigate plants using locally produced green electricity and, even better, in these hot climates the vegetation planted under the PV panels tends to reduce the ambient temperature, thereby improving their performance.

At the end of the day, agrivoltaics in arid regions can provide local communities with an unprecedented economic activity. Compared to installations in temperate regions, the potential gain in overall yield (solar and agricultural) is greater, mainly due to the significant increase in crop yields. ENGIE plans to develop a pilot project in partnership with farmers around the city of Arica in the Atacama Desert, one of the driest areas in the world.

Wherever crops and solar power come together, agrivoltaics is paving the way for a smarter and more resilient agriculture. In each energy project, the possibilities of this combination must be studied at an early stage in order to make the most of the best available expertise and find optimal agricultural and energy solutions. Proof of the growing interest in agrivoltaics: the INRA and the Fraunhofer Institute ISE will be holding the first international conference on the subject in August 2020 in Perpignan. ■

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ADELINE DUTERQUE,
ENGIE CRIGEN LAB DIRECTOR

LUC GOOSSENS,
CHIEF TECHNOLOGY OFFICER, ENGIE

JAN MERTENS,
CHIEF SCIENTIFIC OFFICER, ENGIE

The "and" of the energy transition

We often tend to oppose different solutions when talking about the energy transition, but at ENGIE, we are trying to find synergies.

At the end of 2019, two energy experts were talking over lunch: one was an international reference in heat pumps and the other a leading expert in the field of biomass combustion. It was striking to note how even highly intelligent people still sometimes only think in terms of black or white solutions. For the heat pump specialist, it was "obvious" that the future of domestic heating would be all electric and that heat pumps were the best (and only) solution. The other lived in an old house that was not as well insulated as a new build and which therefore needed a high-temperature heating system. He argued that a heat pump would not be efficient enough for this type of house, adding that a new biomass boiler using two or even three-stage combustion and equipped with an integrated flue gas treatment system would be perfectly suited for domestic heating, even in densely populated areas, as its emissions were negligible.

The interesting thing about energy discussions is that, as energy is everywhere today and it plays such an essential role in day-to-day life, you don't need to be an expert to have a strong opinion. According to Michael Webber, energy is the key to a good life and, used properly, it provides humans with health, wealth and freedom, enabling our access to clean water and safe food. In many of these otherwise highly entertaining discussions on energy, most people seem to be thinking in binary terms about opposite and mutually exclusive solutions: using either nuclear reactors or gas turbines to compensate for intermittent renewable energy production, either electricity or gas to produce heat, either lithium-ion batteries or Redox Flow batteries for grid stabilisation, electric versus hydrogen mobility, biogas versus synthetic gas etc. After reading the articles in this supplement, you will understand that binary thinking is not the rule at ENGIE. We do not oppose different technologies, but rather think about how they can work in tandem.

WHAT SOLUTIONS FOR TRANSPORT?

One of the most common discussions deals with mobility in the future and whether it will be electric or powered either by hydrogen, biogas or synthetic hydrocarbons. This way of asking the question implies a choice is required, whereas it would be more judicious to see where each mobility solution would be most relevant. For short journeys using cars and light

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vehicles, the battery electric car has such a head start that it will be difficult for other technologies to catch up, however for heavy transport (bus, truck, maritime transport etc.), the energy mix is likely to be diversified and the respective share of the different fuels is difficult to predict today.

The installation of an extensive hydrogen-refuelling network seems unlikely in the near future, but for journeys where vehicles travel between places where hydrogen is produced locally, it would be a good alternative to the use of batteries. The same is true for that part of the railway network which is not yet electrified: hydrogen trains are an interesting option for decarbonising this mode of transport. As far as aviation is concerned, researchers are working on developing electric or hydrogen-based solutions, but it is unlikely that these will replace kerosene for long-haul flights in the immediate future. The reason is simple: both the types of battery available today and hydrogen have a low energy density (the amount of energy stored in a given volume), but then again, electricity and hydrogen-based solutions could emerge for small aircraft and short-haul flights, or for hybrid-powered aircraft, which will use electricity or hydrogen as they taxi on the tarmac and a carbon-neutral synthetic hydrocarbon for flight. Access to synthetic fuels is therefore vital for the future of long-haul flights.

Another interesting and lively debate concerns the transport of energy over long distances. Not everyone lives in an area where cheap renewable energies are abundant and, in our transition to a carbon-free world, this issue is becoming more acute. High-voltage direct current (HVDC) lines will be part of the solution, but as distance increases other means of transportation will need to come into play. These will involve the conversion of electricity into other energy carriers, such as hydrogen, ammonia or synthetic hydrocarbons. Even more innovative solutions are emerging today, such as liquid organic hydrogen carriers and metal fuels. As we have already seen, all of these technologies will undoubtedly work together to transport energy over long distances, which is why this question is a priority for research at ENGIE.

