POLYTECHNICAL UNIVERSITY OF THE MARCHE

FACULTY OF ECONOMICS "GIORGIO FUÀ"

Master's Degree in International Economics and Commerce

THE ECOLOGICAL CHALLENGE

THE ENERGY TRANSITION TOWARDS GLOBAL CARBON NEUTRALITY

LA SFIDA ECOLOGICA

LA TRANSIZIONE ENERGETICA VERSO LA NEUTRALITÀ GLOBALE DEL CARBONIO

Supervisor: Prof. Roberto Esposti

Final Report of: Francesco Lion

Academic Year 2023/2024

To my beloved family, my friends and all those who have supported me on this long and difficult journey.

Despite everything, for better or for worse, you have always remained by my side, giving me the precious awareness of who I can and want to be and to be able to go towards infinity and beyond.

For all this, thank you from the bottom of my heart.

A further special thanks to Professors Nicola Armaroli and Leonardo Becchetti, who have given a generous and participatory contribution that has been fundamental and invaluable to the realization of this Thesis.

INDEX

INTRODUCTION

Impious and violent, Erysichthon did not fear the wrath of the gods: he even deliberately cut down a grove sacred to Demeter, with the intention of building a dining room. To punish his impiety, the Goddess condemned him to inexhaustible hunger. To feed himself, Erysichthon squandered all the wealth of his family, and even sold his daughter Mestra at the market; he did this several times because her lover Poseidon had given her the gift of taking any shape, which allowed her to change into a different animal every day to be sold and then escape her masters. In the VI Hymn of Callimachus Erysichthon is mentioned, but not his daughter. Callimachus tells that Demeter, assuming the appearance of the priestess Nicippe, urged Erysichthon not to cut down the trees that were sacred to her, but when he threatened her and continued with his work, Demeter became a Goddess again and condemned him to eternal hunger; and Erysichthon, having squandered his wealth, was forced to become a beggar. In the end, Erysichthon, to appease his hunger, ended up devouring himself.

The myth of Erysichthon is as illustrative and reflective as it is disconcerting and disturbing if it is brought back and compared to the reality of today's world.[1] The presence, with its devastating and often unpredictable consequences (except through calculations and analyses that go beyond the present time and, therefore, are given little consideration), of the damage that Humanity causes to nature and other living beings, ending up tearing apart and mortifying itself, is now the order of the day. Global warming, often indicated and defined as "climate change" and recently also cited, after multiple and varied global climatic events, often sudden and outside of any previous measurement, as "climate crisis", is one of the key themes of the debate and conflict on current events and future policies to be implemented (or not). It should also be remembered that "climate change" is, from a linguistic point of view, a neutral term unlike the previous one officially used by the scientific world, originated by the presidency of George W. Bush in the White House, which thus converts it

[1] Wikipedia, Erysichthon (Thessalian), https://it.wikipedia.org/wiki/Erisittone_(tessalo)

in a less worrying and pressing way, ignoring that the climate exists and changes cyclically by nature. And yet, for more than thirty/forty years, it was evident that its cyclical balance was progressively more and more distorted and brought to crisis, that this degradation, ever closer to collapse, had serious consequences everywhere and potentially increasingly harmful as the years went by, that the cause of this came from our human activities (that is, from us human beings *sapiens sapiens*, with our actions and activities) and that therefore it was necessary to act on the causes by making important changes to the current model of economic growth, collective human development and concept of well-being in our globalized postmodern civilizations.

This Master's Thesis is essentially aimed at this. That is, to try, despite the limitations of the medium and the vastness of the topic, whose debate is more open than ever (the IPCC report alone, *Intergovernmental Panel on Climate Change*, has 3,000 pages), to shed light on, argue, deny, clarify and make more accessible and understandable facts, elements and objective and evident realities, regarding the actions, sought and in progress, aimed at achieving the current transformation towards a society, an economy and a sustainable life in the most comprehensive sense of the term, humanly dignified and respectful of the environment. Usually in the general debate and comparison, all this ends up falling back and sinking into unresolved and forced doubt, lies, manipulation or the most inextricable confusion. Given the extraordinary and crucial situation, with implications that can also lead to extinction and apocalypse, it is absolutely essential and necessary to declare that everything that is false, or distorted, is unacceptable and must be denied, both for the love of truth and for the mere will to survive. It is often said in Politics "know to decide", ergo it must be stated that the issue of the Climate Challenge and the transformations underway are unprecedented and that, therefore, we are facing the greatest challenge in the history of Humanity. The reasoning and actions that will have to be taken are not, and cannot be practiced by recovering the old model with appropriate modifications. The results can only be minimal and often merely superficial.

We will deal below with the theme of the Ecological Challenge specifically addressed to the theme of energy transition and energy as a whole in order to achieve the ecological one, starting with the issue of global warming, passing through polluting emissions and its climatic consequences in the first chapter. Subsequently, in the second chapter, we will deal with the dilemma of Hydrogen and, through it, we will illustrate and connect the various characteristics, themes and needs of the energy transition. Finally, in the third and final chapter, we will focus on the other renewable sources, the most important ones compared to Hydrogen, reviewing the various implications and making the necessary comparisons with the other sources starting with the fossil ones, fundamental with respect to their state and evolution in the changes that must be made and that are being faced.

In any case, one thing must first be made clear: the world that will come will not be and will no longer be the world as we have known it, but a truly new world.

It is up to us to decide whether the change, which is inevitable, will be for better or for worse.

CHAPTER I

GLOBAL WARMING AND ENERGY TRANSITION:

AN ESSENTIAL SUMMARY

"We do not inherit the Earth from our ancestors, we borrow it from our children."

Native American Proverb

I.I – ORIGIN, PROPERTIES AND CONSEQUENCES OF CLIMATE-CHANGING POLLUTING EMISSIONS

It is now known that polluting emissions damage and endanger life on the Planet because, in addition to reducing the ability of the same to reflect the Sun's rays, they prevent the heat received from the Sun from being expelled and tempered, thus ending up being increasingly accumulated in the atmosphere, increasing temperatures beyond measure compared to ordinary cycles - which Humanity has detected for more than a hundred years - thus putting into crisis the balance of climates, microclimates and changes in atmospheres that the Earth, due to its very fortunate and unique conformation, has and that allows life as we know it. This is given by the so-called *Green House Gasses* (GHG) which, accumulating in the atmosphere, create a sheet of particles and molecules that permeate and retain the heat received from the Sun, thus creating the Greenhouse Effect. To get a complete picture, it should be remembered that the Green House Gases that fuel the Greenhouse Effect specifically are: Carbon Dioxide, Water, Nitrogen Oxides, Methane, Sulphur Hexafluoride and CFCs (Carbon Fluoride Chlorine).

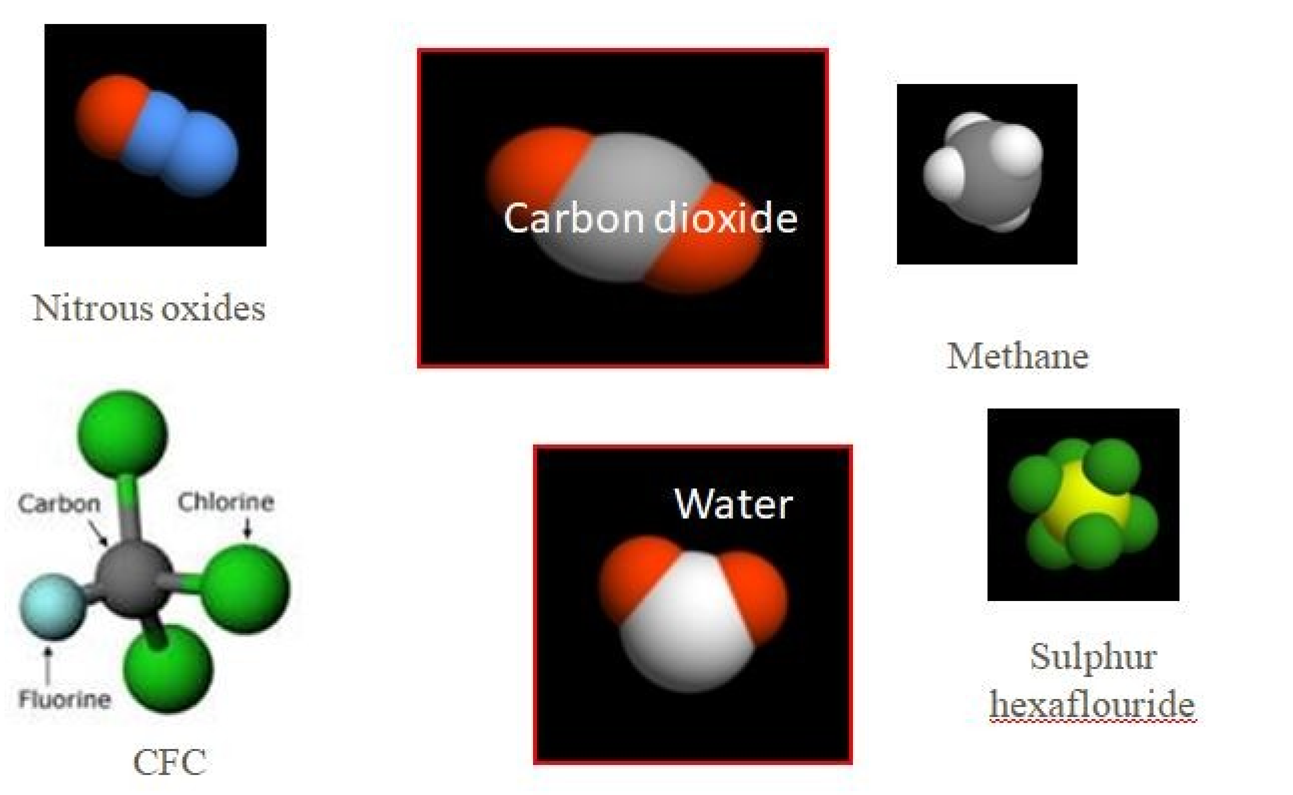


Fig. 1 – *Greenhouse Gasses (GHG)*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics "Giorgio Fuà", Ancona, 2020.

At a global level, due to the combustion and consumption of energy from fossil fuels, we emit into the atmosphere every year as much as 34 Gigatons of Carbon Dioxide (CO2) which is the main cause of Global Warming. Up to now, always taking into account that it is a value that is growing and changing over time, the average increase in temperature at a global level, due to emissions from fossil fuels and, together, from human activities as a whole that unbalance and upset natural balances, is approximately +1.1°C.

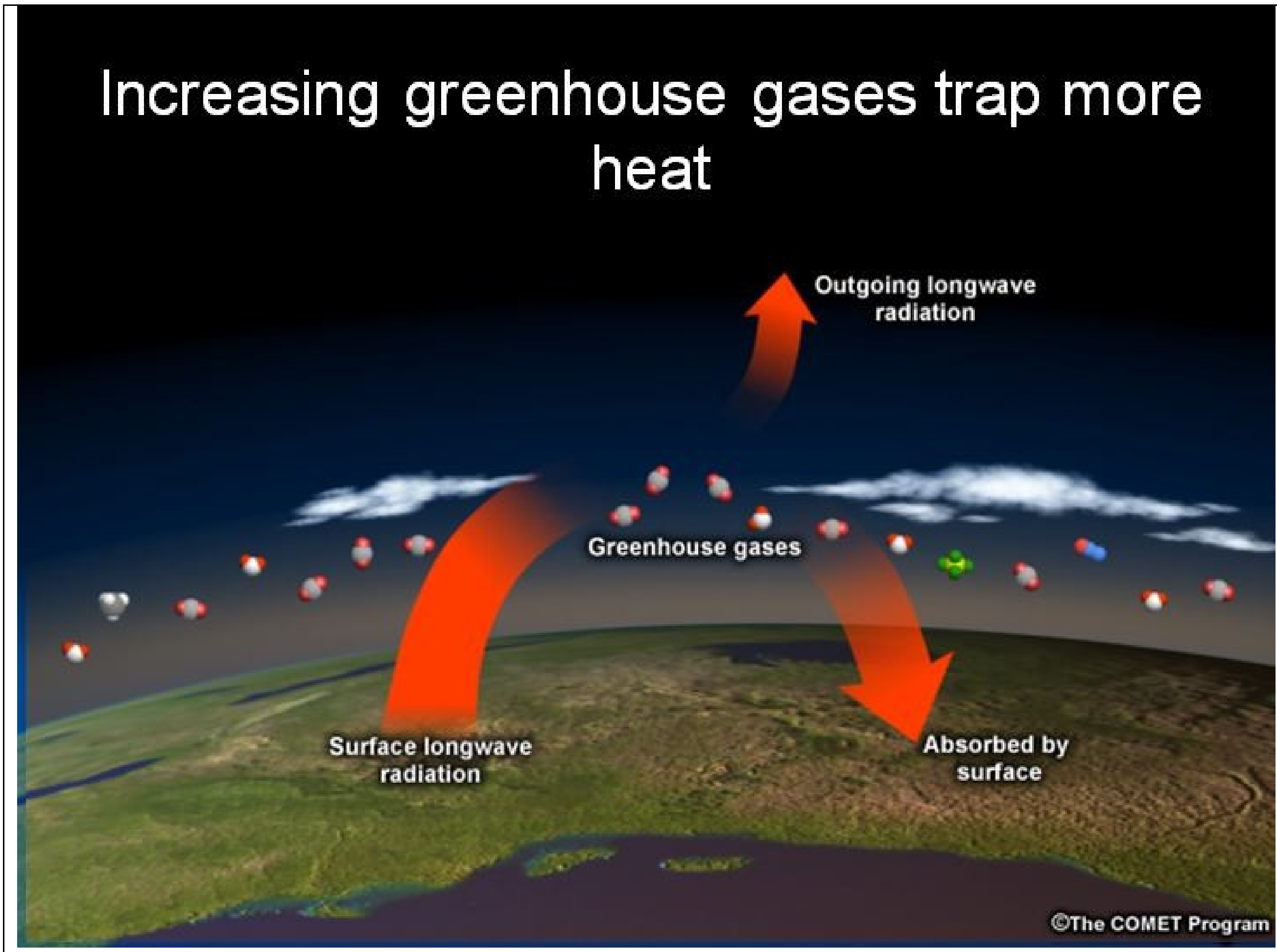


Fig. 2 – *The Global Warming*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics "Giorgio Fuà", Ancona, 2020.

Starting from the current climate situation, three possible future scenarios can be indicated, with an end date of the year 2100: the scenario in which nothing is done and no climate policy is implemented to reduce polluting emissions (also defined as the "B.A.U." *Business As Usual* scenario) which ends up bringing the temperature increase between +4.1/+4.8°C; the scenario of current climate policies with a forecast temperature between +2.5/+2.9 and 3°C and, finally, the scenario with commitments and objectives made by all States with a temperature indicated within +2/+2.1°C. These three different alarm scenarios are referred to respectively as: Catastrophic Scenario, Disaster Scenario and Forced/Mandatory Scenario. A fundamental point that must be highlighted - in addition to the fact that the increase of +1.1°C is already a calamity in itself - is that in any case it will not be possible to return to the climate of the second half of the 20th century.

From the current context onwards, even reaching the Obligatory Scenario, the situation will be, unfortunately, much worse than the current one. For this reason, it will be necessary to accelerate and intensify the energy transition as +2°C already opens up a very arduous and tortuous scenario.

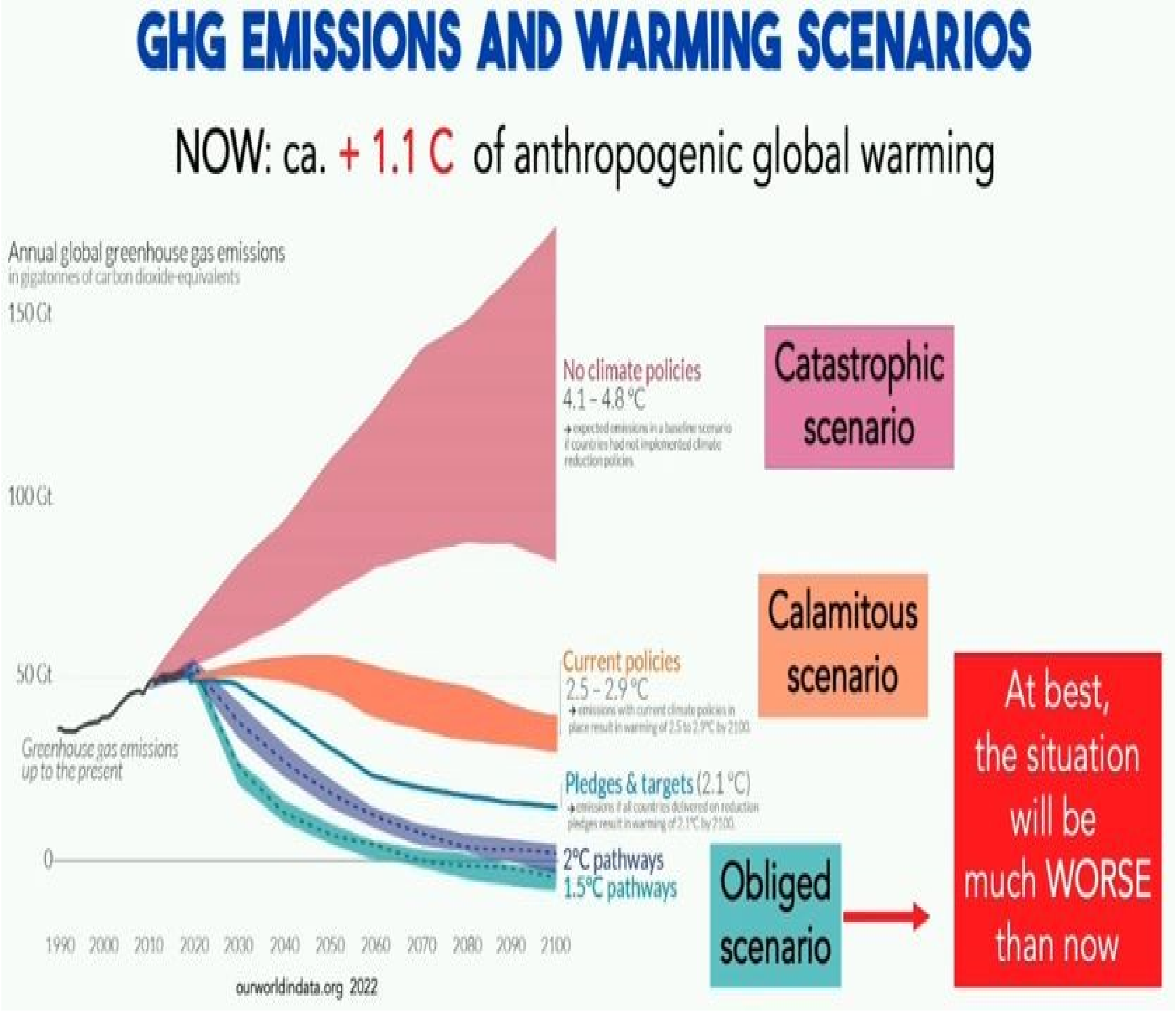


Fig. 3 – *GHG emissions and warming scenarios*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

In fact, there are three characteristics that distinguish this theme and that we must keep in mind: Irreversibility, Uncertainty, Complexity. To address them, three fundamental types of measures are necessary: Mitigation, Adaptation and - where it is still possible - Regeneration. Therefore, to be able and ready to reach the +2°C scenario, we will need to be quick in the energy transition and prepare and commit from now to systematic adaptation measures and policies.

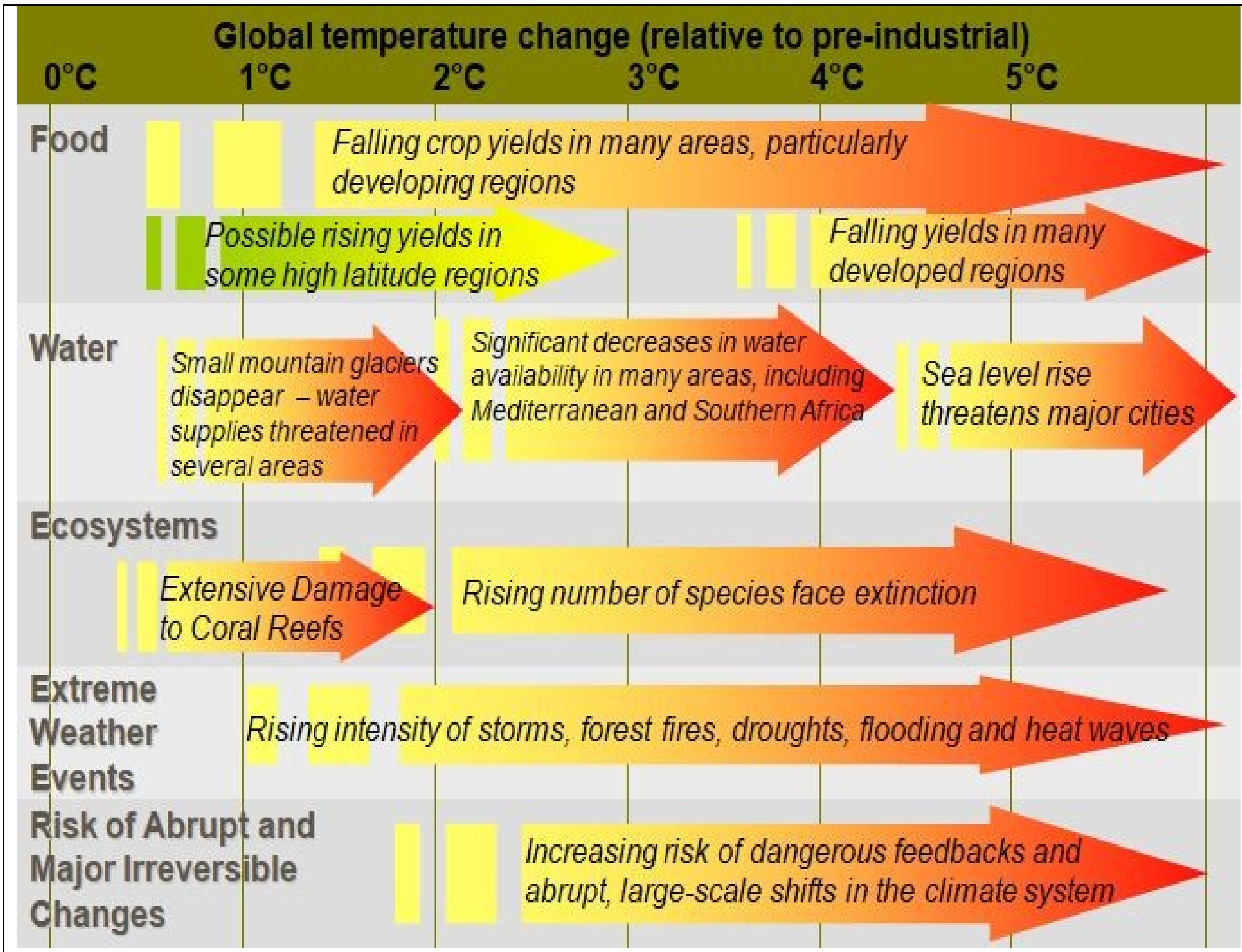


Fig. 4 – *Projected impacts of climate change*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics "Giorgio Fuà", Ancona, 2020.

But how quickly should emissions cuts be expanded? Let's take the case of Italy, for example. In 1990, our country emitted something like 520 Megatons of GHG. With the European measures aimed at reducing emissions and in favour of the climate and the environment, which apply to every country in the European Union, in Italy it will be necessary to implement a 55% cut. Therefore, the Italian State will have to return to the quantity of emissions it had in 1990, the year taken as a reference point by the European Institutions, that is, from 520 to the quota of 234 Megatons by the set date of 2030. So far, in the year 2019, something like 102 have been cut from this reference quota, arriving at emitting approximately 418 Megatons of GHG in the Bel Paese. After the Covid-19 pandemic and other global crises and events - first of all the war in Ukraine together with inflation and the increase in the cost of raw materials due to the various short circuits and international economic movements - the situation has remained more or less the same, despite the foreseeable negative repercussions on the environment. Therefore, calculations in hand, from 1990 to 2019 we have reduced emissions by 19%. Cuts have been made, albeit limited compared to the 55% to be achieved by 2030. This means that from 2019 to 2030 it will be necessary to cut this quota by 418, by 44% and that is, by more than double with less than a third of the time available.

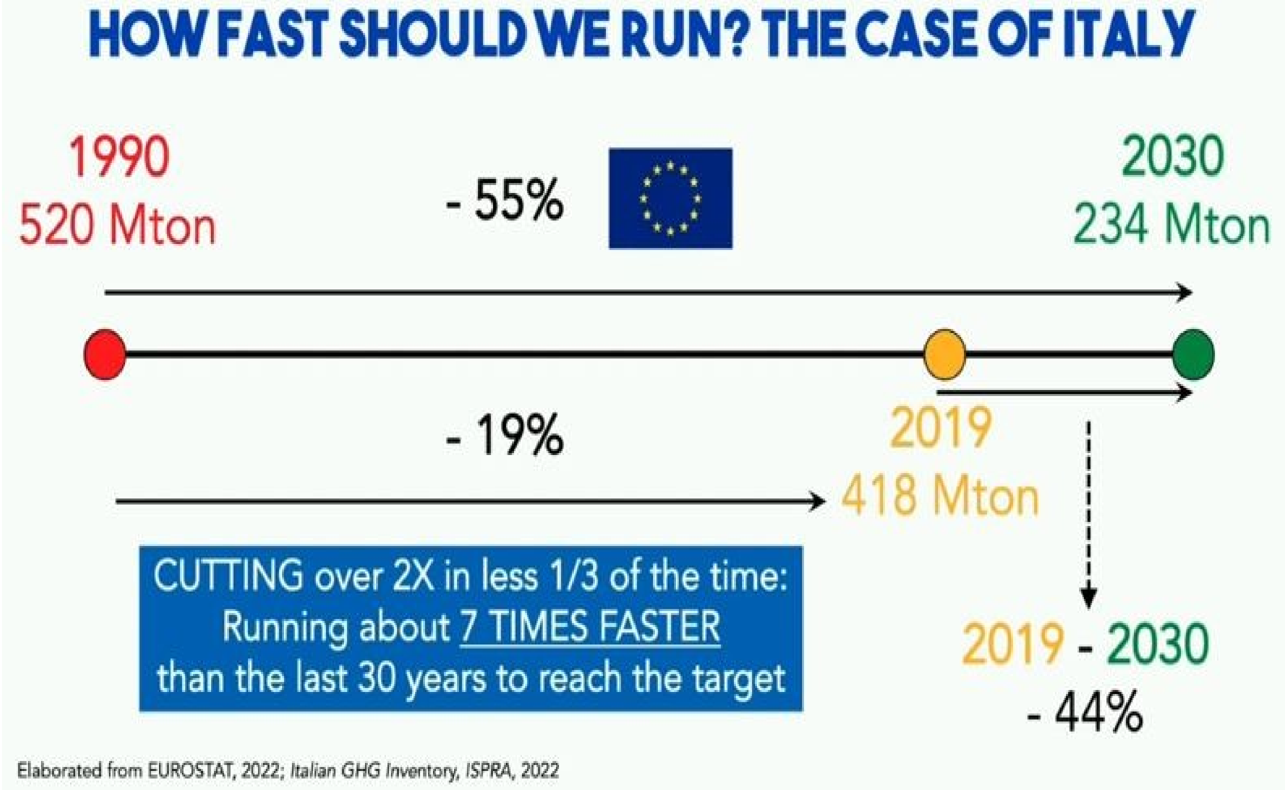


Fig. 5 – *How fast should we run? The case of Italy*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics "Giorgio Fuà", Ancona, 2020.

Inevitably this leads to the question of whether this objective can still be considered realistic. In all likelihood the answer would be, unfortunately, negative, given that we need to speed up the process of reducing emissions by a good 7 times compared to the last thirty years to reach the important goal set. But this must not in any way make us give up and desist from intervening on the damage caused to the climate and to all of us, but, on the contrary, it must give us more strength and perseverance, because in any case everything that has been done and is being done will serve and will be useful to intervene and try to stop as much as possible the impending cataclysm.

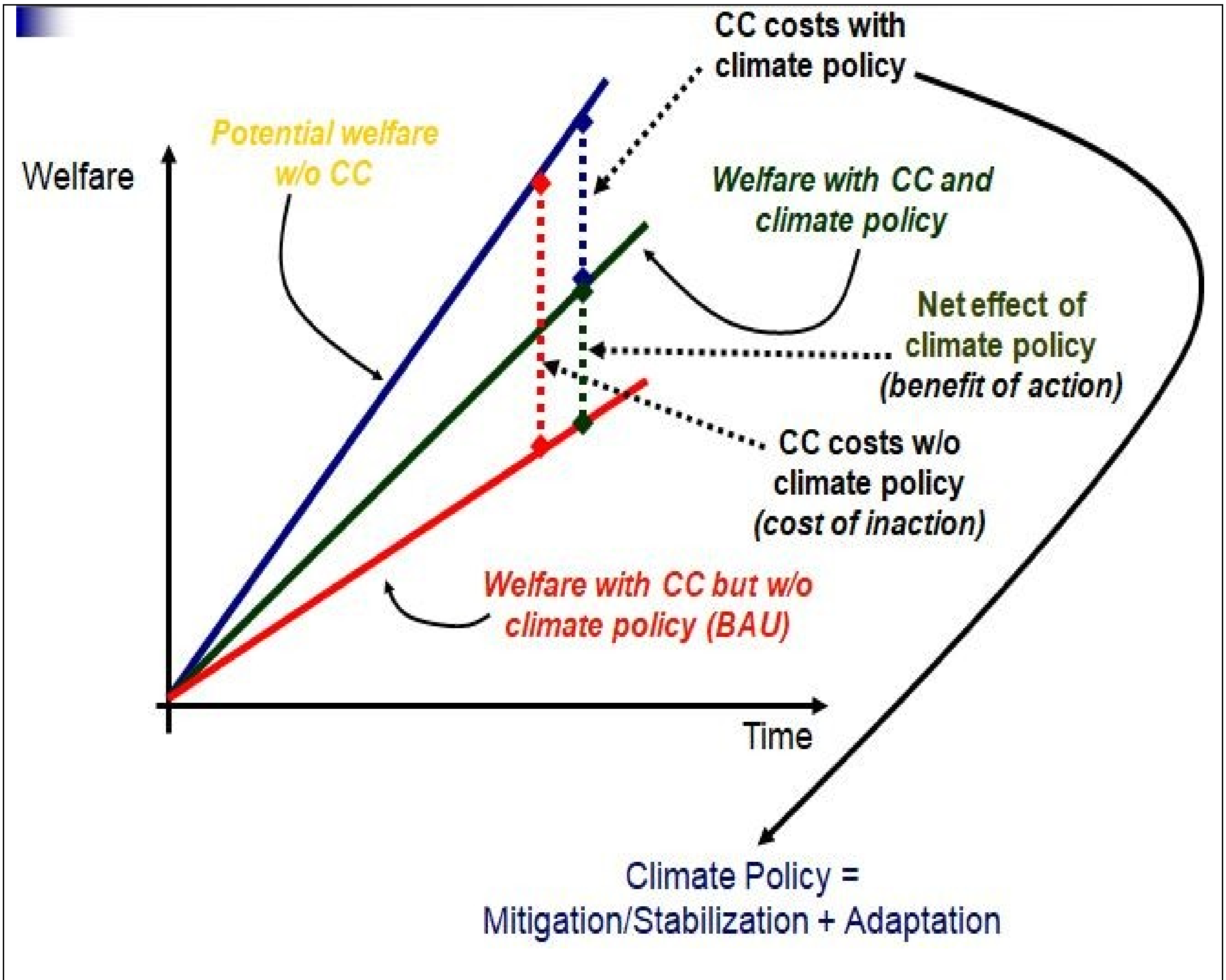


Fig. 6 – *Cost Benefit of Action (CBA) Models on Climate Change/Global Warming (CC/GW) versus Business As Usual (BAU)*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics "Giorgio Fuà", Ancona, 2020.

Let's give a first economic figure on all of them to start to get an idea: even if in specific the evaluations must be made on a case by case basis, it is certain that, generally, the amount of funds needed in the scenario *Business As Usual*, so without intervening in any way to heal and resolve the current climate crisis, it will certainly be significantly more than the scenario aimed at repairing, mitigating and adapting to the damage caused by Global Warming.

I.II – FROM THE RISING PROBLEM TO THE SOLUTION TO BE MADE: THE ENERGY TRANSITION AND GLOBAL WARMING BETWEEN TOPICS, TRENDS AND CONSTRAINTS

But where are we with the energy transition? Climate-altering emissions derive, among the various sources of the different sectors, mainly from the production and use of energy. In fact, polluting emissions are divided between energy emissions, that is, deriving from the use and consumption of energy, industrial production, transport, buildings and homes, etc., and their opposite, as non-energy emissions: land use, agriculture and waste. Energy is essentially divided into two vectors, for two distinct but common uses: heat and electricity. Through them we carry out our activities and obtain goods, services, means and therefore well-being for our lives. In 2022, at a global level, the trend of the energy transition, in its final uses among the three main modes of use, is constantly growing but still in a minority of the total. Energy, as a whole, is used for: Heating and Cooling (51%), Transport (32%) and Energy/Electricity (17%). English: Within each of these shares, the amount of renewable energy used and in function for these three uses, on the total share they consume for each individual use, are: 11.2% (Heating and Cooling), 3.7% (Transport) and 28% (Energy). With the exception of the Energy sector, where the share is well underway with constant positive growth even though it is the least energy-intensive sector (but which also indicates why we need to electrify as much as possible), for the other two more massive and heavy uses even broader and more intense efforts are needed. While for non-energy emissions they can be resolved with adequate land management and land consumption policies, adoption of more sustainable agricultural models first of all that of regenerative agriculture and with measures aimed at recycling and the circular economy, as regards energy emissions things are much more complex, structural and articulated, with transversal repercussions on each sector.

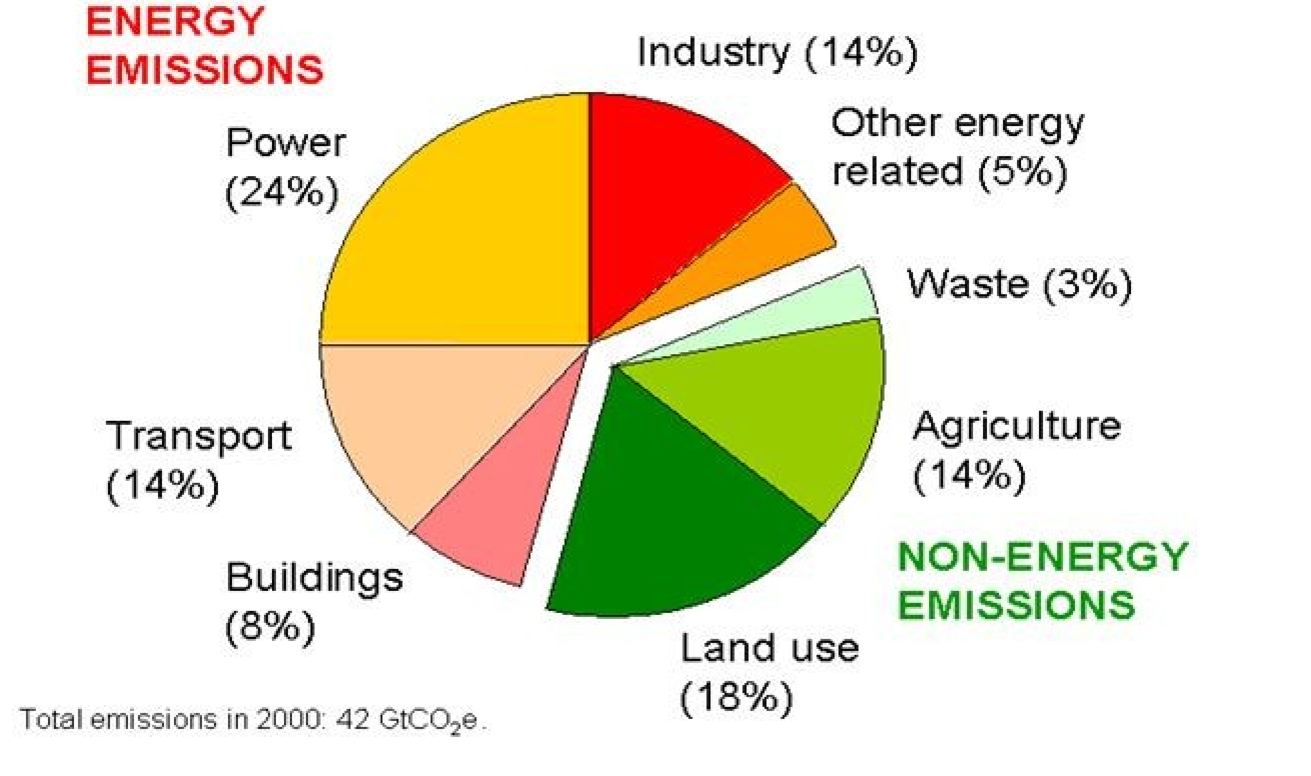


Fig. 7 – *Sources of GHG Emissions, 2000*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics "Giorgio Fuà", Ancona, 2020.

The essence of the energy problem we are facing is that, even today, despite the very important progress made, we still burn too much. While in the past we burned small quantities of natural fuel, such as wood and coal, for essential needs of mere survival and for a not particularly large number of people. Nowadays, after the industrial revolution and the massive introduction of fossil fuels into our production system and daily activities, we burn immense quantities of fuels for heating (which is the most impactful source, taking into account the shares of energy use), to move (cars and other road vehicles, ships, planes, etc.) and to produce electricity (Coal power plants first of all, but also Oil & Methane).

To give a significant figure on all this, despite being the most advanced continent in the world in the energy transition, as much as 75% of the final energy uses employed in the European Union are based on fuels. This is our problem. This is only the first approach to the topic, we will return to this crucial point, with more insights, reflections, data and more recent information.

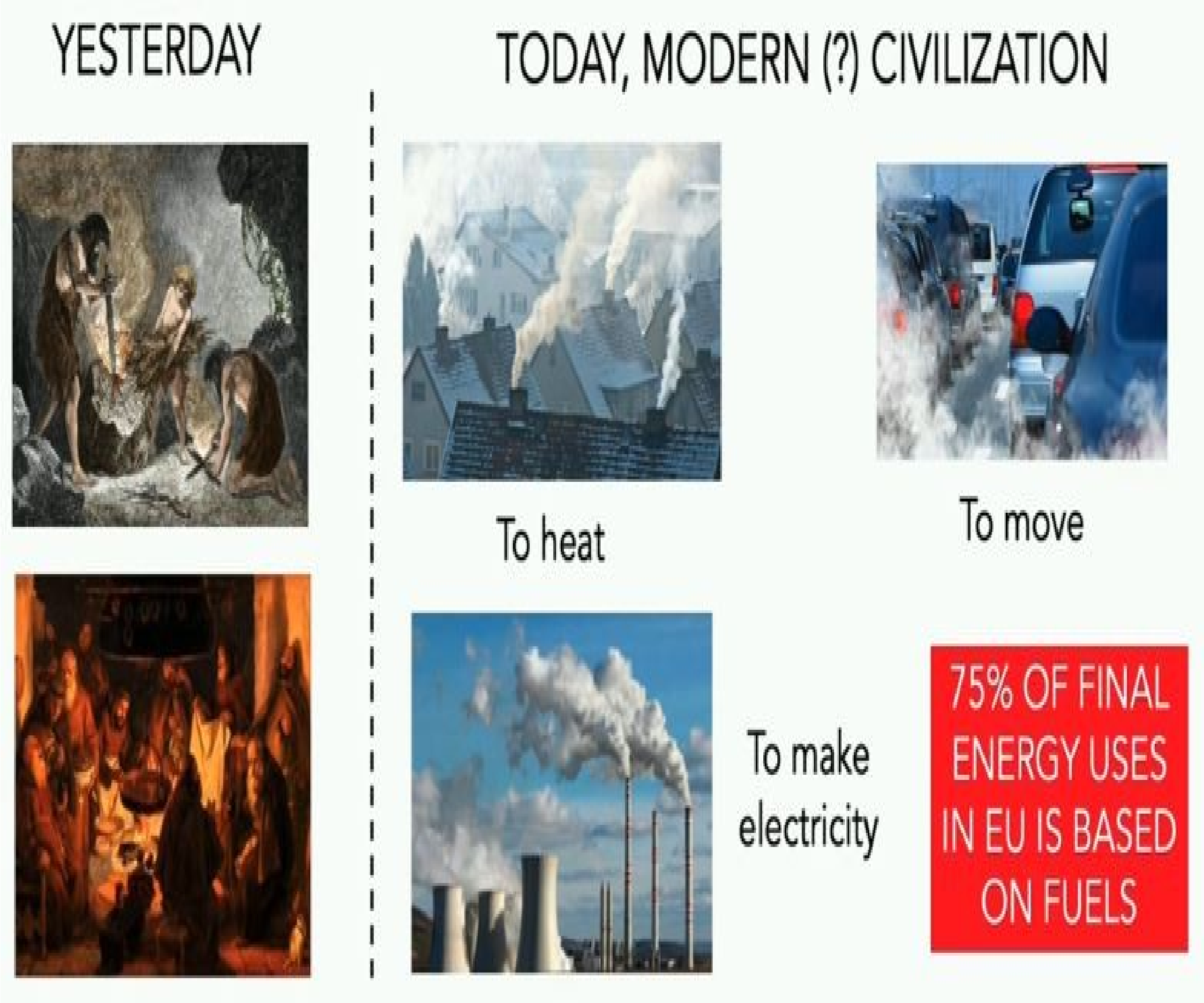


Fig. 8 – *We still burn too much*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

How to get to the bottom of it? The main way out of the catastrophe, and the solution to the greatest challenge of humanity, is to move from molecules to electrons, that is, to implement and multiply electrification as soon as possible and as much as possible and move towards a world powered predominantly by electricity. Electric cars are much more efficient than their combustion counterparts and, moreover, we already have the technologies and tools available on the market with high and profitable competitiveness and functionality, first and foremost Photovoltaic and Wind. But let's go step by step and start to deal with everything starting from the context in which we find ourselves and with which we have to deal.

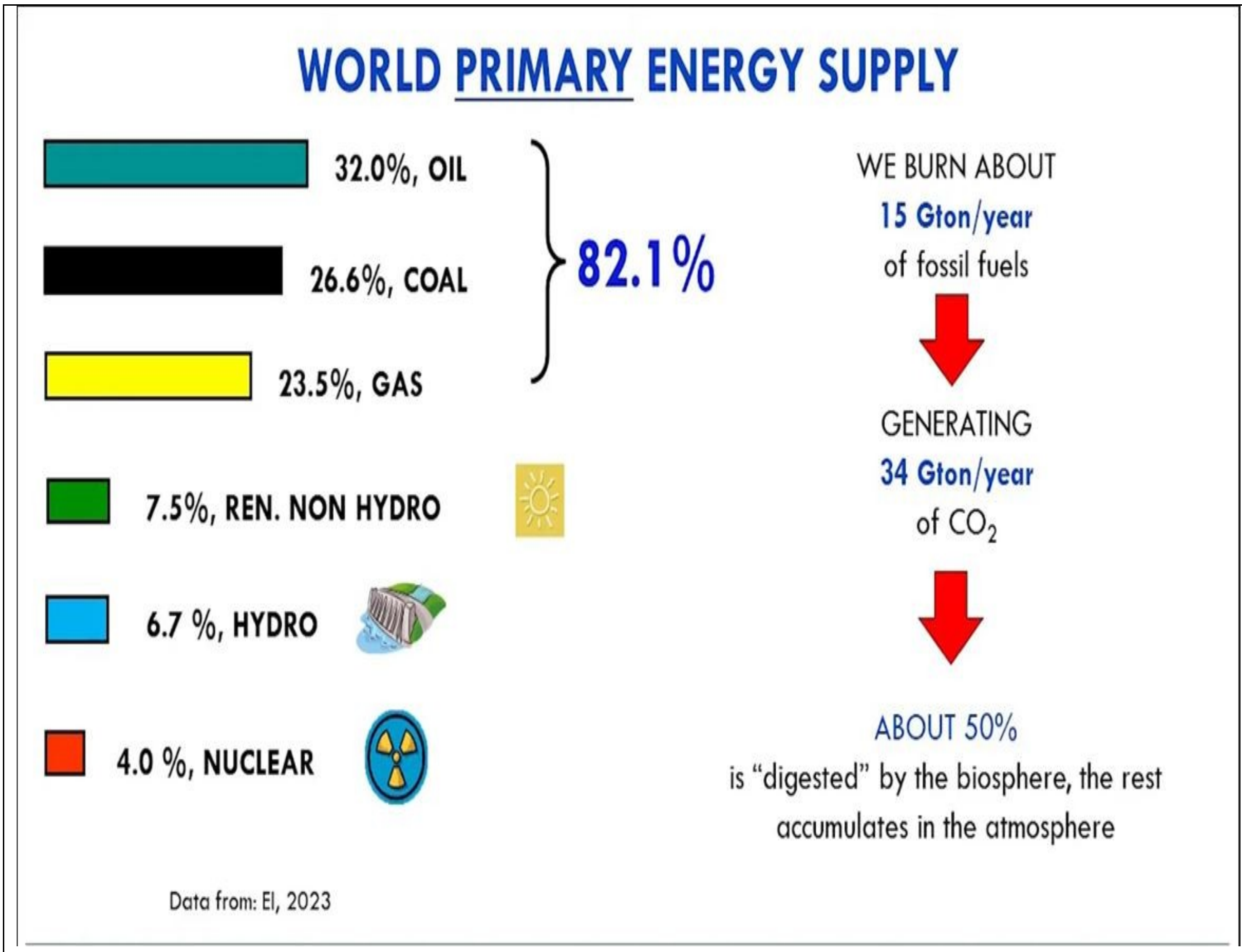


Fig. 9 – *World primary energy supply*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

From a general point of view, referring to recent data from 2023, the world production and supply of primary energy is as follows: 4% from Nuclear, 6.7% from Hydroelectric, 7.5% from other clean & renewable energy sources (always first of all Photovoltaic and Wind), 23.5% from Natural Gas, 26.6% from Coal and, first of all, 32% from Oil. Adding these last three, we have the aggregate share of energy deriving from fossil fuels, harmful and polluting, which correspond to 82.1% of the global total. Given this, 15 Gigatons of fossil fuels are burned every year. These, in turn, generate and emit 34 Gigatons of CO2 per year. A peculiarity of this very important data is that, as can be immediately noticed, the GigaTons of Carbon Dioxide emissions are just over double the GigaTons of fossil fuels that are burned. Why? This is due to the fact that CO2, Carbon Dioxide, combines with O2, or Oxygen, making it heavier and more consistent. Of these 34 Gigatons of emissions, about 50% of them end up being captured, absorbed and "digested" by the Biosphere on Earth, in particular by photosynthesis, while the other half remains to accumulate in the Atmosphere. This is due to the manifestation and growth, so extreme and pervasive, of Global Warming. The increase in average temperatures of the Planet of anthropogenic origin, or due to human activities that increase Global Warming, is equivalent to +1.1°C. The goal, resulting from international climate agreements to avoid ever-increasing damage, is not to exceed the average global temperature of < 2°C, and possibly to keep the temperature as low as possible. Regardless of this, however, the climate and environmental situation will still be much worse and more burdensome than in the past, even if we do our best to counteract this global warming. This is due to the fact that the Earth is not a linear system and therefore doubling the temperature degrees will have amplified consequences compared to their increase. For this reason, the adaptation measures, available and usable, to the various impacts of the climate are more indispensable than ever.