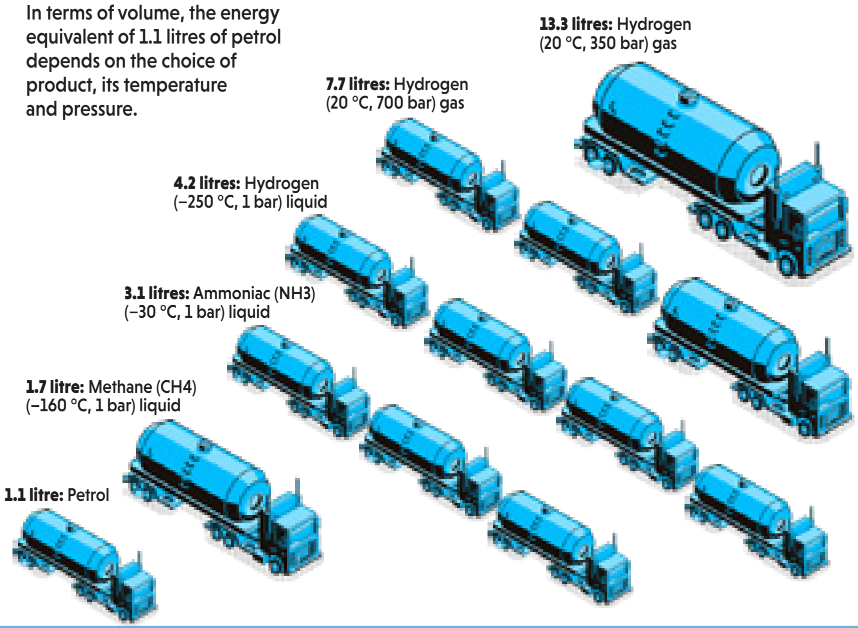
“The interesting thing about energy discussions is that you don’t need to be an expert to have a strong opinion.”

UBIQUITOUS GAS AND ELECTRICITY

The “either or” question also dominates the question of “whether”, as part of our transition to a carbon-neutral world, we should focus on the electrification of industry or opt for green gases. By now it should come as no surprise that ENGIE believes the right strategy is to do both simultaneously. Although it is true that electricity has significant advantages over gas and that converting electricity to gas is less efficient and more expensive than the other way around, gas is still needed for seasonal energy storage and to increase energy density before transportation. In addition, green gases can be transported via existing networks. In fact, with the introduction of technologies such as “Power to Gas” (storing energy from electricity by transforming it into a gas such as hydrogen) and “Power to Gas to Power”, the distinction between electricity and gas tends to become blurred and the transformation from one to the other becomes much easier. As a result, trying to decide between electricity and gas no longer makes much sense since we will be using both!

HOW TO TRANSPORT 10 KILOWATT HOURS OF ENERGY?

In terms of volume, the energy equivalent of 1.1 litres of petrol depends on the choice of product, its temperature and pressure.



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Will the hyperloop revolutionise energy use for transport?

© Hyperloop

FUTURE SURPRISES

The possible impact of game-changing technologies on the energy transition remains difficult to predict. Certainly some will appear in the years to come and will undoubtedly make a big difference. Artificial photosynthesis, replacing short-haul flights transporting passengers and goods by Hyperloop-type solutions (ultra-fast trains running in low-pressure tubes - *see figure opposite*), high-altitude wind energy and turning carbon dioxide into fuel (via biological processes or not) are just some of the technologies that may prove to be a valuable aid on the road to carbon neutrality.

This is why investment in research on these new technologies is so important and why public-private partnerships are essential to developing them. ENGIE is committed to working with partners to co-develop these emerging technologies by means of pilot projects and demonstrators. These technologies have environmental and economic advantages, but public support will also be crucial: public acceptance and the rate of take-up of new technologies will determine whether a given innovation will breakthrough.

The energy transition will therefore be a matter of "and" rather than "or" and will follow two complementary directions. We will need all of these emerging, sustainable technologies because none of them will be able to meet the challenge alone. The objective is so ambitious that it requires everyone - individuals, companies and different business sectors - to work together. So join us on our journey toward a carbon-neutral world. ■

The synergy of solutions, for the most suitable use of energy.