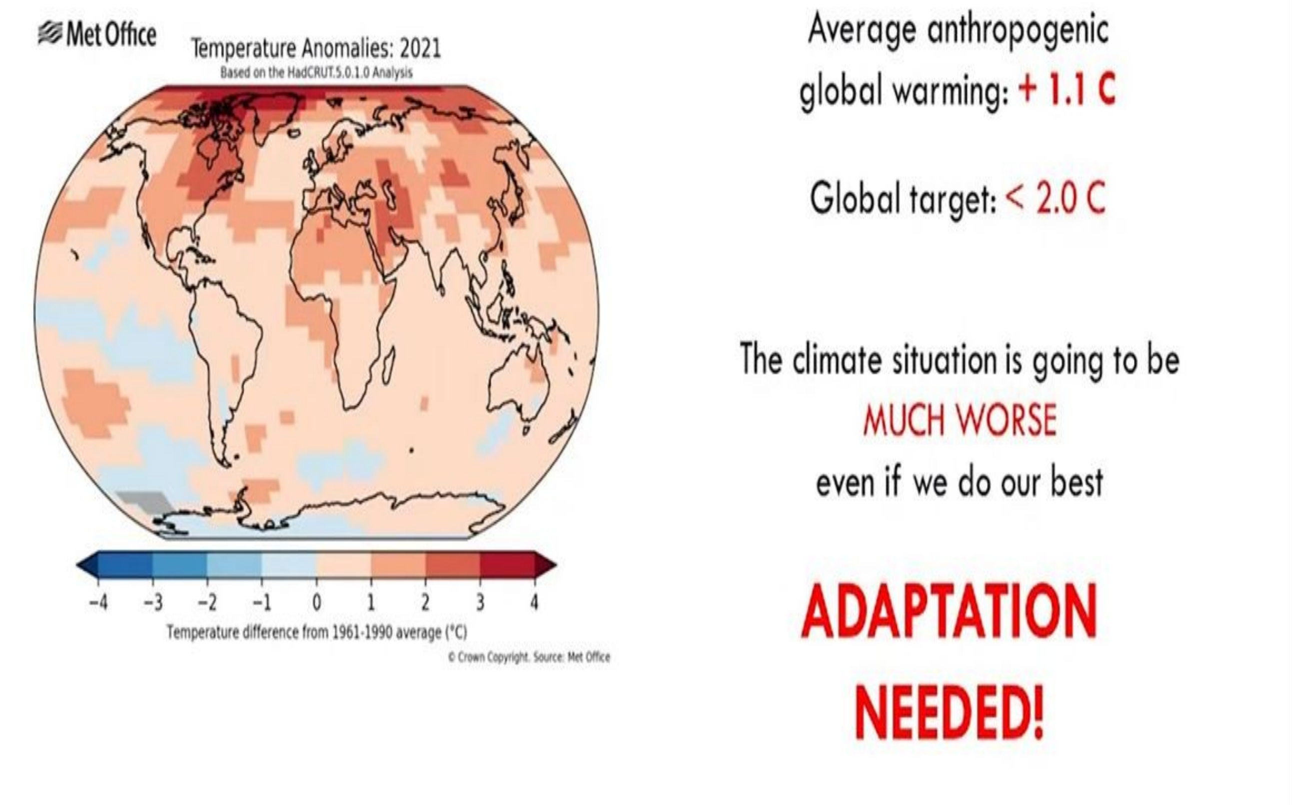


Fig. 10 – *Global Warming on the rise*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Adapting to everything, such as, for example, with the new developments made in the real estate sector. Therefore, we are faced with a complex energy transition studded with numerous constraints (chemical, physical, thermodynamic, technical, economic, political, environmental, etc.) that we must keep in mind and address while trying to maintain a general and global vision. Among all these conditions, the most prevalent of all, and the most destabilizing, is undoubtedly the one that we all inevitably have to deal with: the time factor. The time window to avoid the impending catastrophe is very limited and is decreasing day by day, while the time needed to gradually eliminate and progressively replace the old and harmful technologies in use is significantly extended. This latter extended timeframe derives from the fact that technologies that use fossil fuels are incorporated and distributed everywhere (such as, for example, in the commonly adopted concrete buildings). Even more, together with these two time dynamics, it should be added that the duration of deployment and distribution of new technologies is generally also typically long, if not very long, to be implemented. An example above all: from the invention of Si PV cells, i.e. silicone photovoltaic cells, to the creation, deployment and commissioning of 1 TW of energy produced by plants of this technology at a global level, 68 years had to pass (1954 → 2022). Times too long for emergencies and needs that are instead very imminent.

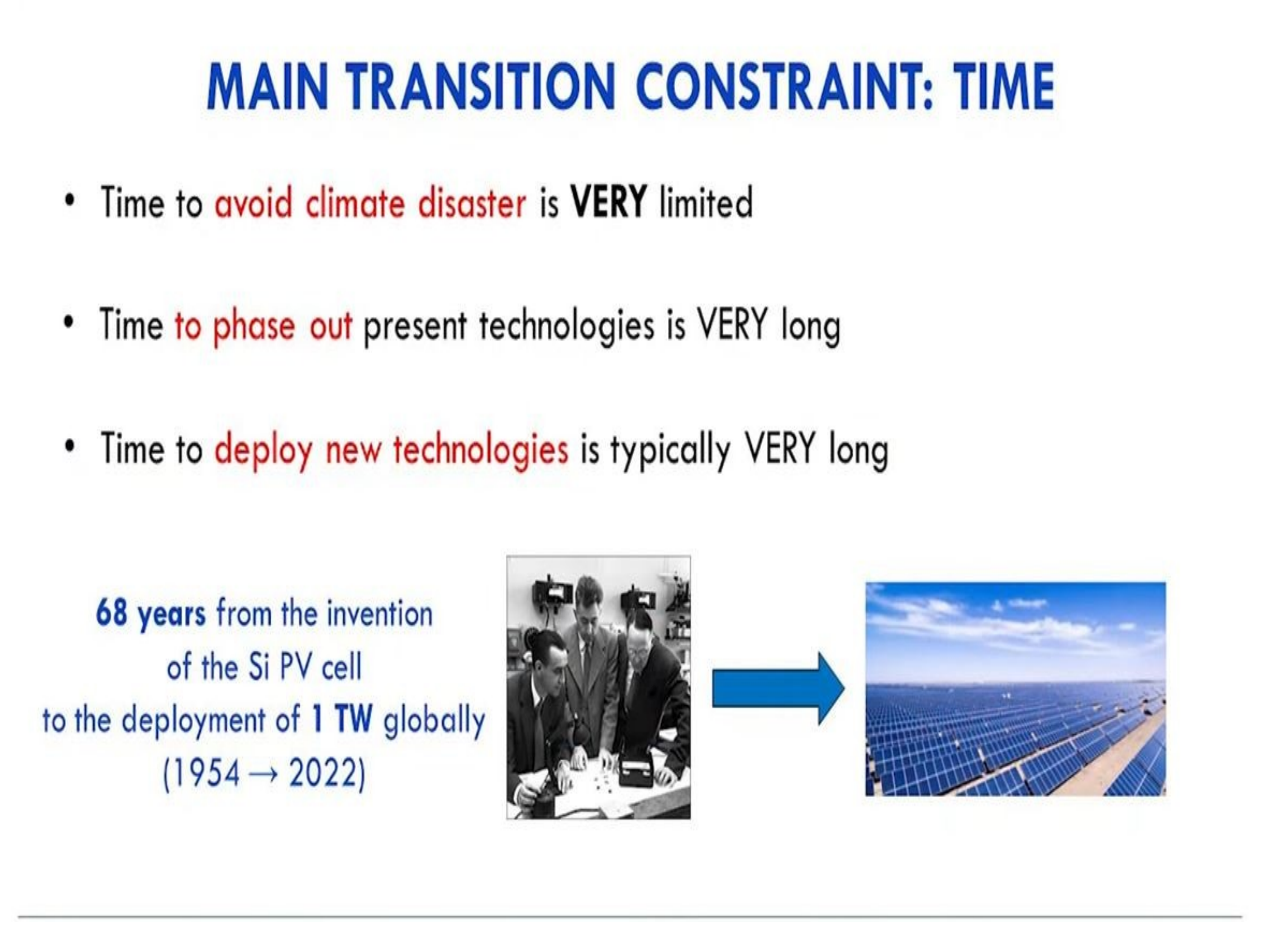


Fig. 11 – *Main transition constraint: time*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

<u>I.II.1 – The key issues of energy: the use of fuels and the energy system in use</u>

What is the key, fundamental point of the energy problem we find ourselves having to face? It ends up being enclosed in a single term: fire. As we will see better later, we still burn too much for our needs. We have evolved as a species and developed as a civilization thanks, also, to the heating and energy given to us by combustion; from the consumption of materials and fuels that have given us the heat and strength necessary to survive and live better. But, having overcome prehistory and the Middle Ages, even today, in our civilizations, which we identify as modern and advanced, we continue to burn fuels, on a massive and sometimes exaggerated scale, for a variety of daily activities: for heating, for transportation and mobility in general as well as to simply produce electricity.

All this despite, and often ignoring, that we already have the technologies and means to do all this without burning and setting fire to anything. The main way out is electrification by moving from molecules, such as gasoline and methane, to electrons.

In line with this, how should the phase-out of fossil fuels be carried out? Taking the energy system of the United States of America, which is not very different from that of Europe, as a reference context, several sensitive information and principles emerge that are absolutely impossible to ignore.

First of all: a good 67%, or 2/3 of the energy that enters and is introduced into the US energy system, is lost and wasted as dissipated and dispersed heat. Only the remaining 1/3, 33% of the energy introduced, reaches the service and is used by people and various users. Another point in question concerns fossil fuels, their use and the related sectors. Starting with Coal, it is used substantially as a source for the production of electrical energy. Therefore, to aim to exit Coal, it is necessary to replace the share of electrical energy generated by it and therefore replace it with the production of electricity from clean and renewable energy. For Methane Gas, however, its exit is much more complicated and convoluted as its use is broader and more articulated. It is used both for the production of electrical energy, like Coal, but also for heating homes, infrastructures and residential, industrial, commercial buildings etc. For this reason, in order to also exit from the use of Methane Gas, it is necessary to both replace its share of electricity with the production of electricity from clean and renewable energy, but also to electrify and make sustainable the heating systems in homes and in working and production complexes in operation. Last, but not least, although simpler than the others, concerns Oil. Black gold is used for 20% for the industrial sector, but even in this case we can proceed with electrification or other sustainable alternatives, while 80% of Oil is used for transport and mobility, but of this 80% is always lost, as combustion engines are quite inefficient and do not use much of the combustible energy that is supplied to them, ending up rejecting it and wasting it. Only 20% of the energy input, in essence, activates and moves the engines and wheels of vehicles and therefore, to stop the use of oil for our jobs and activities, the electrification of vehicles and transport as a whole is necessary.

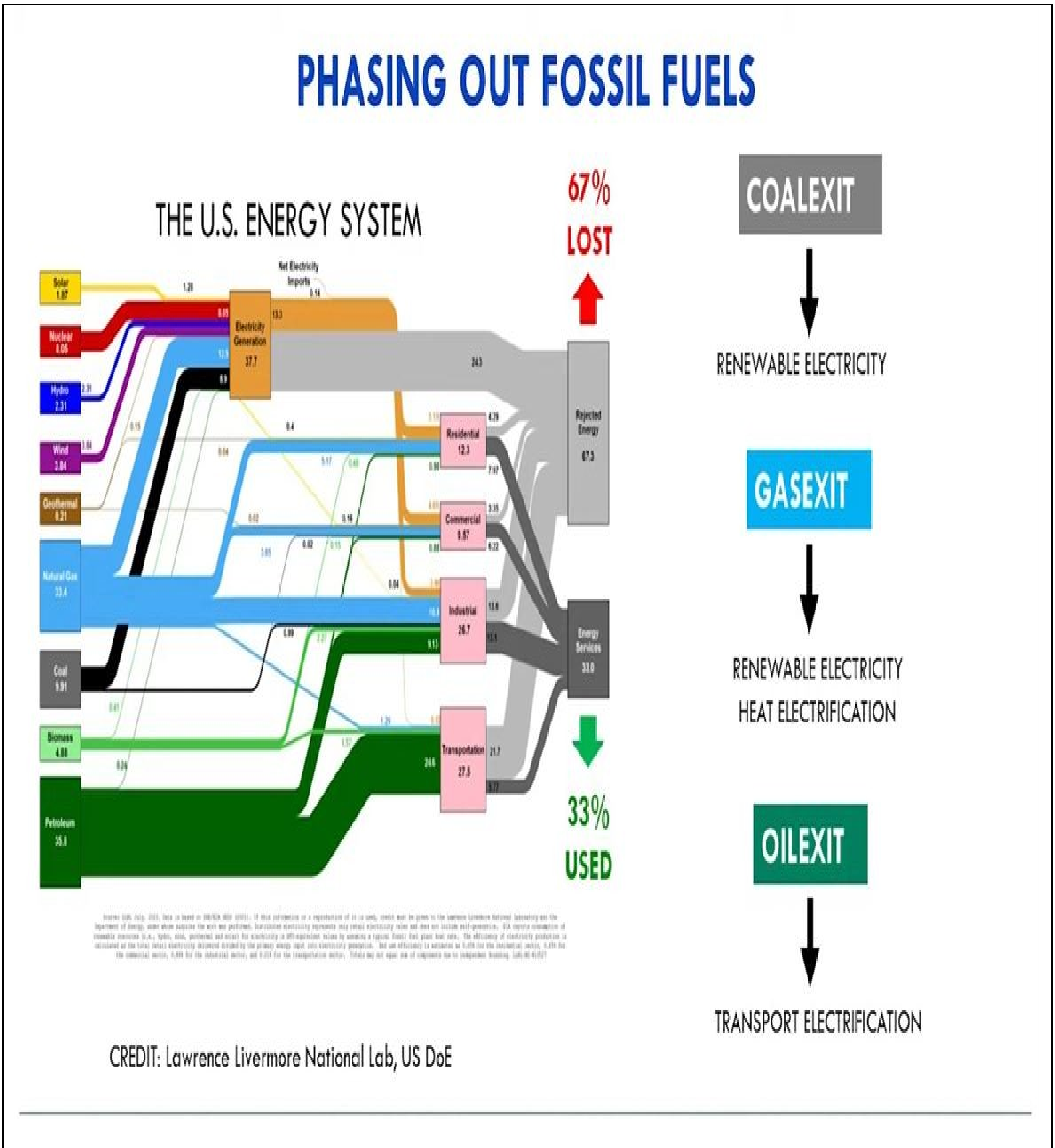


Fig. 12 – *Phasing out fossil fuels*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

To continue further, let's now clarify an important etymological element on the issues that are being addressed: why is the term "energy transition" used? What exactly does it mean? In addition to the debate, previously mentioned, on the use of predetermined terminologies or others that are considered more correct for the most disparate reasons, it is used to indicate it as a transition precisely for the passage, in the energy sector, from the old fossil energy sources, polluting and harmful, to alternative clean and renewable energy sources. The latter allow us to carry out, with the necessary precautions and changes, the same human activities to create and use goods and services and to live our lives, in our societies and civilizations, in a non (or less) harmful and often more efficient and useful way than conventional methods, which have been used for too long. In a word: sustainability. Of course, this is a general explanation that must be adapted and contextualized in turn and, above all, must be put into operation and in support of the true "transition" that is needed as the ultimate goal, which is the ecological one, in order to overcome and resolve, in the best possible way, the damage and disruptive changes that global warming is bringing to our lives and to the lives of those who will come in the future. Therefore, the energy transition is fundamentally based on the production of renewable electricity or, to be more accurate, the production of electricity from repeatable sources that are not harmful to the environment and the health of all living beings, both animals and plants. As we will discuss later, renewable sources are different, have different origins, characteristics and technologies and, mainly, are distinguished according to the following typologies: Biomass, Geothermal, Wind, Hydroelectric and, primarily, Photovoltaic.

In order to achieve the necessary electrification, it is also structurally necessary to develop the so-called "enabler" or "activator" of this process, namely the Network. In fact, the Electricity Network allows users, both producers and consumers, to be physically connected and linked. This functionality allows for real unprecedented opportunities thanks to the ongoing digitalization process, as it allows all users to be interconnected together and to control and consolidate energy supply and demand. Unfortunately, however, this is currently not feasible with the current energy system, in fact we do not have, in our homes, appliances that are connected and harmonized in their use with others in other homes, not to mention today's combustion cars, so until we address this Watershed aspect, we will not be able to have all of this available as part of a much larger, more expert, intelligent and extensive system than it is now, through innovations and improvements that were previously unthinkable. In any case, the Electricity Grid, to function correctly and to its maximum potential, needs to be balanced, stable and with cyclical and constant updates, requiring adequate and superior use and organization.

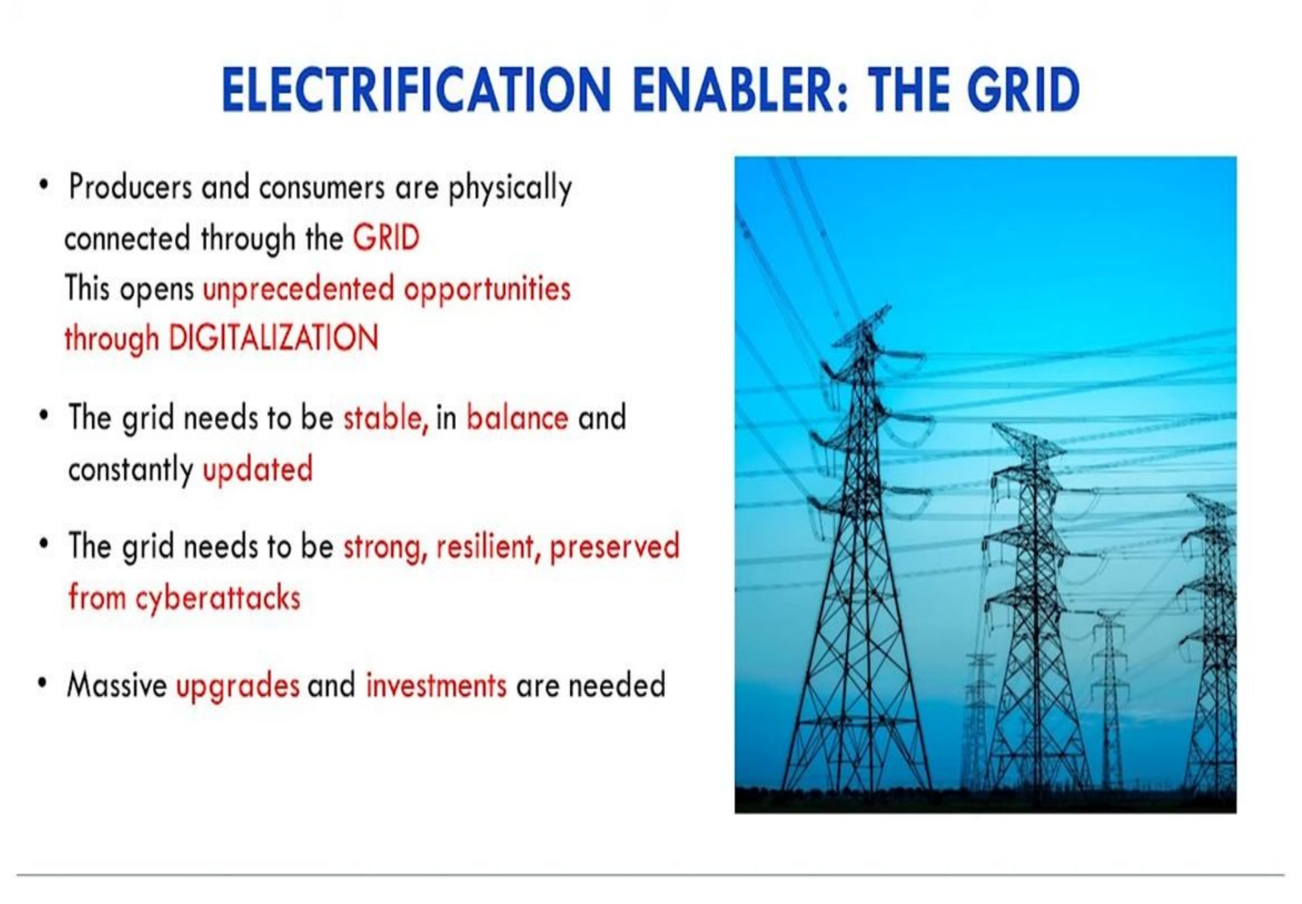


Fig. 13 – *Electrification enabler: the Grid*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

In addition, it must be solid, structured, resilient and capable of dealing with threats such as *cyberattacks* which is an ever-growing problem and from which it is now imperative to know how to defend ourselves also for other sectors of crucial importance. Given this goal, careful and appreciable updates and investments will be increasingly necessary, something that, at the moment, is being carried out with slow but constant progress that will however need to be followed up more and more.

I.II.2 – But what about funding? The little-known topic of energy funding as a whole

In the face of all this, the same and repeated objection repeatedly comes up in the public debate: the energy transition is too expensive. It would make no sense to talk about it, given that we cannot do it because we cannot afford it, given its excessively expensive expenses to fix and make everything that would be needed work. The energy transition would be economically unsustainable, an unachievable utopia, an unattainable chimera and also harmful and counterproductive to human and social well-being, a naive and sad illusion compared to the "true reality" in which people actually live. Nothing could be further from the truth. The International Monetary Fund (IMF) has calculated that globally, in the entire year 2022, fossil fuels received subsidies, direct and indirect, amounting to 7 trillion dollars (that is, 7 billions of billions $) which in turn is equivalent to a good 7.1% of global GDP.

Fig. 14 – *Too expensive?*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Huge figures, unimaginable to most, yet they are calculated and verified data. In reality, there is no lack of money for these measures and investments, rather, there is a lack of Policies worthy of the name to implement them and bring them to completion. So the question is where we want to finance, invest and economically support development and energy supply. It is essentially a theme based on purely Political decisions and choices more than any other aspect, as it is Politics that has the role of choosing where to put the funds for the activities that are needed or that we want to carry out and realize. Once again, it depends on us and on the choices we want and make, both directly, with our personal and daily choices, and indirectly, with the vote and with the decisions we make others take. This is the "true reality", a term that is so often used to leave things as they are, throwing and leaving those directly involved in despair and resignation and allowing those who benefit from it to continue to profit from it to the detriment of the community, nature and ecosystems of our Planet Earth. One *Status Quo* more and more indefensible.

But not all molecules must be discarded. In fact, there are decarbonized molecules that are potentially of great importance to be able to complete the energy transition and, therefore, to be able to reach Global Carbon Neutrality (or Global Decarbonization). Among these, the main one, by far, is Hydrogen (H2).

CHAPTER II

THE DECARBONIZED MOLECULE PAR EXCELLENCE BETWEEN SCIENCE, TECHNOLOGY AND HISTORY: HYDROGEN

“Ecological conversion can only take hold if it appears socially desirable.”

Alexander Langer

II.I – PRESENCE, CHARACTERISTICS AND GENERATION OF THE H2 MOLECULE

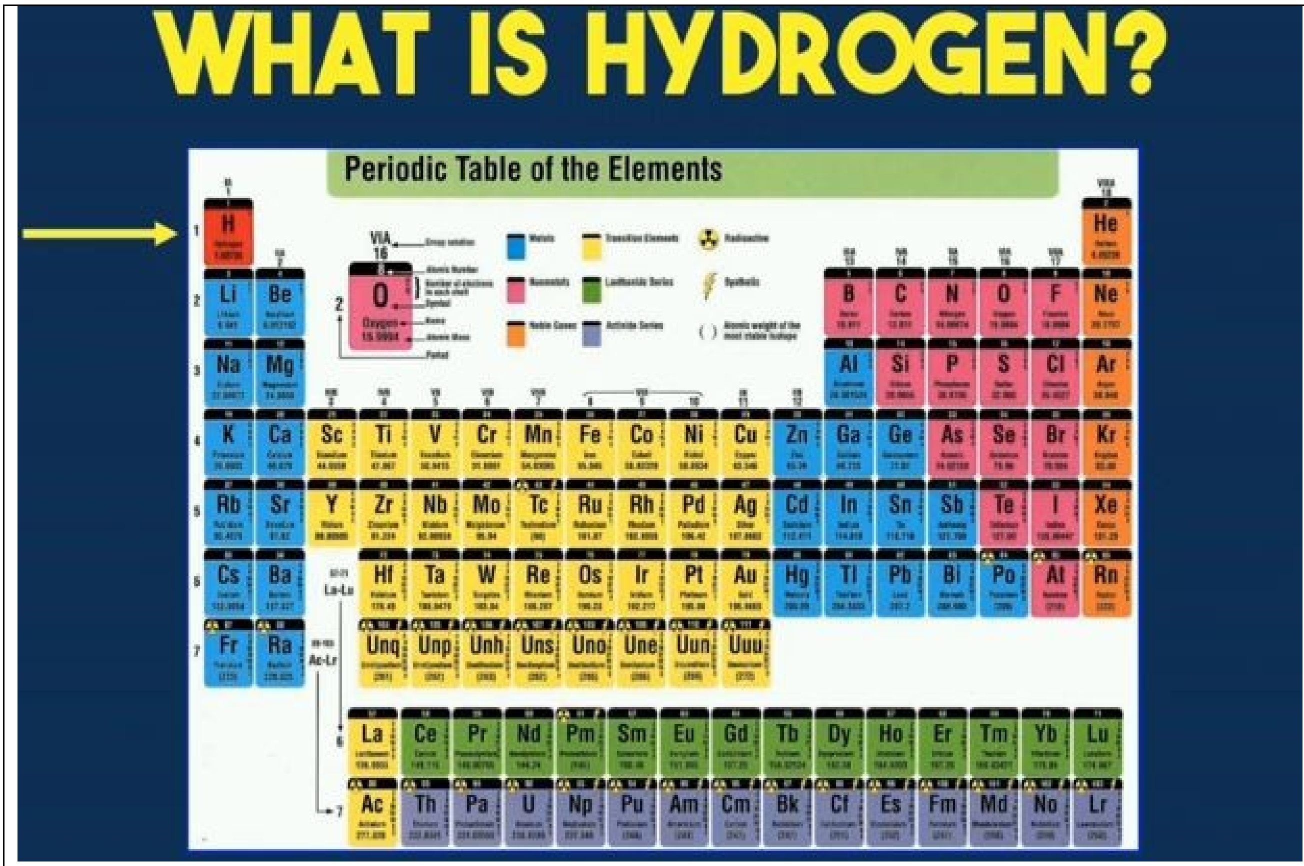


Fig. 15 - *Hydrogen in the Periodic Table of Elements*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

But what exactly is Hydrogen? This molecule, represented in the common *Periodic Table of the Elements* like H2, it is the lightest molecule in the aforementioned list. Consequently, it is the lightest element in existence, but not only that! In addition to being the lightest, it is also the most abundant element in the entire Universe. In proportion, comparing it with other molecules, in the Universe Hydrogen is present at 73.9% (almost ¾ of the total), followed by Helium with 24% and Oxygen with a meager 1% (!), while other molecules, such as Carbon, Iron and Nitrogen, are at a lower quota than the latter. Therefore, the pervasive presence and role of Hydrogen, from a general/universal point of view, is of fundamental importance for how the entire reality is structured and how we know it today. Looking at our Solar System and comparing Earth with Jupiter, in the latter Planet the atmosphere is almost entirely made of molecular Hydrogen, while our Planet is primarily composed of Oxygen, fortunately for us, because without it there would be no life. In the Planet that is our home, molecular Hydrogen, which is richly present in Jupiter, is instead substantially absent and, consequently, in order to have and use it, it must first be produced.

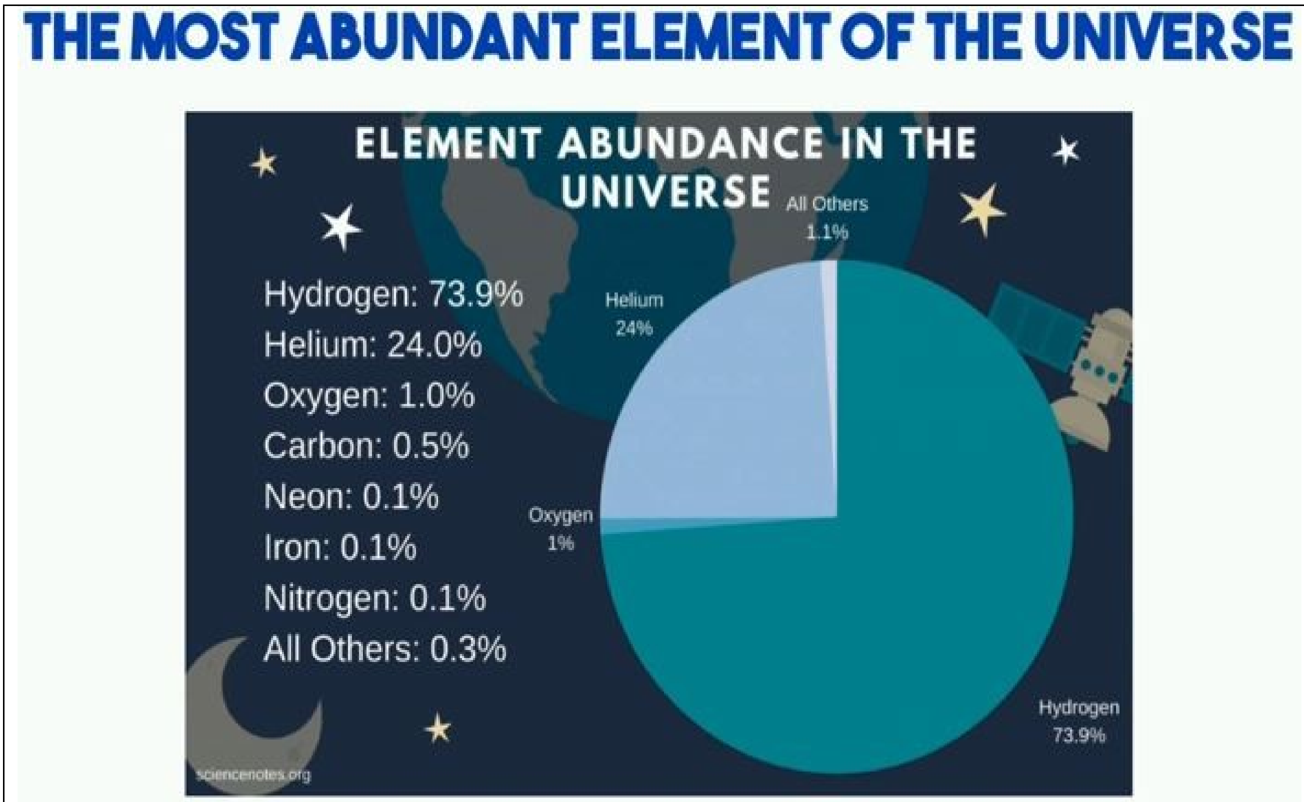


Fig. 16 - *The most abundant element of the Universe*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Keeping this in mind, one must look at Hydrogen not only for the aforementioned *Periodic Table of the Elements* - which must rightly be taken into consideration when dealing with chemistry, molecules and mineral elements that it illustrates and recomposes - but in our case, it must be accompanied by the numerical version present on Earth: *The Quantitative Periodic Table*.

The latter, proposed by the European Chemical Society, represents how our Planet is made and with what quantities of elements are present and available, also making an estimate of its future availability with respect to the more or less intensive uses that we currently make of it.

The Quantitative Periodic Table It is essentially the material "Identity Card" of the Earth and indicates that Hydrogen is available in abundance, without problems or risks of scarcity in both the near and distant future with respect to today's uses and consumption.

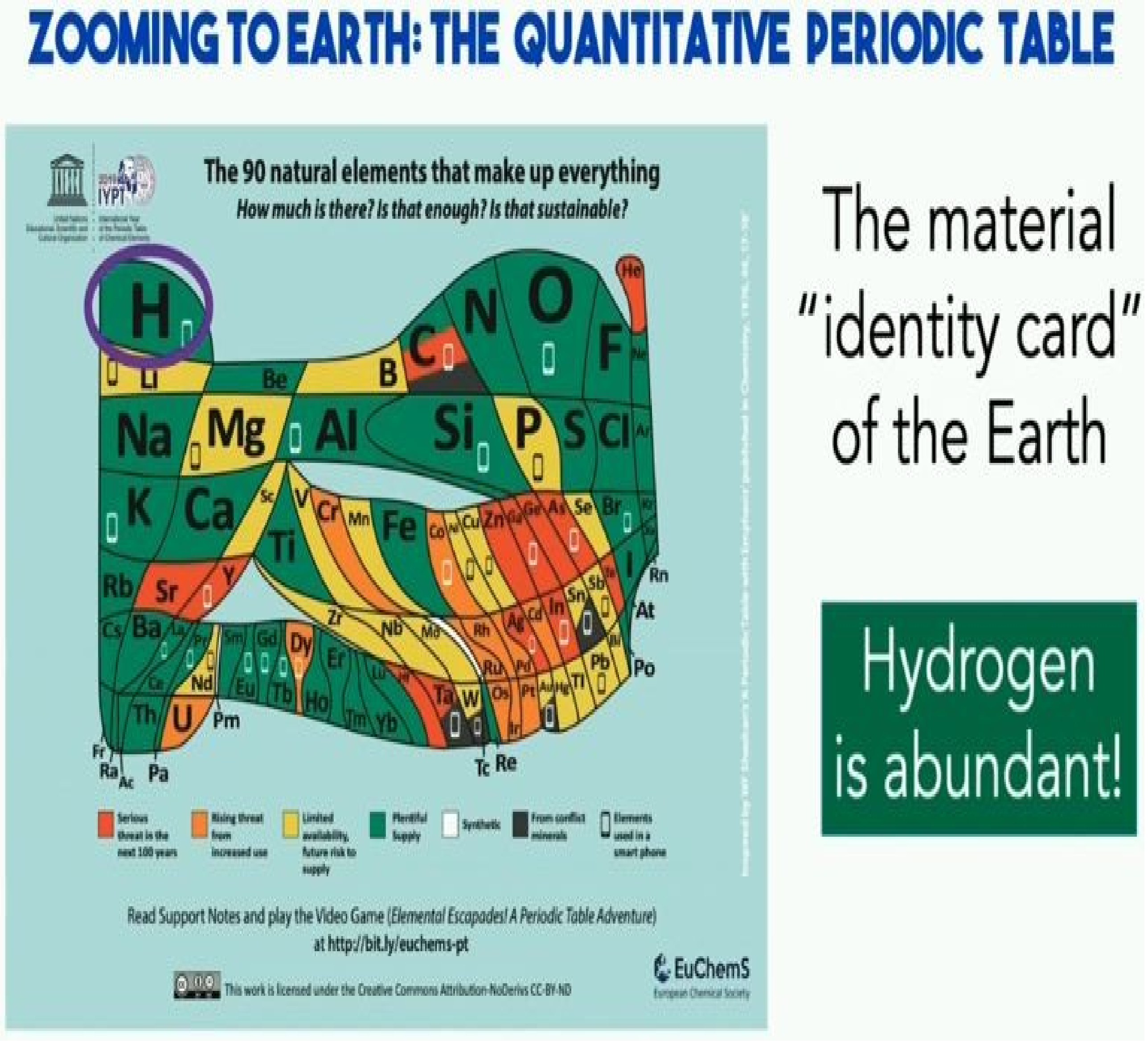


Fig. 17 – *Zooming out to Earth, The Quantitative Periodic Table*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

So what is the problem? The problem is that Hydrogen is abundant but it is also combined and amalgamated with other terrestrial molecules and materials. These are Water (H2O), Methane (CH4) and Glucose (C6H12O6). Our Planet is essentially full of Water, which can be found and had with relative ease and availability. Methane is a fossil fuel whose quantities must be extracted and come from the subsoil. Finally there is Glucose, where the Hydrogen present in it can be found in millions of different organic molecules, including organic, biological and synthetic forms.

Recapitulating and getting to the point, what is useful and necessary and what we need from here for our future is molecular Hydrogen which, as we said, is virtually non-existent on Earth and which to have it must be extracted and obtained from other molecules combined with it.

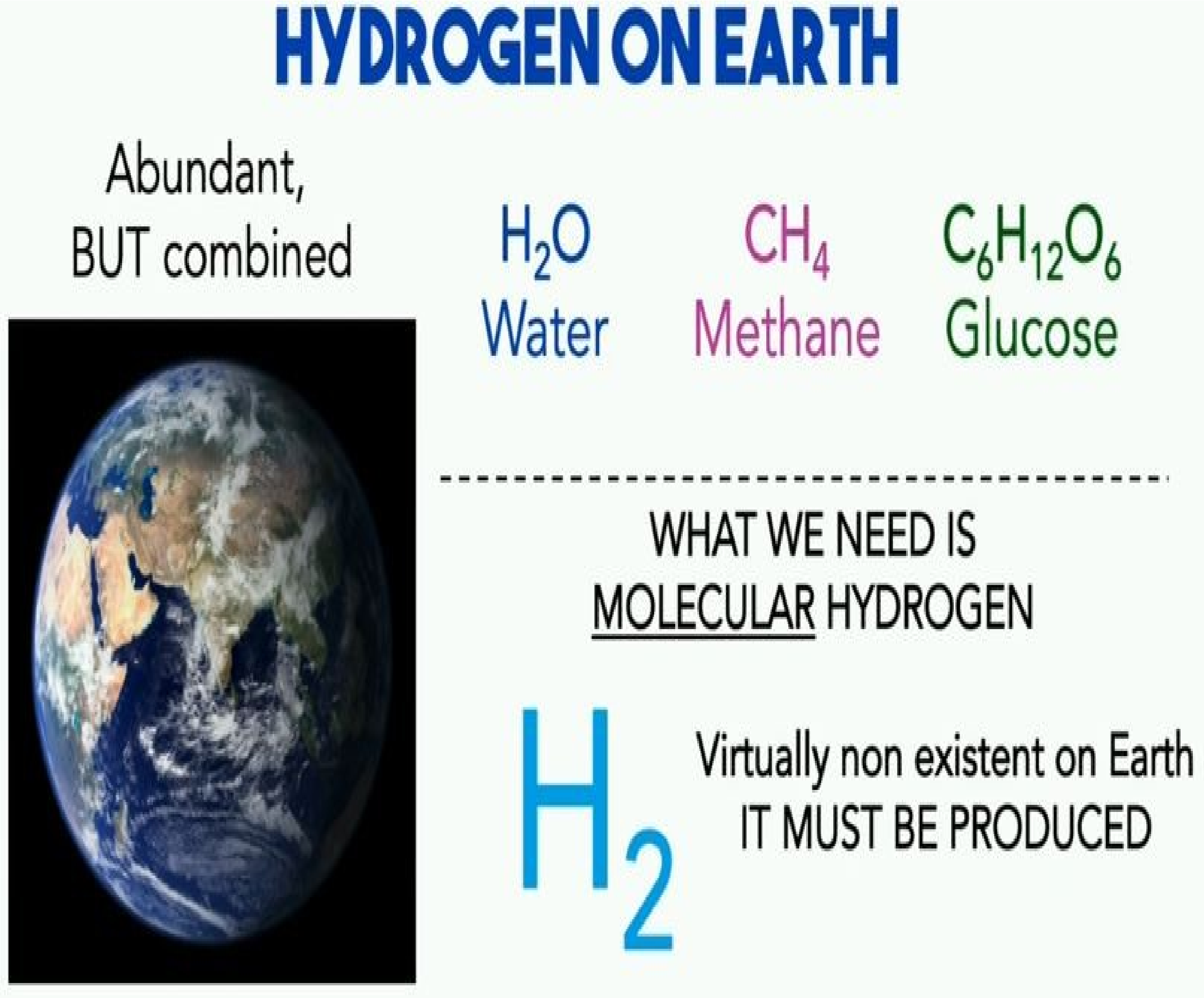


Fig. 18 – *Hydrogen on Earth*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

The characteristic that makes the difference compared to other types of energy is that: while on Jupiter Hydrogen is an energy source in all respects simply because it is already present and available for use in a raw and pure state, on Earth, in such a direct sense as an energy source, it is not at all but can be defined and pointed out as an energy vector. To have it available and use it as an energy source, it must be created.

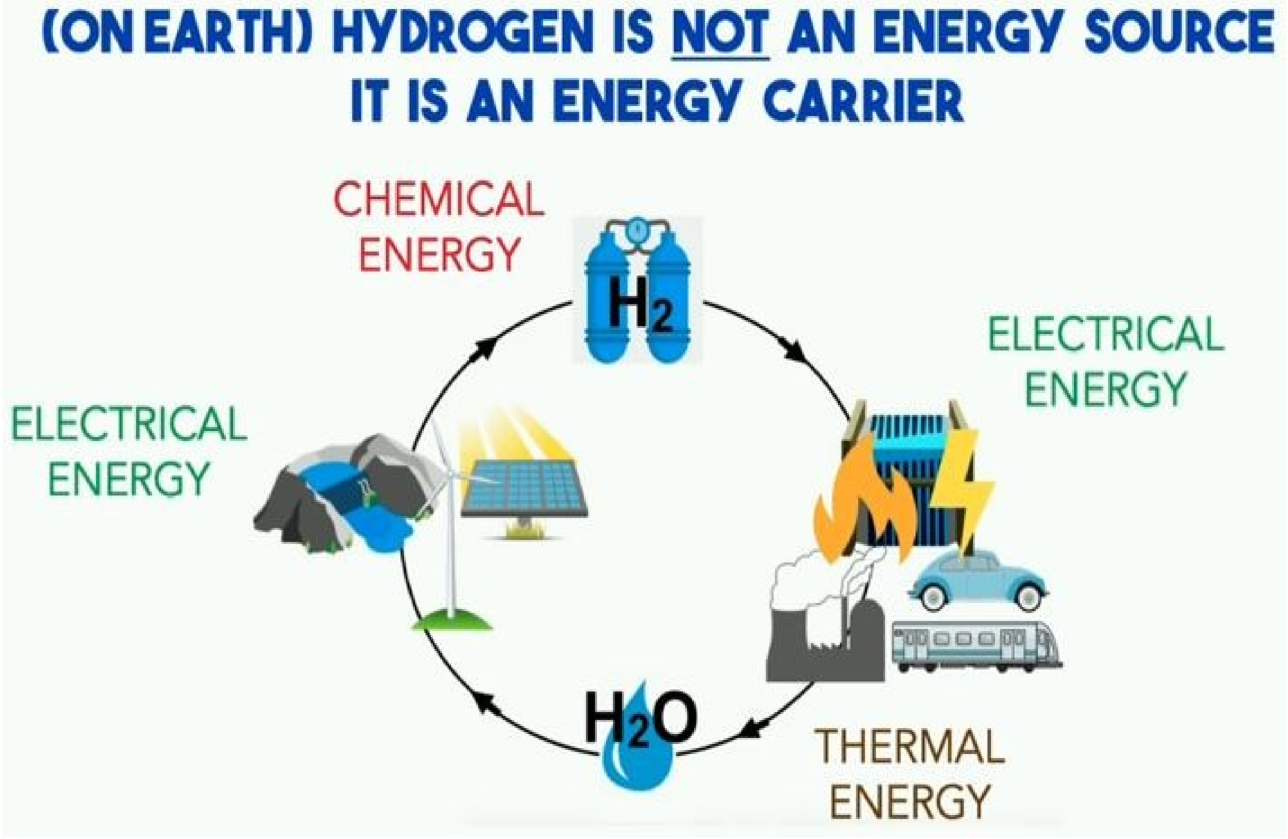


Fig. 19 – *On Earth, Hydrogen is not an energy source, it is an energy carrier*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Based on the data described above, the most rational way to produce Hydrogen is to start from Water, that is, starting from obtaining the necessary energy from renewable sources (Photovoltaic, Hydroelectric and Wind first and foremost) and, in fact, after having converted the electrical energy used into chemical energy and once obtained and sent where it is needed, it ends up being treated as fuel by burning the chemical energy and providing thermal energy in its place (remembering that this combustion occurs without producing GHG as combustion only emits Water) or it goes to be reconverted again, from Hydrogen (or chemical energy) as it has become into, again, electrical energy (via the so-called Fuel Cells) to then be able to be used for the uses and jobs we need: that is, the three sectors seen previously: Heating and Cooling, Transport and Energy/Electricity. Whether burned to obtain thermal energy or converted again to obtain electrical energy again, Hydrogen returns, in the form of emissions for its combustion, Water, that is, the same material with which it was originally given to the conversion and use processes of the three energies illustrated: electrical, chemical & thermal. Having Water back, the starting material of this entire process, therefore allows us to enable and create a potentially infinitely reusable Circular Economy circuit. A certainly positive fact that must be taken into account and remembered. Are there any problems in all this? Inevitably, unfortunately yes. Looking at the physical properties of this special molecule, Hydrogen is first of all a Gas, has, in ordinary conditions with a standard pressure (like the one we usually are in), a temperature of 20°C, has a molecular weight of 2.02 (the smallest and lightest in existence), is colourless and odourless, has a boiling point of -253°C, a melting point of -259°C (which, the latter, is even close to -260°C which corresponds to the absolute zero point), is chemically reactive (making its management and handling anything but easy and convenient) and is, in particular, a Gas that is even more easily flammable than Methane (and, potentially, even more explosive than Methane) and, together with these other factors of danger in its handling, with a flame particularly close to invisibility under sunlight.

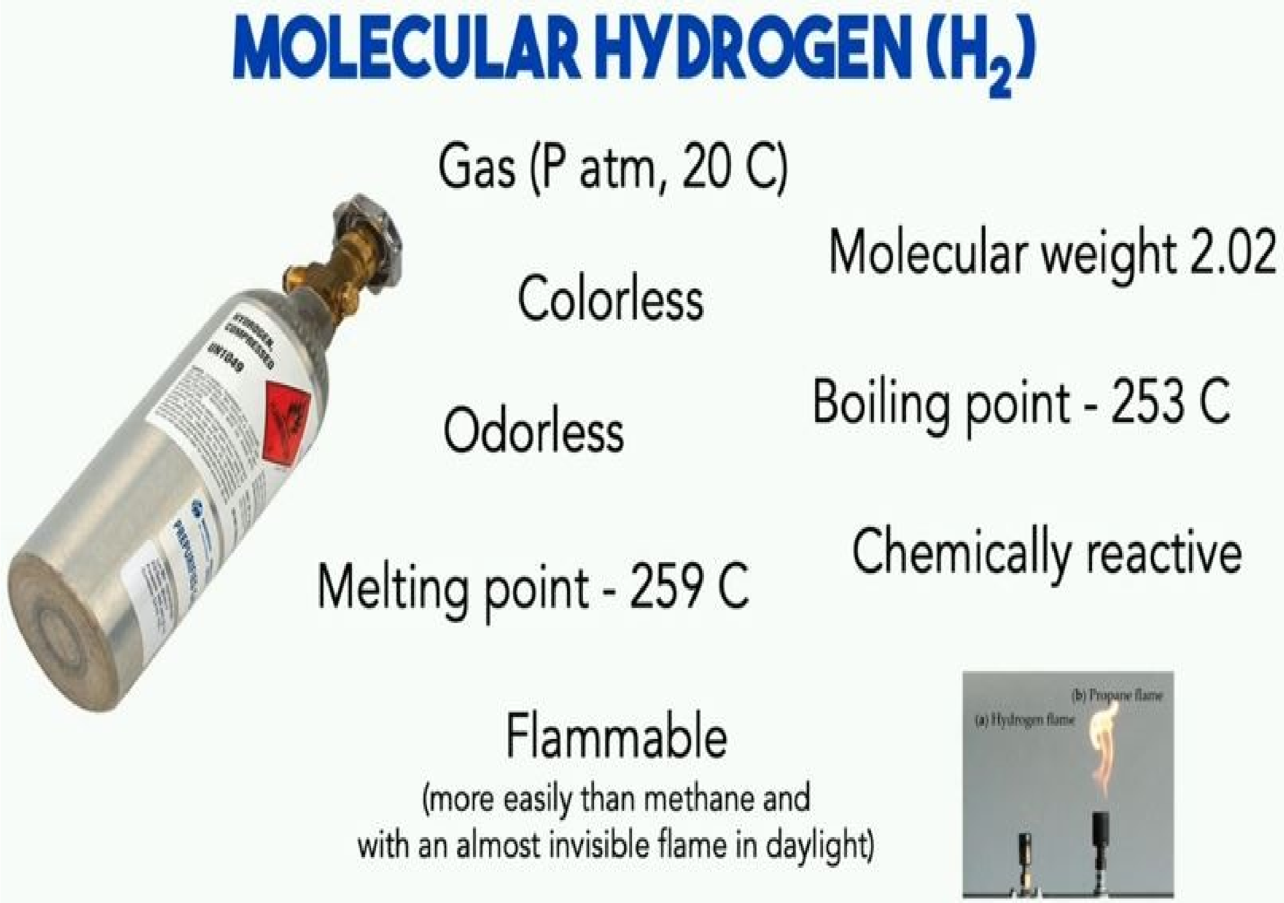
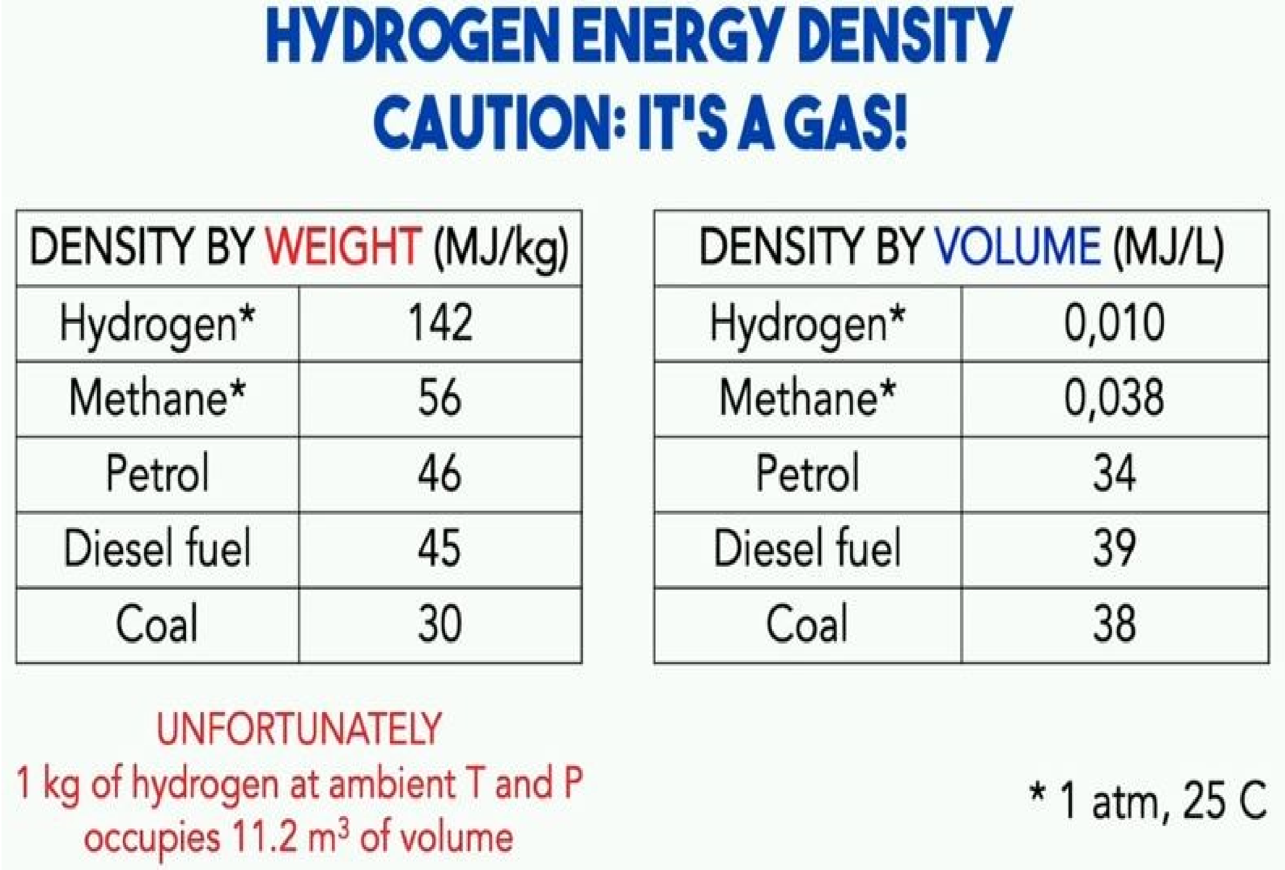