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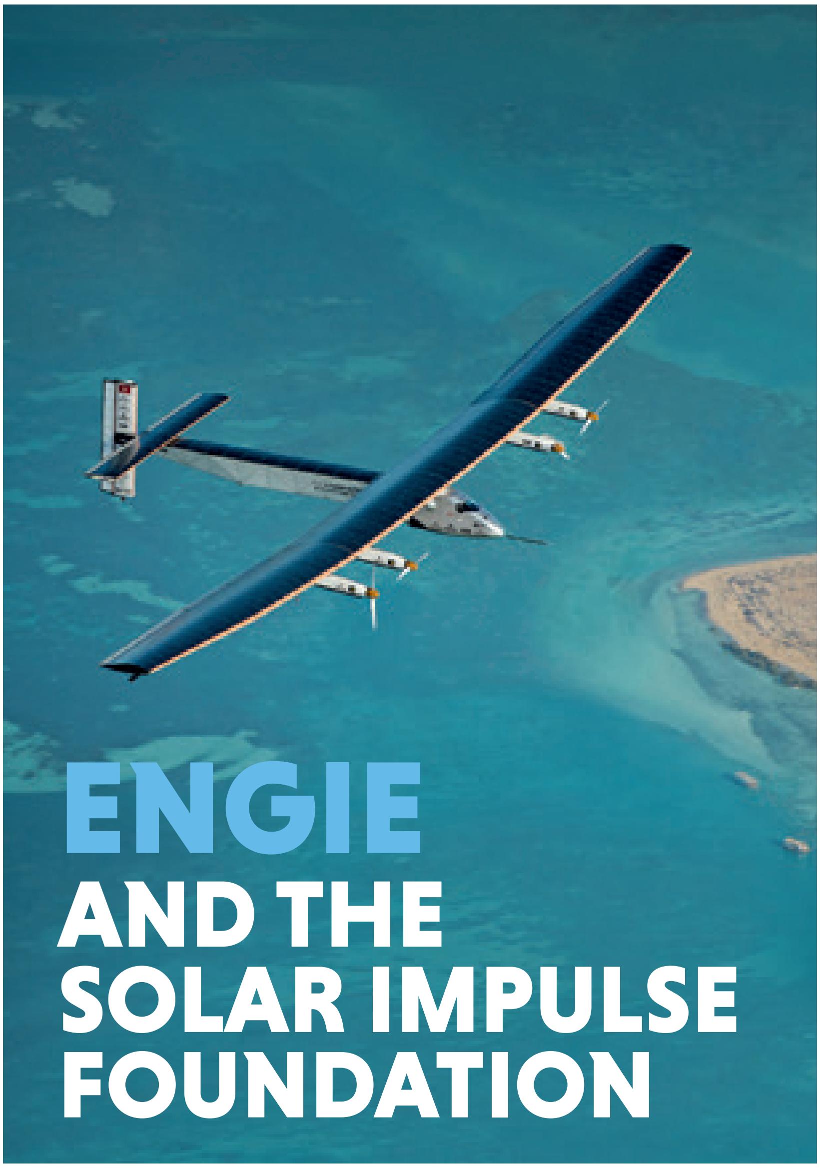
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ENGIE AND THE SOLAR IMPULSE FOUNDATION

Since 2017, ENGIE has been a partner of the Solar Impulse Foundation, which was co-founded by Bertrand Piccard. The aim of the foundation is to reduce our impact on the environment, whilst encouraging economic development. It has set itself the challenge of identifying 1,000 responsible, efficient and cost-effective solutions that will incite the authorities and other decision-makers to commit to more ambitious environmental objectives and energy policies.

A POSITIVE IMPACT

Shared values provide a major opportunity to stimulate action and innovation and accelerate the zero-carbon transition by developing "clean" solutions that reconcile environmental protection and economic profitability.

Individual and collective advantages: this partnership encourages both industries and local authorities as they work to become carbon neutral and accompanies the younger generation toward a future on a greener planet.

CERTIFIED SOLUTIONS

The Solar Impulse Foundation's "Efficient Solution" label certifies projects that have a positive impact on the environment as well as the potential to be profitable. The goal is to provide entrepreneurs with the support they need to speed up the implementation of these solutions and increase their visibility.

Among ENGIE's certified solutions:

- **PowerCorner** provides reliable, sustainable and affordable energy services using mini-grids to supply electricity to rural customers in developing countries.
- **Community Solar** is a solar power plant whose electricity is shared: customers can rent a "share" in the solar energy it produces without having to equip their roof, or even have a roof.
- **District cooling systems**. In Paris, ENGIE has been operating CLIMESPACE, one of the world's largest district cooling systems, since 1991. It uses renewable electricity to deliver chilled water to more than 600 customers (hotels, offices etc).
- **Vertuoz Pilot** optimises energy consumption. Smart devices provide data that enables an artificial intelligence to control heating and lighting etc. ■

EXPERTS OPINIONS

“At ENGIE, we can rely on a wide range of professions and expertise to identify effective and sustainable solutions. My role is to coordinate the group's experts in order to develop economically and environmentally effective zero-carbon solutions.”

ELODIE LE CADRE LORET, ENGIE RESEARCH,
ENGIE expert since October 2019

“At ENGIE Innovation, I source the most innovative and efficient solutions across a wide range of professions. With Solar Impulse, the challenge is to identify those that will be effective rapidly and have a lasting impact on the planet. There are 20 ENGIE experts worldwide and we are amongst the experts who evaluate the most solutions.”

JEAN-MICHEL REYNAUD, ENGIE INNOVATION,
ENGIE expert since 2018


Developing renewable energies
to boost the agricultural sector in our rural communities.
ENGIE, solutions to support your zero-carbon transition.
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