Fig. 20 – *Molecular Hydrogen H2*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Regarding its characteristics, it has been said that Hydrogen has a very high energy density and this is true, but only in very distinct conditions and, for this reason, not always in the same way. Therefore, examining its energy density specifically - but attention: never forget that it is a Gas! - from the point of view of weight it is truly energetic dense: it has a density, with 1 atm and 25°C, of 142 MJ/KG compared to the 56 MJ/KG of Methane and the 46 MJ/KG - therefore three times greater - of Gasoline/Petroleum. Unfortunately, however, given that it is a Gas, this occurs in a truly large area, in standard conditions: 1 KG, a single kilo of Hydrogen, occupies something like 11.2 m3 of volume. On the other hand, and since it is a Gas, if it is calculated not as weight but as volume, its energy density is radically opposite: always in the condition of 1 atm and 25°C, while Methane reaches 0.038 MJ/L, its density is 0.010 MJ/L, that is, four times less; not to mention Gasoline/Petroleum which stands at 34 MJ/L with a difference in orders of magnitude smaller in comparison.


HYDROGEN ENERGY DENSITY
CAUTION: IT'S A GAS!

DENSITY BY WEIGHT (MJ/kg)	
Hydrogen*	142
Methane*	56
Petrol	46
Diesel fuel	45
Coal	30

DENSITY BY VOLUME (MJ/L)	
Hydrogen*	0,010
Methane*	0,038
Petrol	34
Diesel fuel	39
Coal	38

UNFORTUNATELY
1 kg of hydrogen at ambient T and P
occupies 11.2 m^3 of volume

* 1 atm, 25 C

Fig. 21 – *Hydrogen energy density – Caution: it's a gas!*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

With these data, one might wonder whether it makes sense to use it for any practice other than the energy transition. And instead, yes! Because Hydrogen is anything but a novelty or an unused and perhaps experimental molecule. None of the above. Hydrogen is already present in human activities, in rooted and conventional forms, in roles and sectors of exceptional and considerable importance and value. The difference is that, currently, it is primarily intended not so much for the energy sector and industries but for those of the chemical sector. In fact, it is used to produce fertilizers and, in a rather intensive manner, to refine Oil (hydrocracking, hydroisomerization, dearomatization).

Fig. 22 – *Hydrogen today*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Let's look at some data and numbers about it. The global production of Hydrogen, carried out in dedicated plants, is 70 Megatons per year. What makes the molecule quite bizarre and extravagant is that, despite being produced in massive volumes and quantities, it basically has no market where it can be marketed and traded. Therefore, an energy vector that can be used in different ways is produced in significantly high quantities, but it is not sold. Why? Because most of the time it is produced by companies for use *on site*, direct and immediate, to fertilize, to do hydrocracking etc. and not for anything else. But not only that: transporting Hydrogen is quite expensive and, let us remember, can be very dangerous if badly managed. Taking into account the type of industries that produce it, and then consume it, its generation is fundamentally, and unfortunately, done via CH4, i.e. Methane.

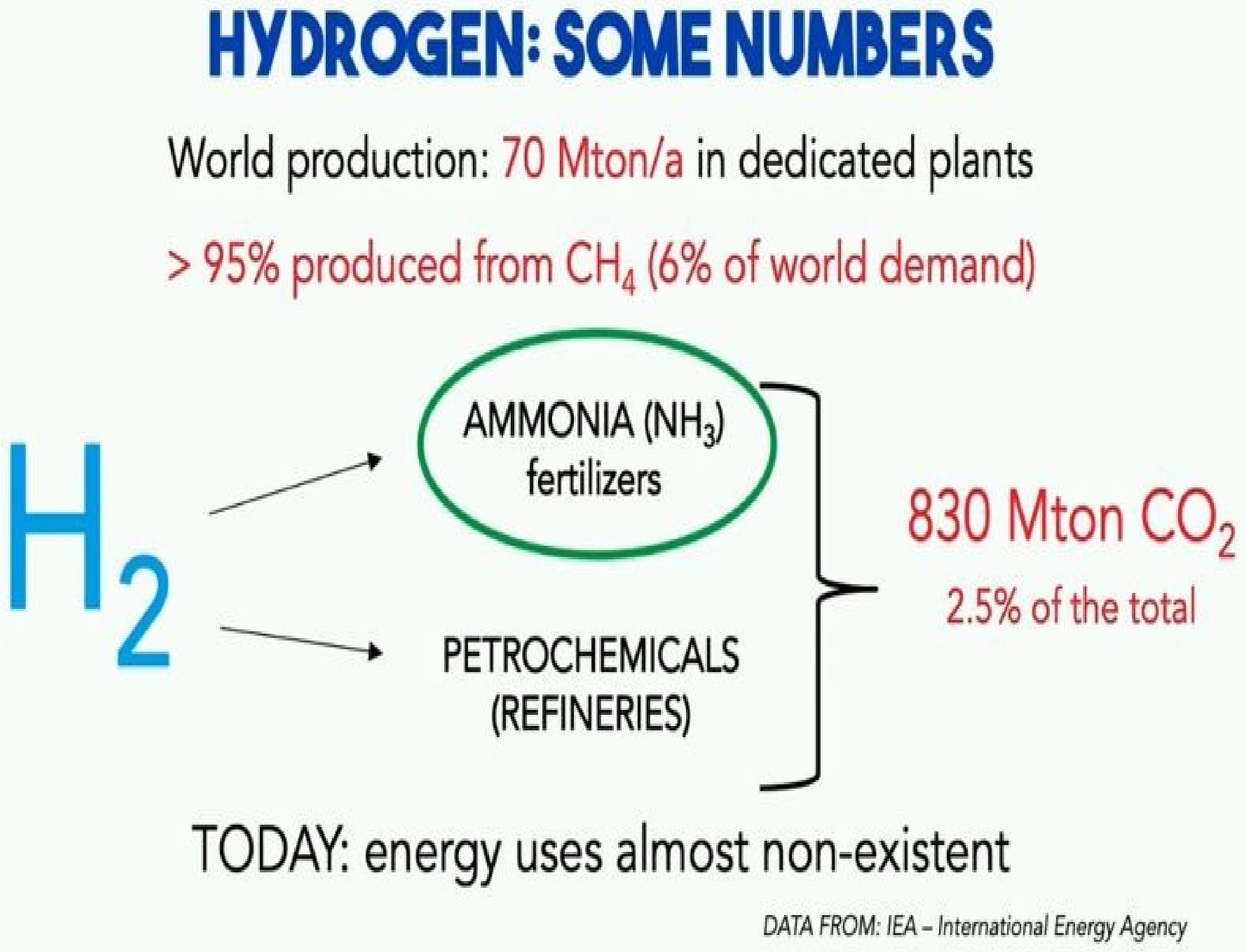


Fig. 23 – *Hydrogen, some numbers*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

In fact, over 95% of global Hydrogen is made from this molecule derived from polluting fossil fuels, corresponding in turn to 6% of global demand for Gas. By virtue of this, a particularly remarkable fact must be taken into account: Methane, which like other fossil fuels will inevitably have to be replaced. Today it is used, as is known, both to heat our homes and to give energy and power to our activities and our productions but, equally, something often little known, to make and produce goods and objects such as plastics, fertilizers and so on. For this reason, if large companies such as European ones, chemical and not only, are blocked due to current problems, such as wars, there will be a domino effect on the entire industrial and production system. This is a fact that is too often not present at all in the public debate: in our time, for these data and for the usefulness that Hydrogen currently has and given its derivation from Methane, this Natural Gas is essential for the chemical industry and not only at the moment. To give a relevant figure above all: 15% of the Natural Gas imported by Germany goes to its historic and thriving chemical industry. These data must be kept in mind for the future of changes that await us. Returning to the industrial use of Hydrogen, it is used substantially for Ammonia, NH3, always for the fertilizer district, and for petrochemicals/refineries. The use for energy is practically inconsistent. With all this, the production of Hydrogen of this type derived from fossil fuels is responsible for the emission of 830 Megatons of CO2, which correspond to 2.5% of global climate-altering emissions, thus leading it to have a powerful impact on our Planet and on everyone.

II.I.1 – The extraordinary connection of Hydrogen with the History of humanity: the discovery of Ammonia

However, a brief addition must be made regarding Ammonia. NH3, Ammonia in fact, and in particular its method of creation known as *Haber-Bosch process*, have both been recognized as the revelation that profoundly changed the world. This was achieved by two very illustrious and renowned, yet ambiguous and controversial German chemical scientists, namely Fritz Haber (1868-1934) & Carl Bosch (1874-1940).

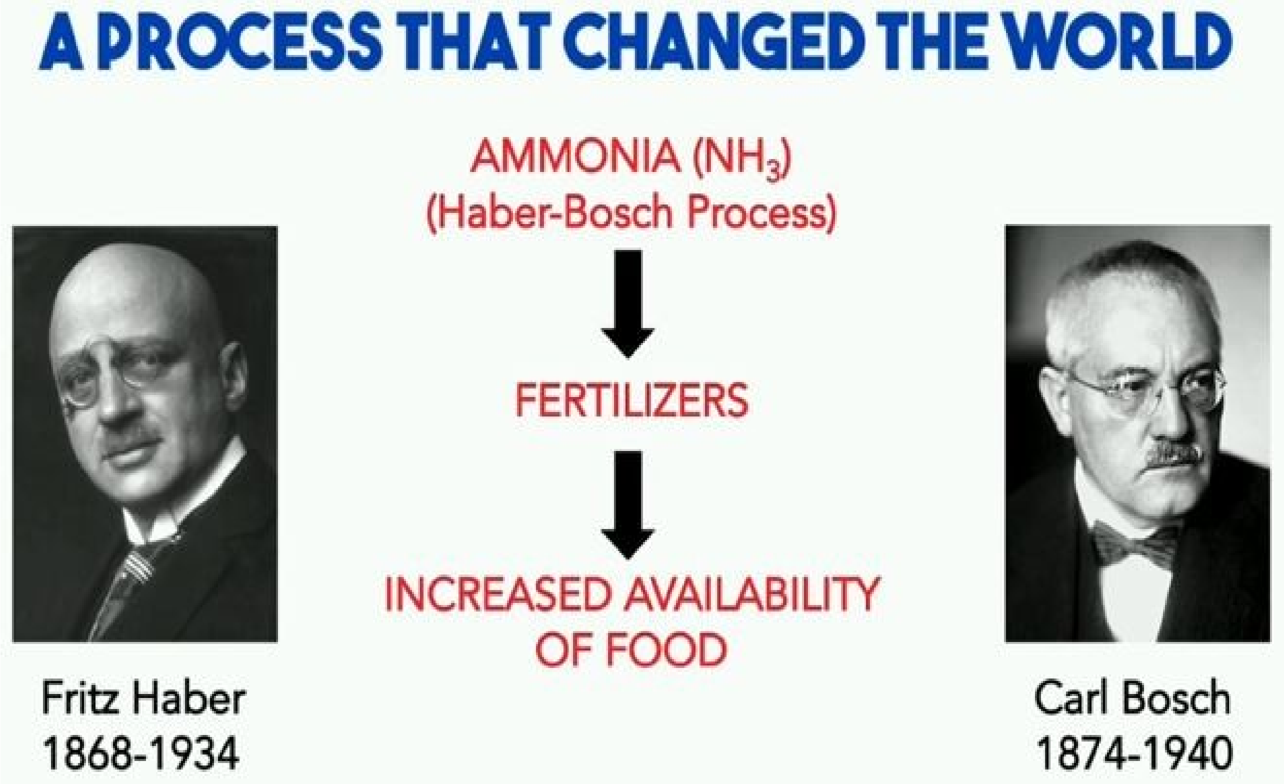


Fig. 24 – *A process that changed the World*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

The process that bears their surnames comes from their studies on the fixing of Nitrogen to make explosives for the German war industry and the German Imperial Army during World War I. Through that fixing it was discovered that it was possible to make Ammonia and with it the fertilizers based on it, which immensely increased the yield and the quantity of availability and productivity in agriculture and in the food sector as a whole. With this, by increasing the availability of food and provisions to any animal species, including Humanity, we proceed to expand its population. And this is exactly what happened to the human species like never before and will continue to be so for the next decades. Why does this fact, in addition to being a Watershed in the History of Humanity often ignored by most, concern this text and in particular the molecule we are talking about? Because it is a fact that Hydrogen has allowed and is closely interconnected with the fixation of Nitrogen and the consequent synthesis of Ammonia, with the creation of fertilizers based on its salts and, together with them, with the growth of the world population. Without Hydrogen, this structural change would not have occurred in such a short time previously only dreamed and imagined. While only in 1834, after centuries and centuries of history, we reached a global population of 1 billion people and, in just under a century later, in 1927 we reached 2 billions, thanks to the implementation of fertilizers and their consequent disproportionate increase in food supplies, from 2 billions in 1927 we suddenly reached 3 billions in 1960, 4 billions in 1974, 5 billions in 1987, 6 billions in 1999, to then arrive at 7 billions in 2012 and, in this year, 2024, at a good 8 billions human beings on Planet Earth. In essence, thanks to this extraordinary discovery made possible by Hydrogen, we have arrived at increasing the population of the Planet by 6 billions people, with trends and forecasts of reaching 9 billions towards the middle of the century, towards 2048 to be precise, and over 10 billions after that. All of this at the turn of the twentieth century, in the midst of the most frenetic, schizophrenic, overwhelming and revolutionary era in the History of Humanity.

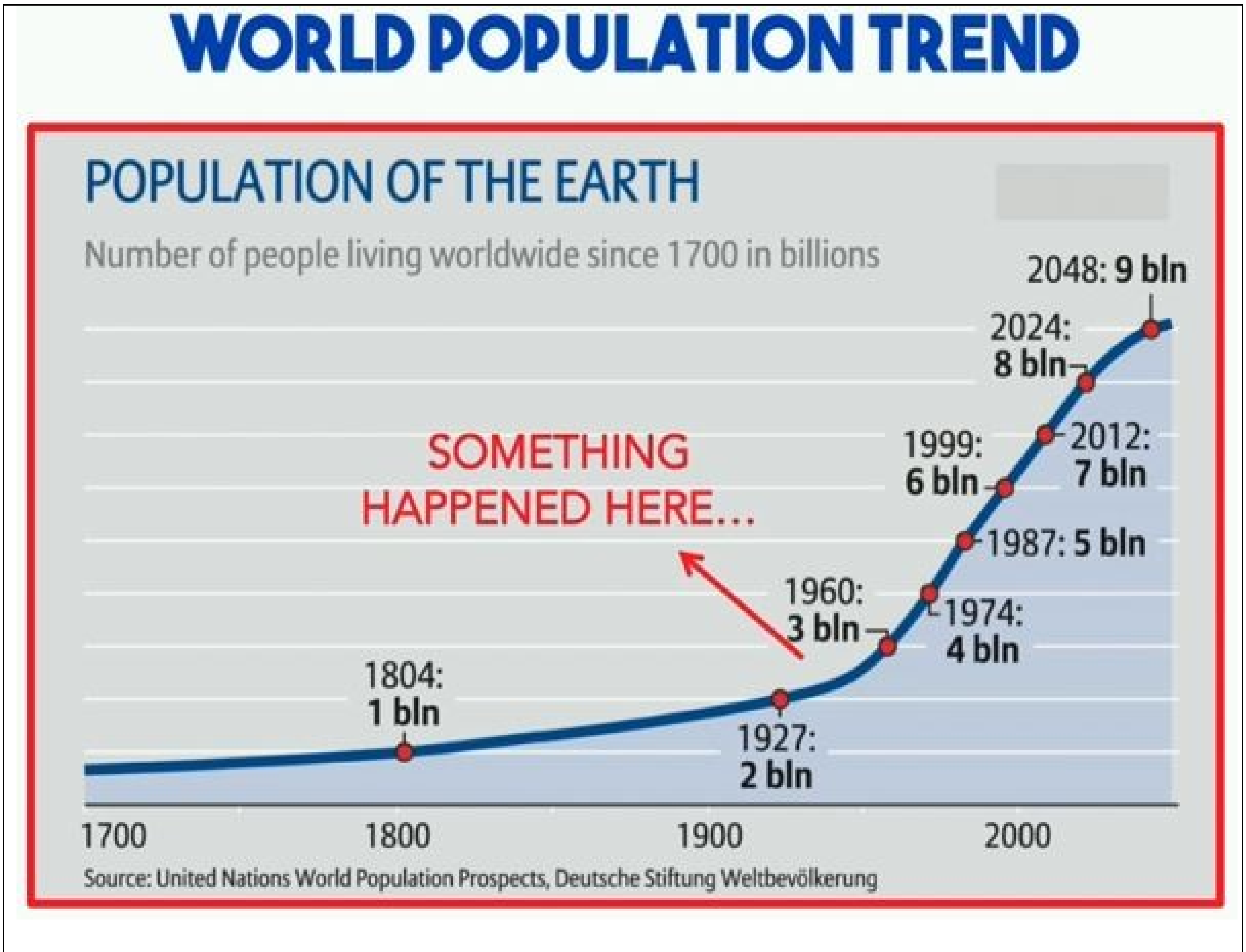


Fig. 25 – *World population trend*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

II.I.2 – The Production and Use of Hydrogen in the Contemporary Age

This gloss was necessary: for the impact of the population increase in our days and for the challenges and consequences that this increase will also bring in the field of environmental, energy, economic and social sustainability. Returning to Hydrogen and its destinations, as we said, this molecule is currently used, in a substantial way, in the chemical-biological and petrochemical industries and generally does not have a real use in the energy sector where it is used in a rather minor way. But then, where is Hydrogen used as a proper energy use? Let's remember: it is a vector and not a source of energy on our Planet. Well, Hydrogen is used by the space industry. It was used for a long time in NASA's Gemini, Apollo and Space Shuttle projects. In these projects it was used as fuel for the launches of spacecraft, the gigantic dark orange conical-pyramidal shaped tanks, present for example in the launch of the Space Shuttle towards the atmosphere and beyond, were loaded not with conventional fuel such as Gasoline or Kerosene but with Hydrogen and Oxygen. Hydrogen was also used to power the so-called Fuel Cells, that is, devices for the production, in flight and depending on the aircraft, of electricity *on board*, as occurred, for example, with Apollo.

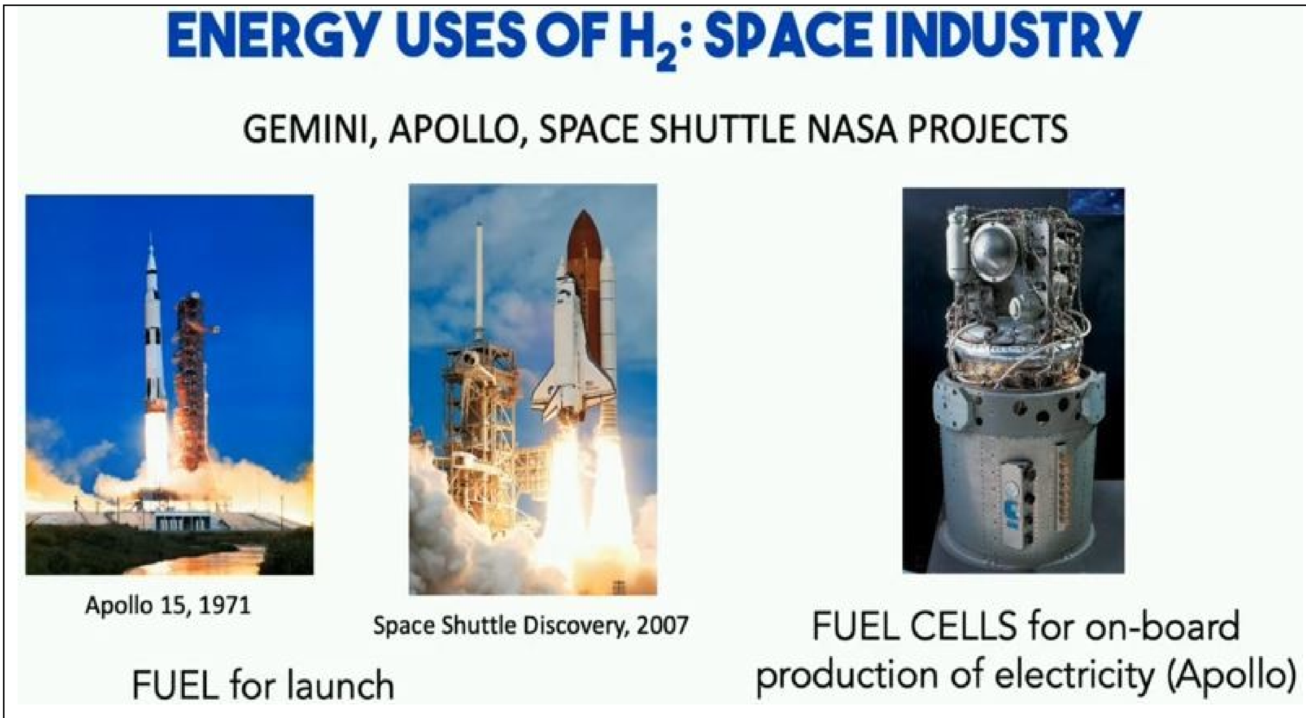


Fig. 26 – *Energy uses of H2: Space Industry*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

So Hydrogen, in the energy sector, is the prerogative of the space industry only, so far. But let's analyze the role that hydrogen could have in the energy transition.

II.II – HYDROGEN IN THE FUTURE? ITS ROLE IN THE ONGOING ENERGY TRANSITION

II.II.1 – But when did the energy transition begin? A historical analysis

The energy transition - which is still ongoing, and which must lead us to abandon the use of fossil fuels in our daily lives, in accordance with the plans adopted and ratified, by the middle of this 21st Century - began well over 200 years ago. As a human species, in fact, we have been in energy transition for over two centuries, starting from the beginning of the 19th Century as basic users of wood and other traditional Biomass and with a small share of Coal. Following the 1st Industrial Revolution, Coal grew pre-eminently in its energy use unlike the original Biomass, and this happened until the 20th Century. Then came Oil for much of the "Short Century", ending up being ousted by Gas until the present day, with the subsequent development of the most modern and sustainable renewable and alternative energies to pollutants. Therefore, even if it may seem absurd to many, it makes no sense to be worried or destabilized by the term energy transition, because it is part of our History, both the most remote and especially the most recent, and is very familiar to us as a whole.

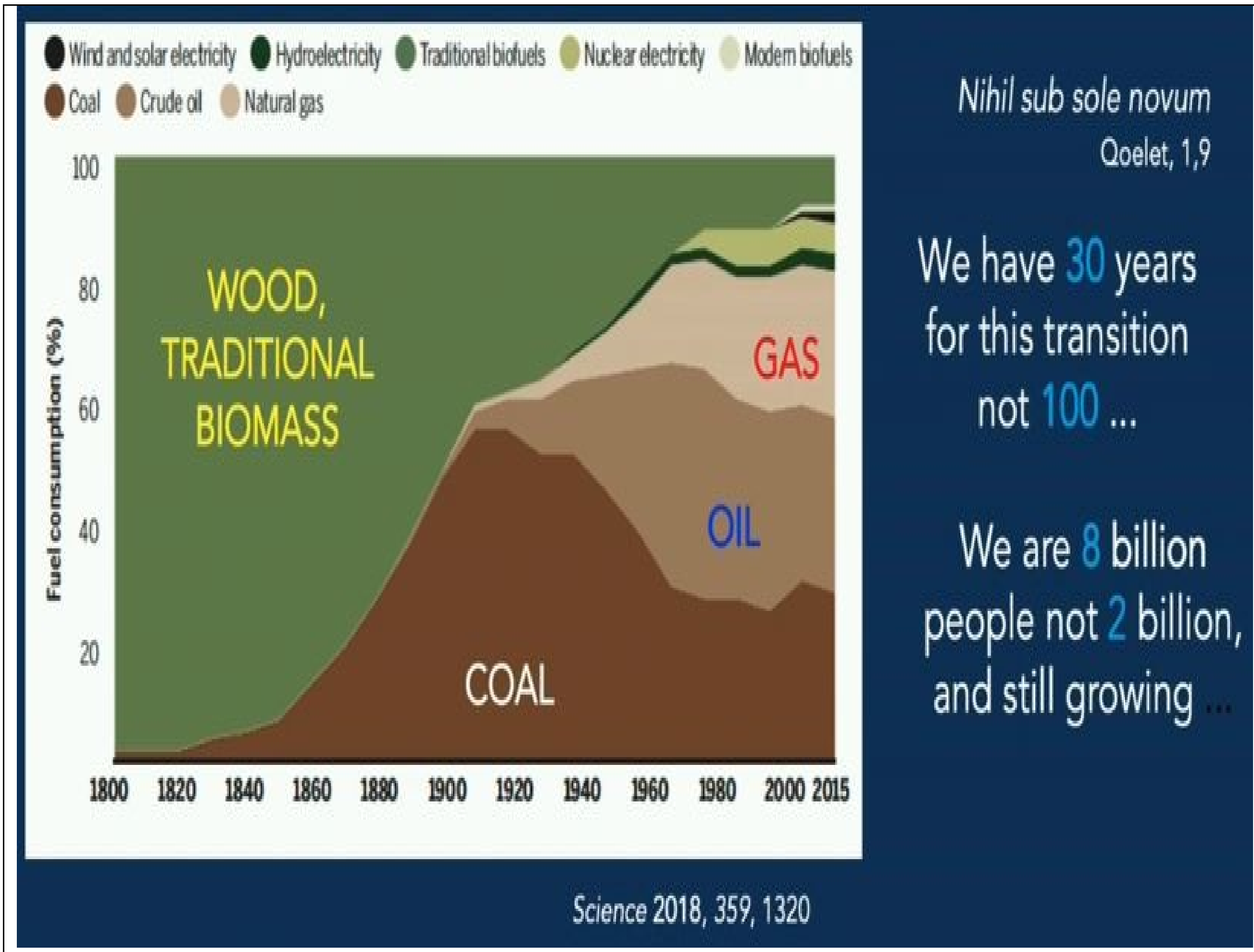


Fig. 27 – *A few hints on the energy transition*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

"Nihil sub sole novum" (Qoelet, 1,9). Nothing new under the Sun. However, it is more necessary than ever to highlight two fundamental points: we do not have centuries of time for this energy transition, but only about 30 years and, as we mentioned previously, we live in a world inhabited not by 2 but by 8 billion people, rapidly increasing towards 10 billion, who live within a globalized and intrinsically interconnected economic system which, as you can imagine, makes things more problematic and difficult to complete.

This pair of numbers shows the extensive complexity of the current energy transition. In fact, in our time, the vast majority of primary energy supply comes from fossil sources, which emit 34 Gtons of CO2 which, in turn, fuel and increase global warming. In this use of fossil fuels we are still blocked and stuck for decades, too long. This use of fossil fuels is extremely combined and integrated into our economy and, as a result, it is truly difficult to change it given the inertia to which we have been accustomed by this context for so long. However, we know that this, even if it is not the only one, is the main responsible for global warming. Therefore we return to the key phrase that contains the essence of our energy problem: we still burn too much. We continue to burn too many fuels to meet our productive energy needs. Electrification powered by renewable energy, first of all by Photovoltaic and Wind, is the path we are following, albeit slowly despite the significant progress underway.

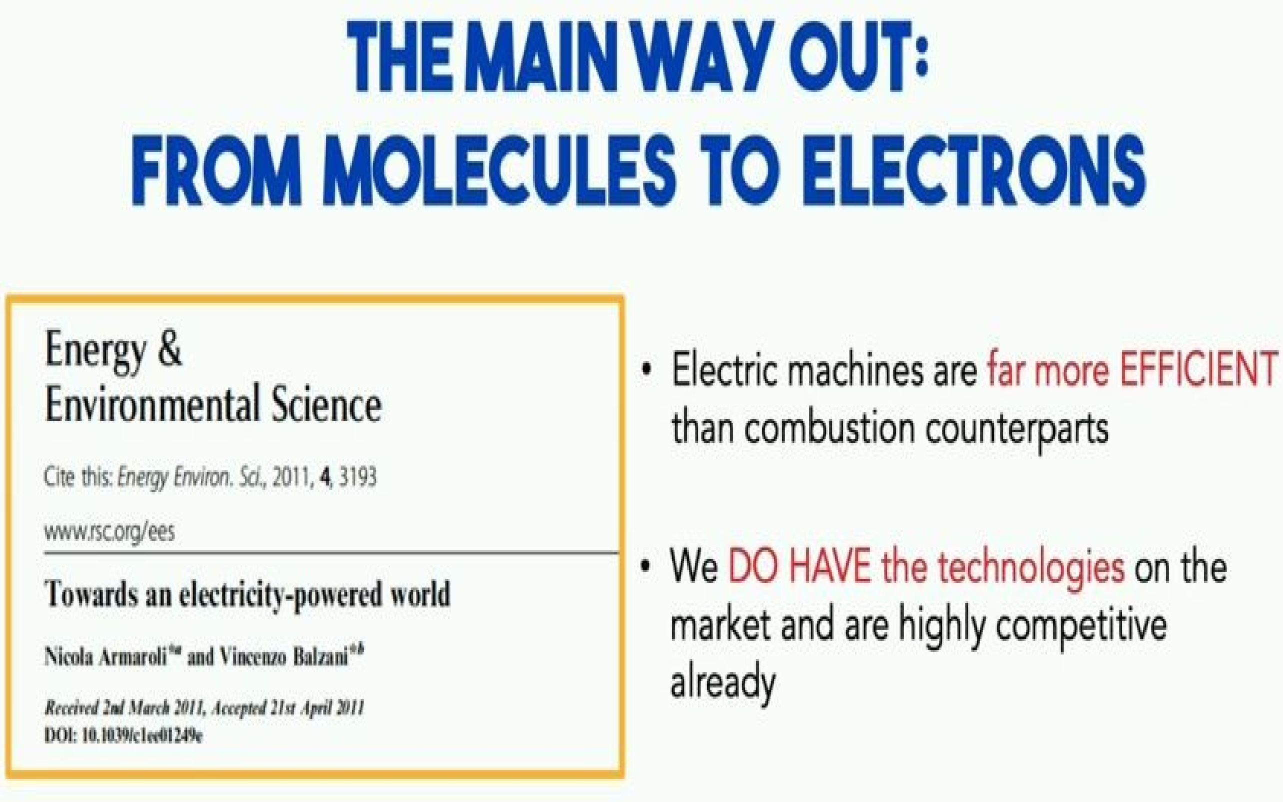


Fig. 28 – *The main way out: from molecules to electrons*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

But still, for certain activities and sectors, we need molecules for fuel to burn, but this fuel must be decarbonized and free from polluting causes both "quantitative" - without GHG to avoid increasing the greenhouse effect - and "qualitative", that is, avoiding deteriorating the environment, biodiversity, health etc. as happens, for example in some areas, with pollutants such as PFAS and with plastic and its microplastics dispersed everywhere. And it is for these particular activities that Hydrogen arrives, and helps us. Regarding these activities, 10 Gton of CO2, which is equivalent to about 30% of the total annual global carbon emissions, come from industries, energy-intensive sectors first and foremost, furthermore, the share of remaining emissions will grow further when other sectors such as the energy sector (Energy/Electricity), buildings (Heating and Cooling) and Transport (first of all light transport) such as road transport are decarbonized. These sectors, defined as hard to abate, these economic activities, essential for today's civilization and globalization, are specifically two: heavy industry (cement, steel, plastics) & heavy transport (cargo planes/commercial aviation, cargo ships/maritime transport, freight truck logistics/heavy road transport on rubber).

Fig. 29 – *But we still need decarbonized molecules*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

We now come to the next part regarding the practical use of this special molecule: production, management, transport and use of H2.

II.II.2 – How is the molecule generated? Analysis of its creation from the present to the future. Hydrogen between fossil variants and its clean and renewable version

Hydrogen created today, derived from CH_4, or Methane, is usually defined as Grey Hydrogen but also as Blue Hydrogen - later we will see the peculiar difference - and has a complex chemical process with various reactions in sequence. The chemical description (very simplified and in extreme synthesis) with the general reaction is the following: $CH_4 + 2\ H_2O \rightarrow 4\ H_2 + CO_2$. In practice, through the extraction processes commonly used for a long time, Hydrogen is produced from Methane but, together with it, also Carbon Dioxide since the Carbon molecule is combined with that of Oxygen and there is nothing that can be done to avoid it. Carbon Dioxide is the problem and, after the production process, it ends up in the atmosphere, globally 2.5% of the total of this process. The energy needed is proportionate: this chain process, composed of other sub-processes within it in sequence, has a very low energy requirement and this is why it is used extensively given its very advantageous chemical technology (47 kJ/mol relative to the primary CO process). For Blue Hydrogen, in practice, the process is the same as Grey but, to deal with the emission of CO_2, instead of emitting it into the atmosphere, the CO_2 is injected and confined underground, aiming to "store" it. So, Blue Hydrogen is differentiated by the so-called “CCS” which is, in fact, the confinement of the Carbon Dioxide created by the process underground. It seems like a simple and feasible process, but essentially it is just theory. In practice, 30 years of this type of CCS confinement of emissions have brought very poor and laughable results. Essentially, almost all the CO_2 “shot” underground has been used to “squeeze” a depleting deposit and be able to extract the last barrels of crude oil. Subsequently, this extracted fuel will, of course, be burned, thus emitting further CO_2 which, however, will not be captured or stored but released into the air. It does not seem like an intelligent or useful exercise from an environmental point of view, it may make sense from a purely productive and economic point of view but not from the point of view of environmental sustainability. Not only is the Blue process not a zero-emission technology, but it has drawbacks and exposes it to significant risks. Since the CO_2 is not confined in a specific structure, which can guarantee its containment over the years, there are real risks of leaks. Even small fumes can have serious effects since Carbon Dioxide remains in the atmosphere for a good hundred years. There are also risks of induced seismicity since the injection of CO2 creates real seismic shocks, in essence we create earthquakes with our own hands. Certainly it is a very convenient production method for the Gas industry which, however, is not necessarily in favour of the common good and in the interest of the community.

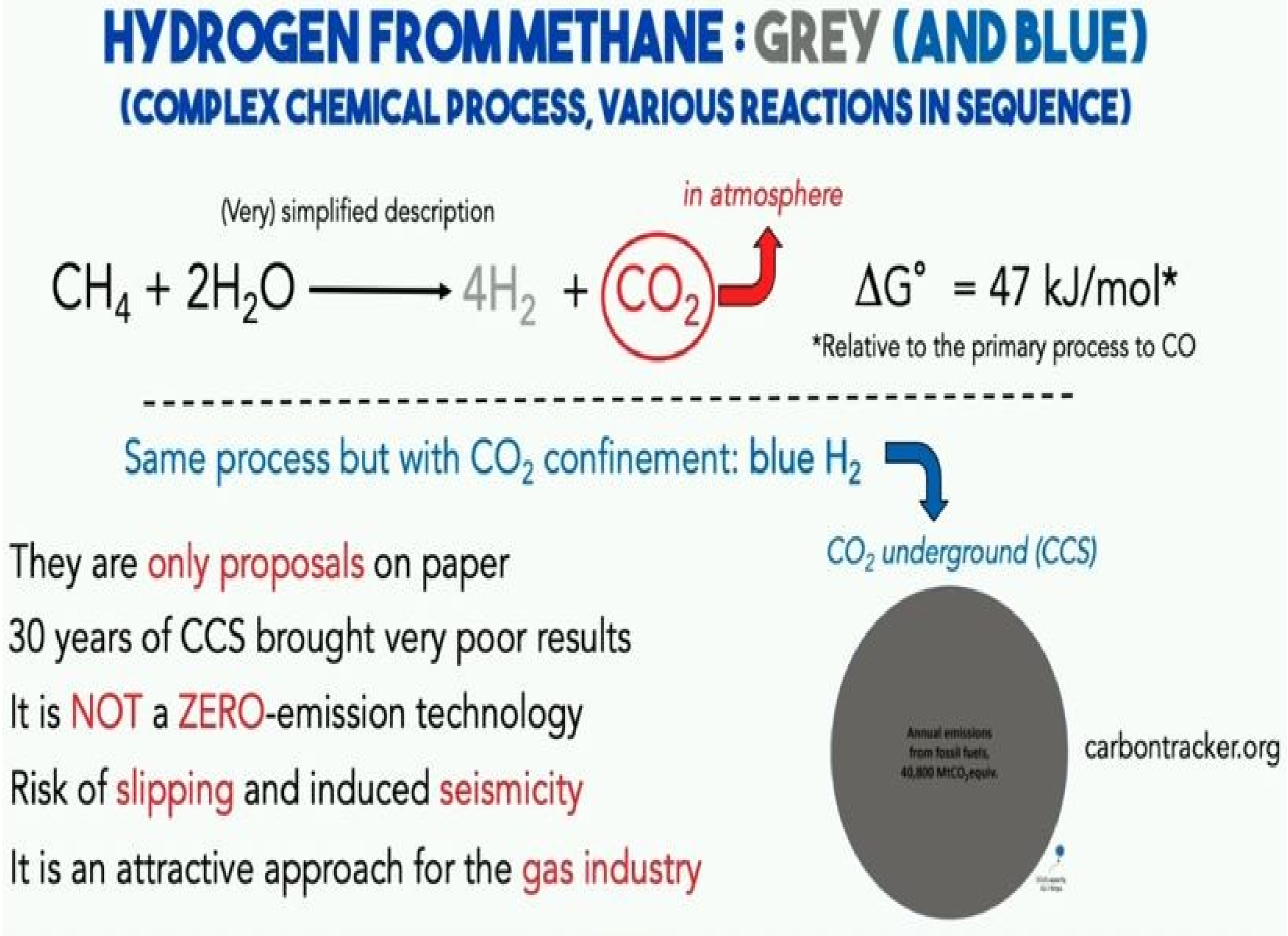


Fig. 30 – *Hydrogen from Methane, Grey and Blue*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

But this is the past, now to be overcome. Is there an alternative? As we had previously anticipated, the production of Hydrogen is currently done through Methane, but fortunately it is not the only way. In fact, it is also possible to realize it, without Carbon, through one of the most important and present resources on our Planet that gave us life: Water. This process is defined as Green Hydrogen, that is, realized through clean renewable energy and it is clear that it is the only way that actually allows us to produce decarbonized Hydrogen. How does it work? Through special machines called Electrolyzers, electricity can be used to divide and extract, from the Water, the Hydrogen present that is naturally combined with Oxygen. The chemical description with the general reaction, this time, is very different from the previous one: 2 H_2O → passage of electricity through Electrolysers → 2 H_2 + O_2. This process is the real way to achieve decarbonized Hydrogen as it can, and must, be produced through clean, non-polluting renewable energy, which we already have and use in the present. The emissions are only of harmless Oxygen, without damage or problems for the atmosphere and perfectly compatible with nature and, moreover, also usable for vital human purposes and activities. We know well, with the Covid-19 Pandemic that all of Humanity has faced, how fundamentally important the cylinders and supplies of Oxygen for medical/hospital use have been for the lives of thousands, if not millions of people. On the other hand, while the production of H_2 from Methane required an overall favourable energy supply (47 kJ/mol), for the production of the same through the electrolization of Water the energy required is seriously and enormously more expensive (286 kJ/mol). This is the problem. Is there an explanation for this marked energy idiosyncrasy? This is because our Planet is composed of low-energy molecules (like Water, for example) and therefore, if you want to have energetically intense and high molecules starting from them, you have to "charge" them with energy, and it takes quite a bit. The production of 1 kg of H_2 through the Green process requires 55 kWh of electricity, together with 9 liters of H_2O, and contains 33 kWh of energy in the form of heat as Gas. Paradoxically, it has 30% less energy than that consumed to produce it. To make some significant comparisons, 55 kWh correspond to the average electricity consumption of an Italian family over the course of an entire week, while 33 kWh are the approximate equivalent of 3 cubic meters of Methane which, in turn, correspond to a simple single day of the average annual consumption of an Italian family. Therefore the balance is that to obtain one day of energy having it in the form of equivalent Natural Gas corresponds to the use of electricity of a week. Whatever is done with Hydrogen this is the problem to face and to deal with, given also that with thermodynamics there can be neither negotiation nor compromise in any way.

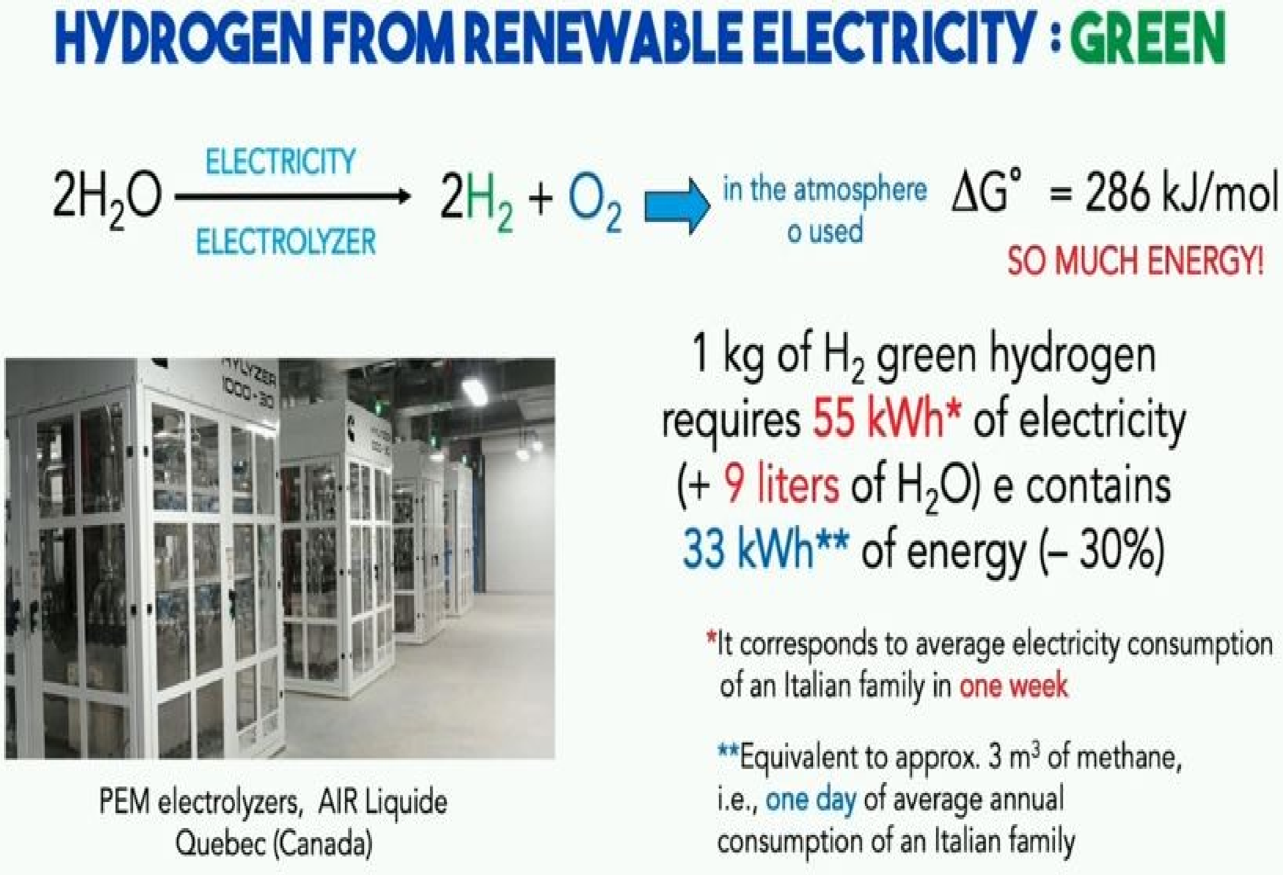


Fig. 31 – *Hydrogen from renewable electricity: Green*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

The scheme of an Electrolyzer, and consequently the device itself, is quite complex. These complex and multifaceted machines have 2 commercial technologies, preferably need a continuous energy flow such as that given by Hydroelectric. In fact, the large plants that create Green Hydrogen in the world are all essentially powered by dams and Hydroelectric complexes thanks to their possibility of continuous flow over time, while it is more difficult and complicated for intermittent energy flow structures such as Photovoltaic and Wind without adequate flow rebalancing structures, i.e. through energy accumulation and storage systems. Despite all this, these Electrolization technologies are set to be updated and improved, substantially over the next 10 years. This is a great opportunity for the industry, especially for the European industry, because if you look in detail inside all the machines, devices, apparatus and components of it, the European industry is very and highly specialized, competent and prepared in every aspect of them. This is a great positive point, if we are able to build better and more efficient Electrolysers it will be, for the whole industry of Europe, extremely beneficial, because it has a great and experienced *know-how* and of the indisputable capabilities in this constructive path and in this technological line of development.

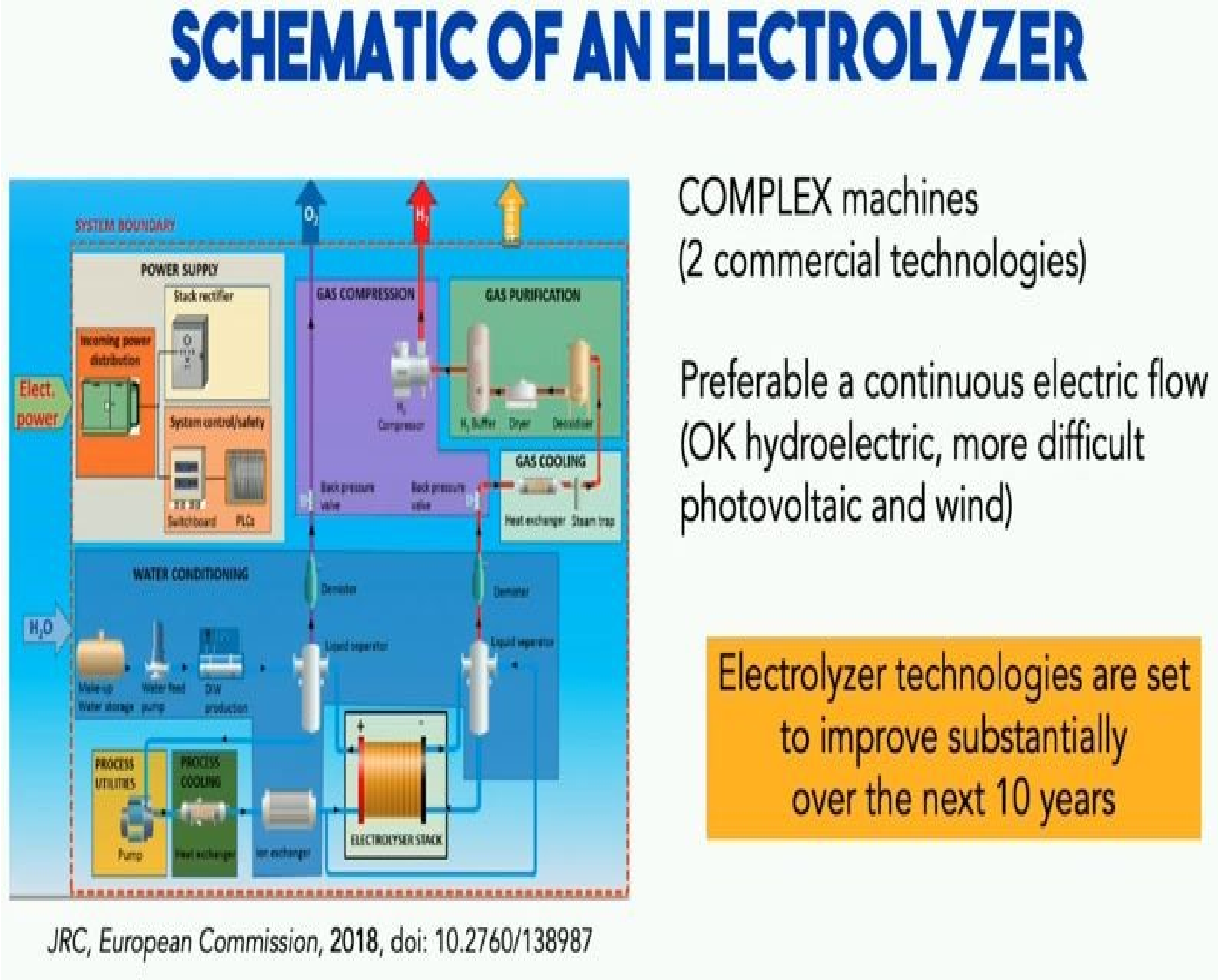


Fig. 32 – *Schematic of an Electrolyzer, Green*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

In relation to the present and future costs of the two main methods of producing Hydrogen, the Grey process and the Green process, it was calculated that, in 2020, to obtain 1 kg of H2, 1.6 $ were needed for the Grey process, while 6 $ were needed for the Green process.
In the future, hydrogen production with the Green process will certainly cost less than the Gray

process, with an estimate, respectively for 2030 and 2050, of $ 2.5 and subsequently $ 1 per 1 kg of H2. Hydrogen created from Water will be extremely more competitive and affordable than today. For Methane, however, things get quite complicated, given that, for the near future, forecasts are rather fluctuating and above all volatile. With the recent post-Covid economic & financial events and geopolitical crises, first of all, the war in Ukraine, the price of fossil fuels, Methane first and foremost, has had never-before-seen fluctuations and today we have prices significantly higher than the pre-pandemic and pre-international crisis past. We also keep in mind that, by 2050, according to international agreements, in particular with the energy transition envisaged by the European Union, only non-polluting energy sources must be used.

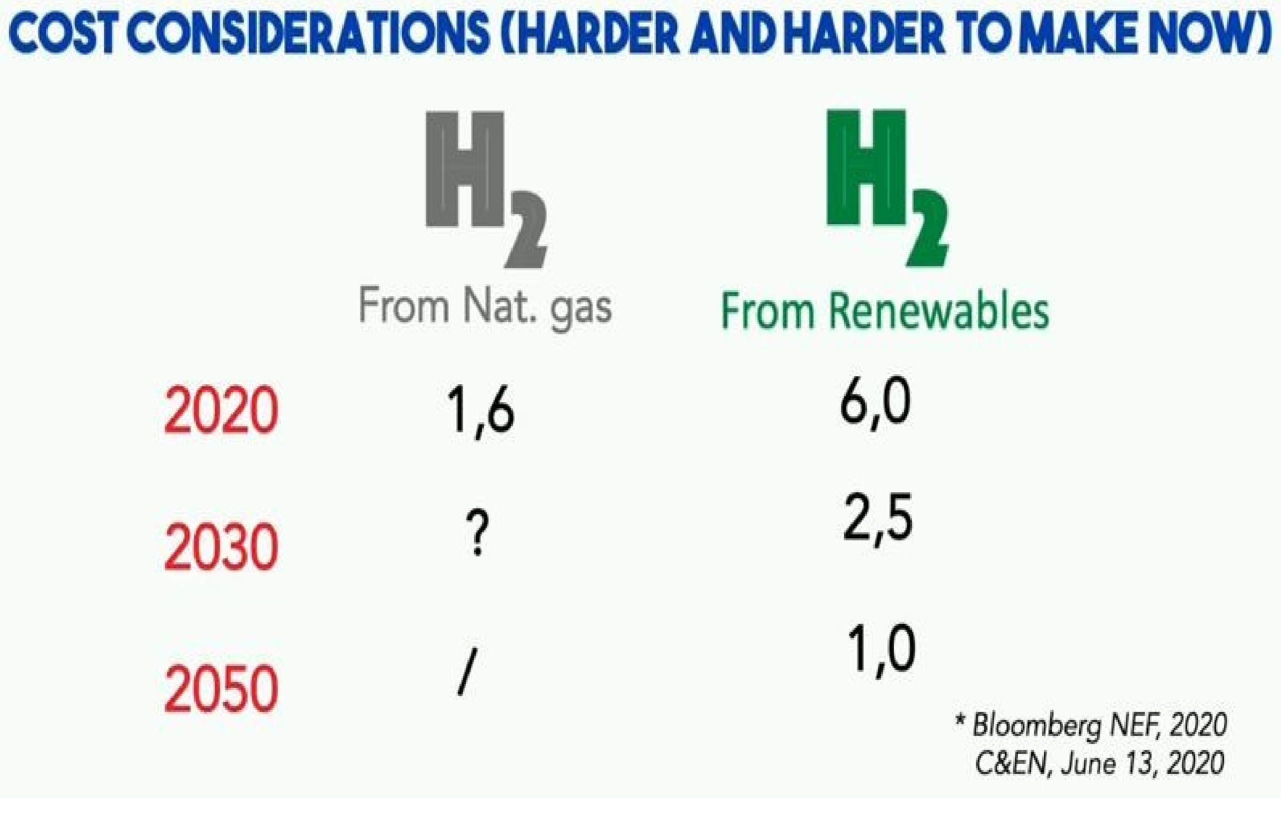


Fig. 33 – *Cost considerations harder and harder to make now*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

We also add that to produce Hydrogen you can use Natural Glucose, more specifically defined as the direct conversion path towards Hydrogen, a process that uses the *Solar Fuels* for the direct production of H2 through photoelectrochemical systems. Unlike Electrolysers, which are a proven technology and increasingly developed and evolved over time, this third process is essentially in the research phase. It will take some time to have significant data and feedback.

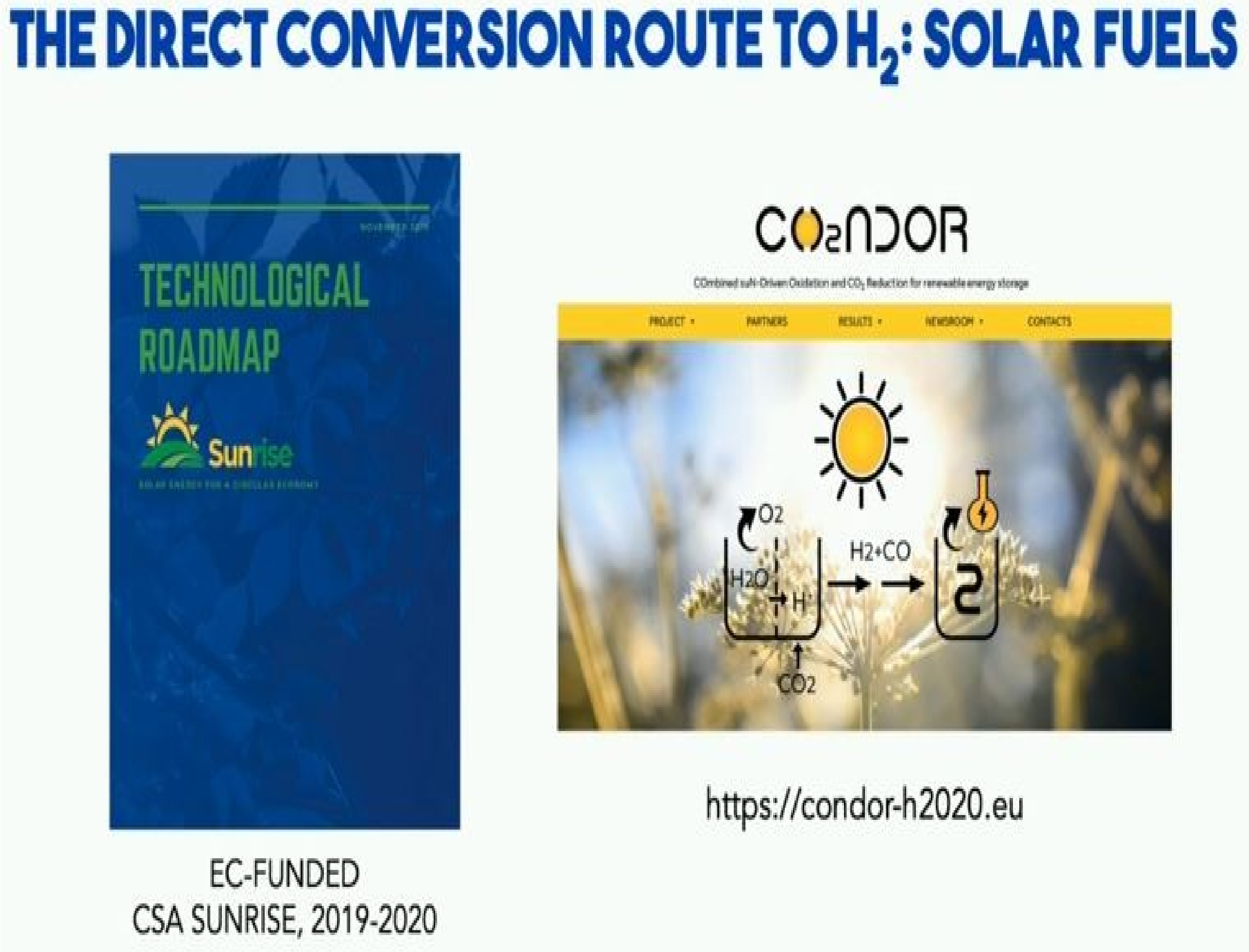


Fig. 34 – *The direct conversion route to H2: Solar Fuels*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

II.II.3 – Hydrogen management between chemistry and technology

Let's now move on to the aspects related to the management and storage of Hydrogen. How can it be handled? Let's take as models some products and systems existing on the market. The Mirai, a sedan produced and sold by Toyota, is the most famous Hydrogen car available for purchase. It has a tank capacity of 5/6 kg of H2 and exerts ultra-high pressures corresponding to between 350 and even 700 bar, which is a truly conspicuous pressure. The other example are the already mentioned and mammoth tanks equipped to launch rockets and space shuttles, in this case the molecule is liquefied at -253°C. The not to be underestimated drawback of this use is that to liquefy the H2, from the original gaseous state, considerable quantities of energy are used and consumed with relative very high costs. Only a few institutions and agencies, such as NASA, can realistically afford similar costs. So, in summary, there are currently two best methods of managing the molecule: through liquefaction and through ultra-high pressures. The energy consumption - calculated with a theoretical minimum - of these two technical methods is for highly pressurized H2, 1.4 kWh/kg, while for liquefied H2 it is as much as 12 kWh/kg. With regard to liquefied H2, with respect to the production difficulties of the molecule, it should be highlighted that, on a given volume, as much as 30% of that energy quantity produced is in turn used to liquefy the remaining 70% and, consequently, this represents the intrinsic energy cost of its implementation, which is unsustainable on a small scale.

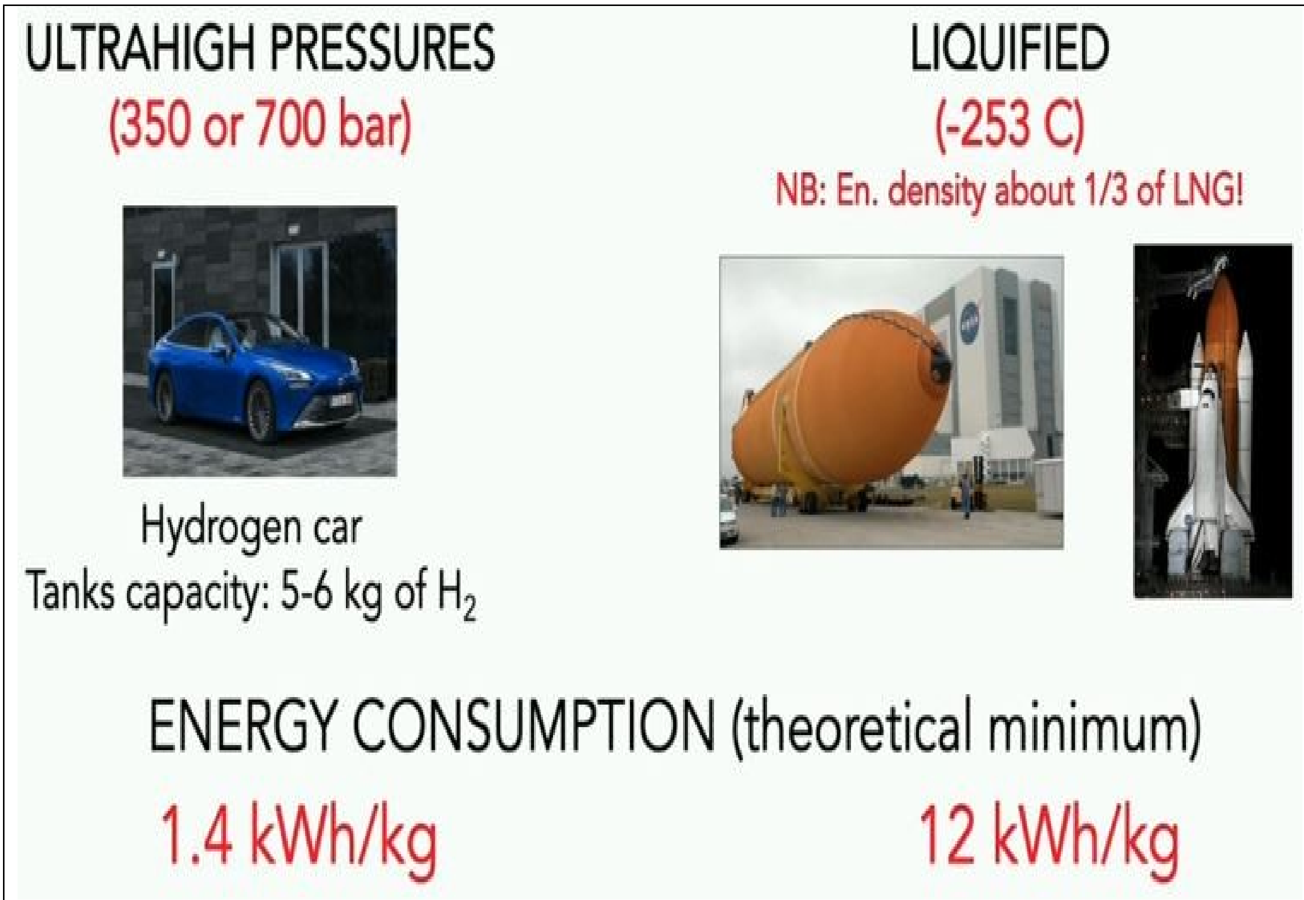


Fig. 35 – *How we handle H2*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

So, how can H_2 be handled? Is it possible to manage it in another way that is more efficient and easier than the ones we have listed, which are unthinkable except on scales that are unattainable to most? There are actually other ways.

The first of these is to incorporate it into solid materials that can absorb Hydrogen, such as pores, and connect it to them to then release it and deliver it through, for example, an increase in temperature.

The second of these procedures is literally to hide it, inserting it into other molecules such as *Liquid Organic Hydrogen Carriers* (LOHC) taking the one that, among other molecules, is the simplest of all: NH_3. In fact, Hydrogen can be hidden inside Ammonia which can, in turn, liquefy at a temperature even higher than that of H_2 alone: only about -30°C is enough instead of the -253°C considered before. After that, in any case, the implanted H_2 must be released and it will be necessary to implement a catalytic process to extract it from the Ammonia. This cannot be done only with NH_3 but also with other molecules even more complicated than the latter.

Finally, the third and last possible alternative route is to store the Hydrogen inside the subsoil but, as can be easily understood, this methodology is nothing more than a diversified reproduction of the scabrous CCS. Why, not even in this option, can the use of the subsoil work? Because doing so would activate the reactivity of the Hydrogen. By storing it underground it can undergo and be subjected to geochemical processes and also processes caused by bacteria. For example, by storing 100 kg of Hydrogen underground, there is a real risk that, after a few months, the same amount will no longer be found, but about forty kg, due to its extreme reactivity. So this is not a viable option either, also because it should be favoured and financed over other, certainly better, alternatives.

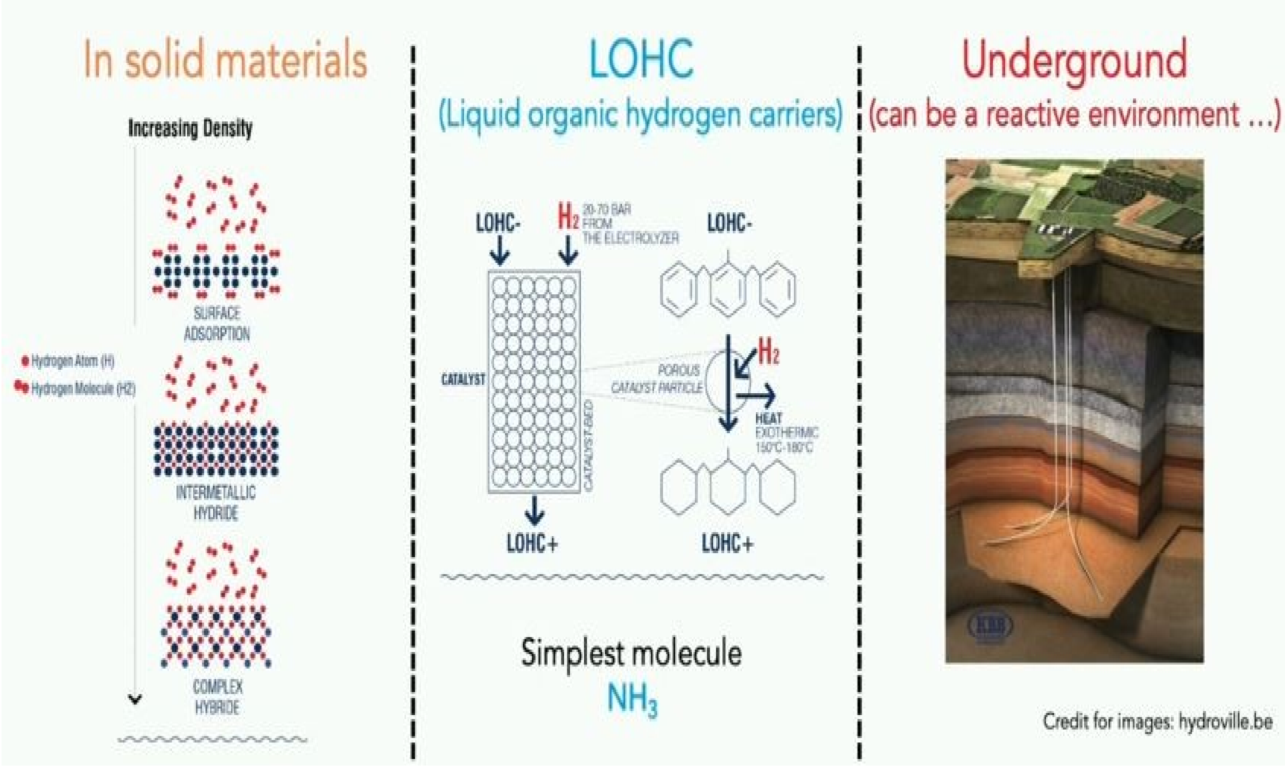


Fig. 36 – *How we will handle H2*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

II.II.4 – The thorny, complicated and sensitive question of molecule transportation

Let's now move on to another but very delicate issue: the transport of Hydrogen. Let's return for a moment to Methane. Throughout continental Europe there is an impressive and very extensive intersection of pipes: the Natural Gas transmission network, better known simply as Gas Pipelines. These pipes have a diameter of 1.2 meters and are practically everywhere in Europe. Can we think of using them to transport not the polluting and now dated Methane but Hydrogen? Probably not. Globally, there are "only" 5000 km of pipes that convey Hydrogen, while Methane has well over 3 million km. The reason is that the reactivity of Hydrogen, together with the fragility of the structures, can be tremendously dangerous and, to deal with it, specific steels are needed that are anything but cheap. For this reason, if we want to use the current transmission network in its entirety, it will be necessary to substantially replace almost every work. That is, it will be necessary to switch and adapt pipes, valves, compressors and so on; checking each time, case by case, what can actually be done. Therefore, it is not a guaranteed or obvious solution.

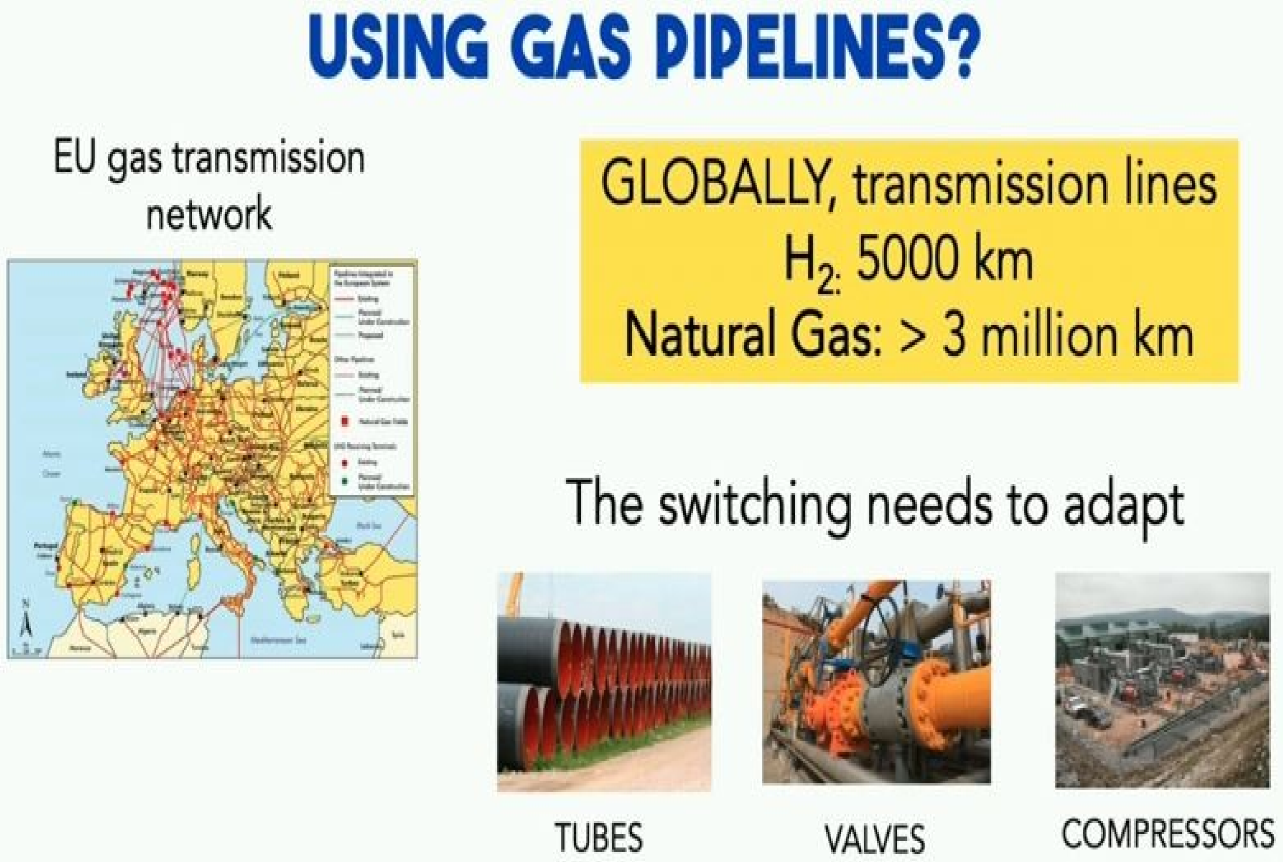


Fig. 37 – *Using Gas pipelines?*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

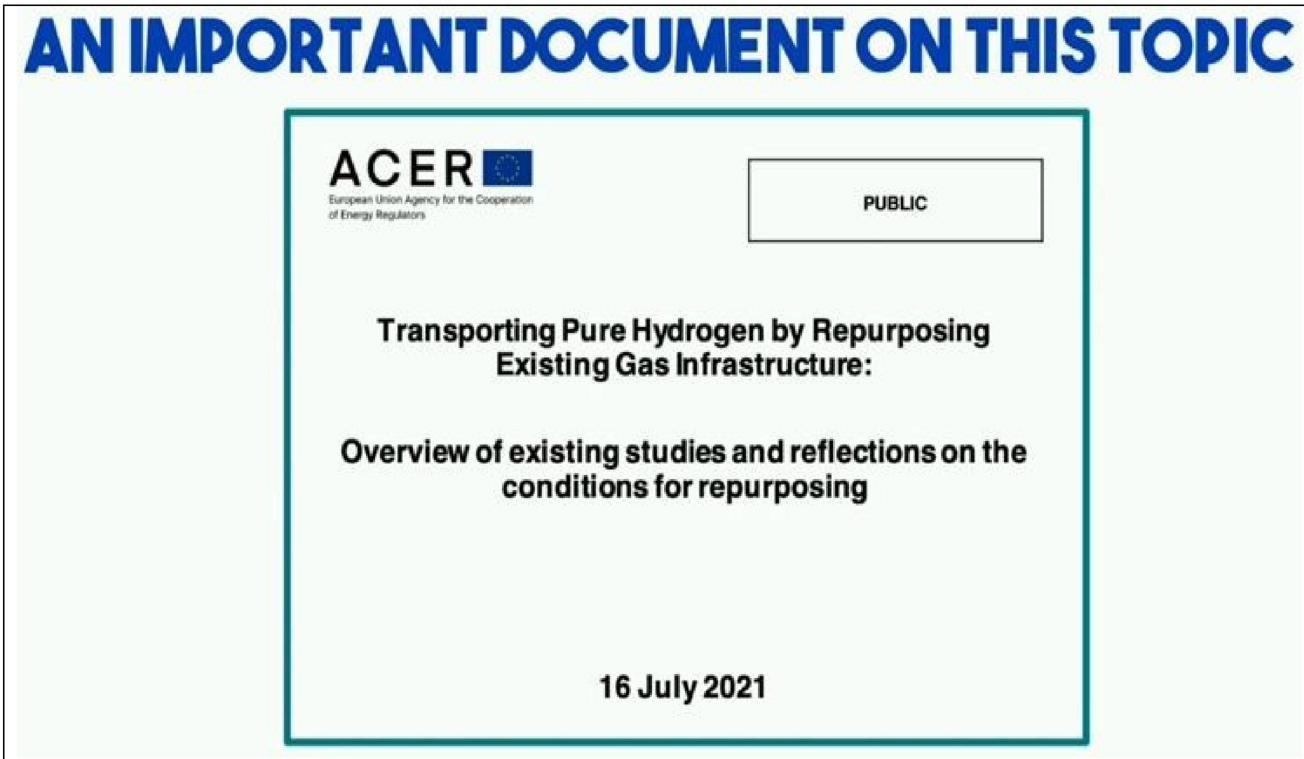


Fig. 38 – *An important document on this topic*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Having made this observation, we are thinking of moving these hydrogen production infrastructures from the European continent to North Africa, in countries relatively close to Europe, such as Egypt, Libya, Tunisia, Algeria and Morocco, where these works can be built, with lower risks and at the same time making the countries that host them earn money. So why not produce hydrogen elsewhere instead of producing it and conveying it for thousands and thousands of kilometers in our countries? In these sunny, large and desert countries, there would be ample possibilities for photovoltaic production that can be installed to produce hydrogen through electrolysers and then send it through existing gas pipelines or by building new ones. This possibility has positive and negative aspects that must be carefully analyzed before any decision. The advantages are that: renewable energy can be exploited and used on a large scale and at reduced costs, a prospect of stability and social development would be given to those countries, still underdeveloped and with limited availability of resources and alternative production for their economic development. Some of these countries, such as Libya and Algeria, are major exporters of fossil fuels. If their production were to cease, what could they base their economic system on? They would be destined for a decline in their already fragile economy, as well as a breakdown in social cohesion. Therefore, this outsourcing of the production of Hydrogen, and other sources of renewable energy, could be a valid alternative and a crucial possibility for the future of these States. On the other hand, the disadvantages are that: models of energy dependence are unfortunately perpetuated and, in the future, we cannot know whether the geopolitical situation will remain stable and favourable for outsourcing of such vital sectors. An event and a fact that significantly shows how burdensome all this can be is the fortuitous case of DESERTEC. DESERTEC was a project, about twenty years ago, that intended to create a structure in North Africa for the creation of electrical energy through photovoltaic solar production. A visionary and extraordinary project, carrying substantial advantages for everyone. Despite this, with the outbreak of the Arab Spring and the subsequent regime changes, often carried out with the unscrupulous use of force and with the oppression of the people who wanted to free themselves from dictatorial and illiberal contexts, this project had to stop and ended up suspended until a date to be determined. This is the most serious risk of these extraordinary and visionary projects: the great uncertainty and unpredictability for their realization. Before DESERTEC was a foundation, now it has gone into oblivion.

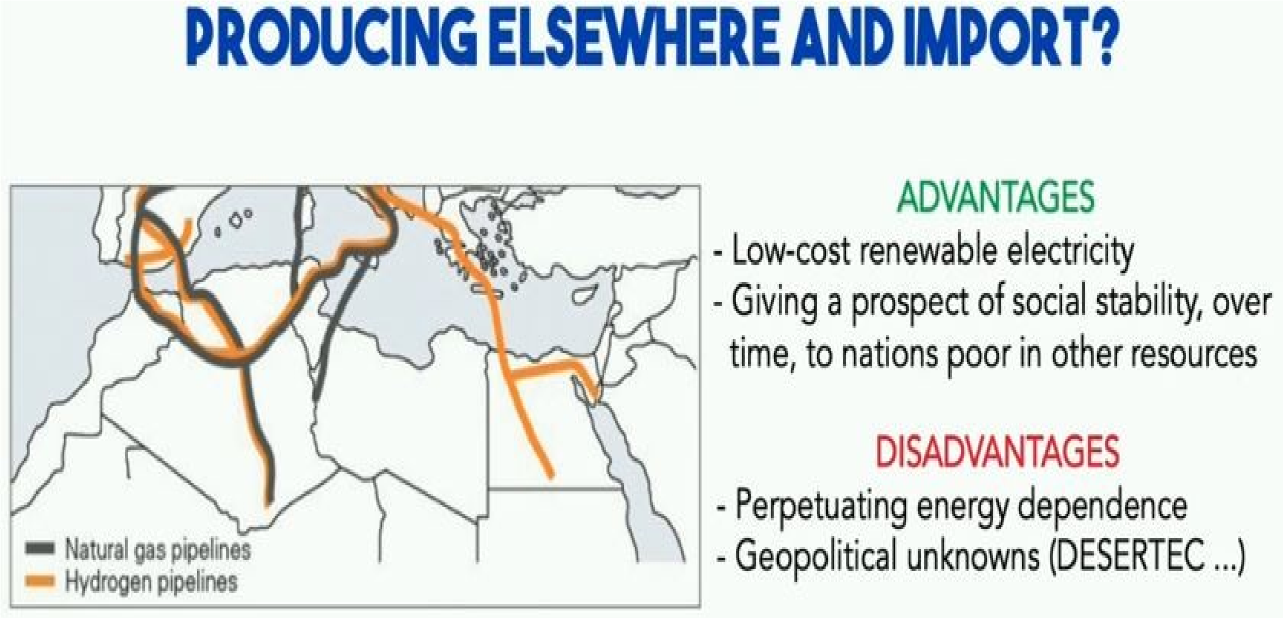
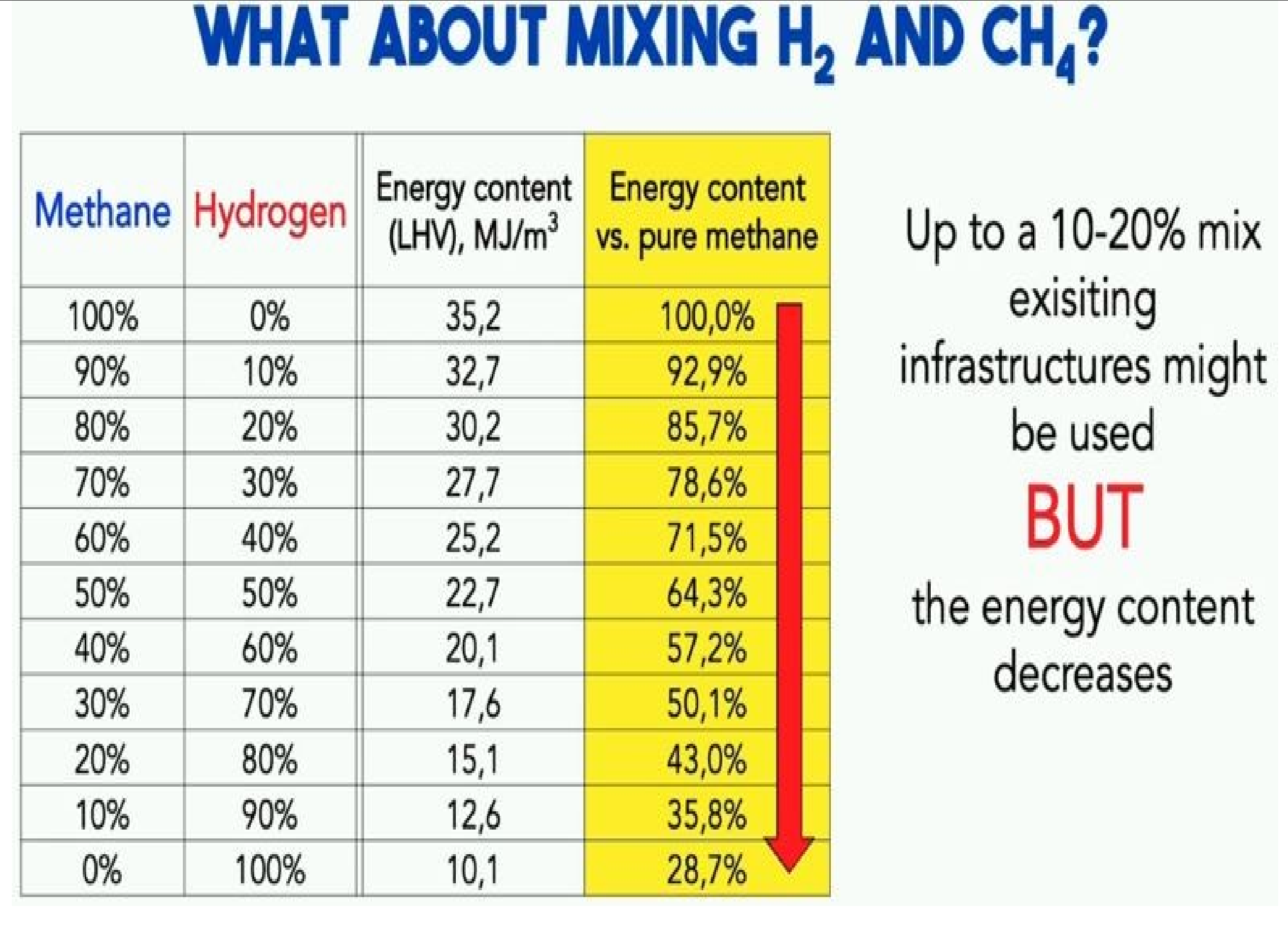


Fig. 39 – *Producing elsewhere and import?*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Other "scientists" have put on the table the proposal of mixing Hydrogen with Methane in order to solve the problems of instability and transport of the ecological molecule while continuing to use the polluting one. Unfortunately, as the amount of Hydrogen increases with respect to Methane within the same share of Gas, the energy quantity will end up decreasing again, and again, as the share of H2 increases with respect to CH4. This is not a fact that pleases those who manage energy plants because with a margin between 10% and 20% of Hydrogen with respect to Methane, existing infrastructures can be exploited for this type of "hybrid" Gas but their energy content decreases with respect to Natural Gas alone (with 20% Hydrogen the available energy drops by about 15%). Furthermore, with this mix the reduction in CO2 emissions emitted by the Methane containing it is only -6%. Too little and the game is not worth the candle. So, from a thermodynamic point of view, mixing H2 and CH4 is far from practical and advantageous. It may be for Natural Gas companies, but it is not really useful for the energy transition.



WHAT ABOUT MIXING H_2 AND CH_4?

Methane	Hydrogen	Energy content (LHV), MJ/m^3	Energy content vs. pure methane
100%	0%	35,2	100,0%
90%	10%	32,7	92,9%
80%	20%	30,2	85,7%
70%	30%	27,7	78,6%
60%	40%	25,2	71,5%
50%	50%	22,7	64,3%
40%	60%	20,1	57,2%
30%	70%	17,6	50,1%
20%	80%	15,1	43,0%
10%	90%	12,6	35,8%
0%	100%	10,1	28,7%

Fig. 40 – *What about mixing H2 and CH4?*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

<u>II.II.5 – The use and application of Hydrogen for energy purposes</u>

We now come to another point of significant relevance for the entire analysis of the current molecule as a valid energy vector to achieve the energy transition and win the climate challenge by reaching the longed-for Global Carbon Neutrality: the energy uses of Hydrogen. How can Hydrogen be used for current and future energy uses? There are mainly two possibilities: as a low-temperature fuel, e.g. *heating*, or at high and very high temperatures, e.g. for heavy and energy-intensive industries such as steel mills, cement factories, glass and paper producers, etc. The other use is as a vector for road transport vehicles, via Fuel Cells. For heavy industry, using Hydrogen represents such a vital possibility that it is almost an obligatory choice, as there are no alternatives to the Natural Gas used today.

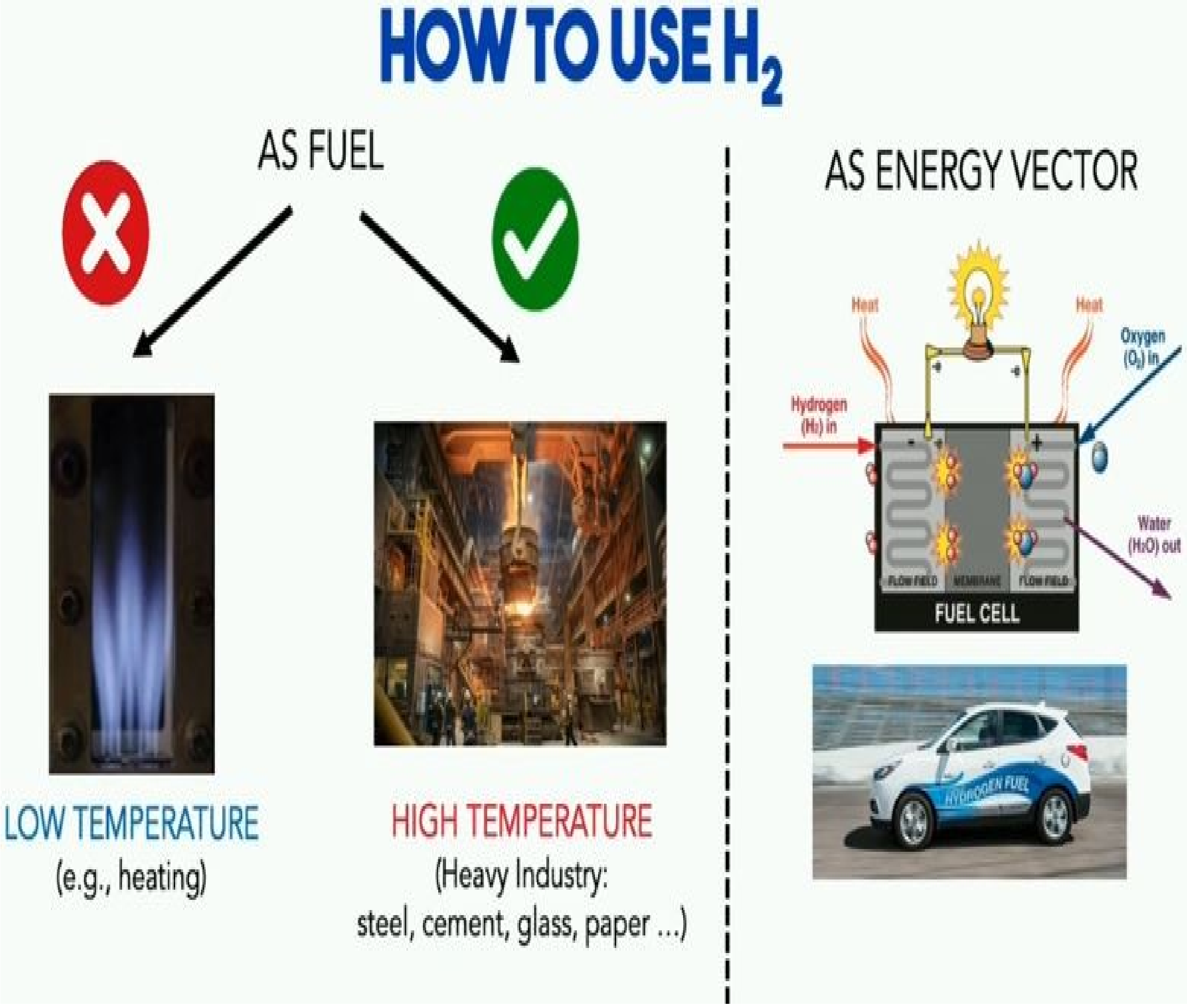


Fig. 41 – *How to use H2*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

On the other hand, the use of Hydrogen for domestic heating is a senseless idea. Because if you had 100 units of renewable electricity produced on the roof of a house, imagining that you had a hypothetical invented domestic Electrolyzer in the basement, and then you produced some Hydrogen to burn for heating the residence, you would only get 60 units of heat from the 100 units of electricity available and, therefore, you would have a 40% inefficiency on the total. If instead you used other technologies for heating, first of all Heat Pumps, such as Geothermal ones, developed for some time and available on the market, you would get much better results: between 300 and 500 units of heat, always based on the original 100 units available from the photovoltaic panels. So, in this case, the Hydrogen molecule would not be of much use.

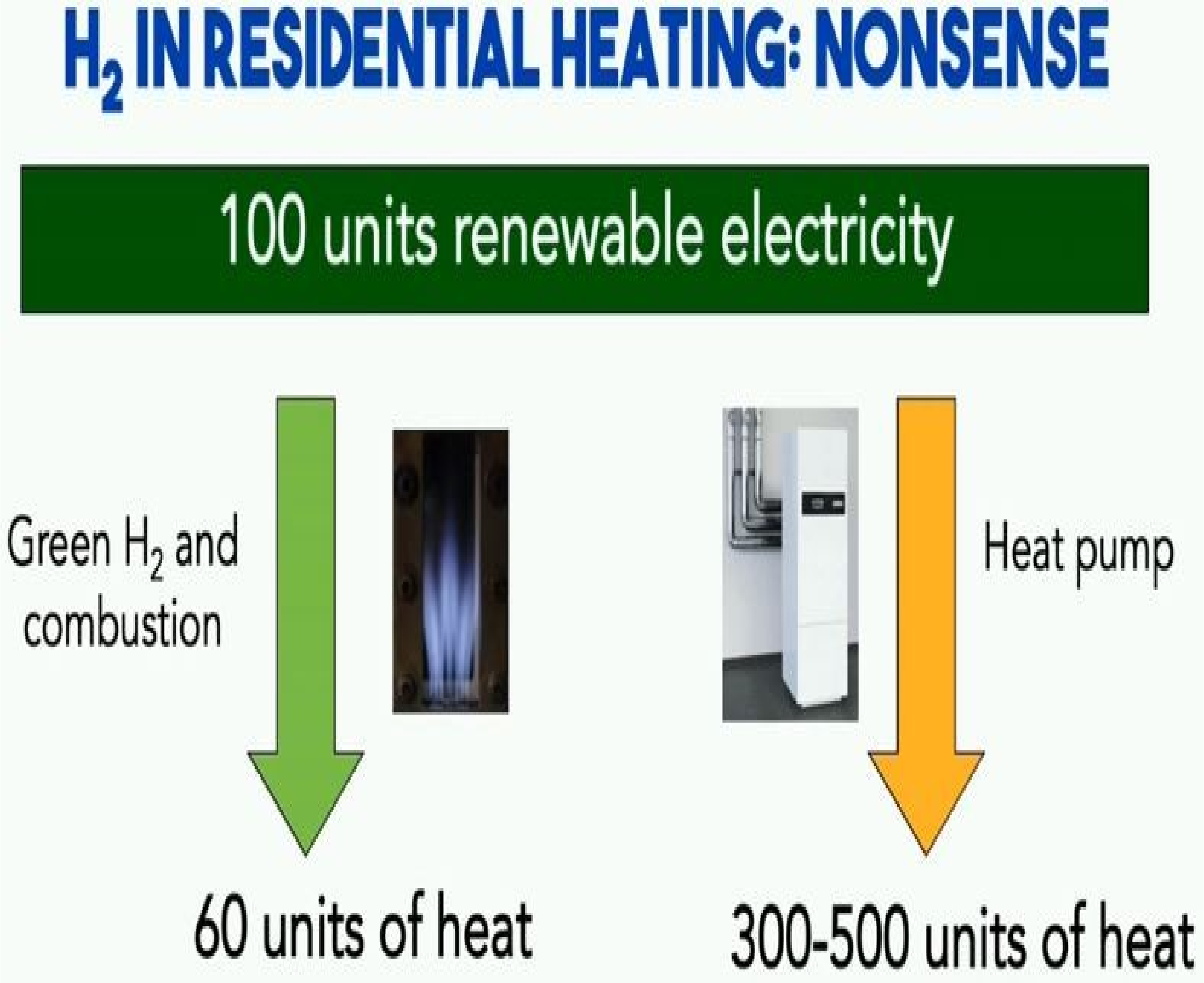


Fig. 42 – *H2 in residential heathing: nonsense*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

How come we get to numbers so much higher than the initial 100 units? You can't create energy from nothing. In fact, the Heat Pump, through the cycles and conversion exchanges that occur inside it - in this case exchanging the energy of the subsoil with the external one - allows this high heating capacity. Basically, it is more energy efficient thanks to this exchange ability - it is no coincidence that they are commonly referred to as heat exchangers - and, as a consequence, it makes no sense to use Hydrogen for this service. It is no coincidence that in the major markets, in the period of the entire year 2021, sales of Heat Pumps are doing rather well, with constant growth in France, in Italy and, first of all, in Poland with the highest diffusion and appreciation results both in Europe and internationally.

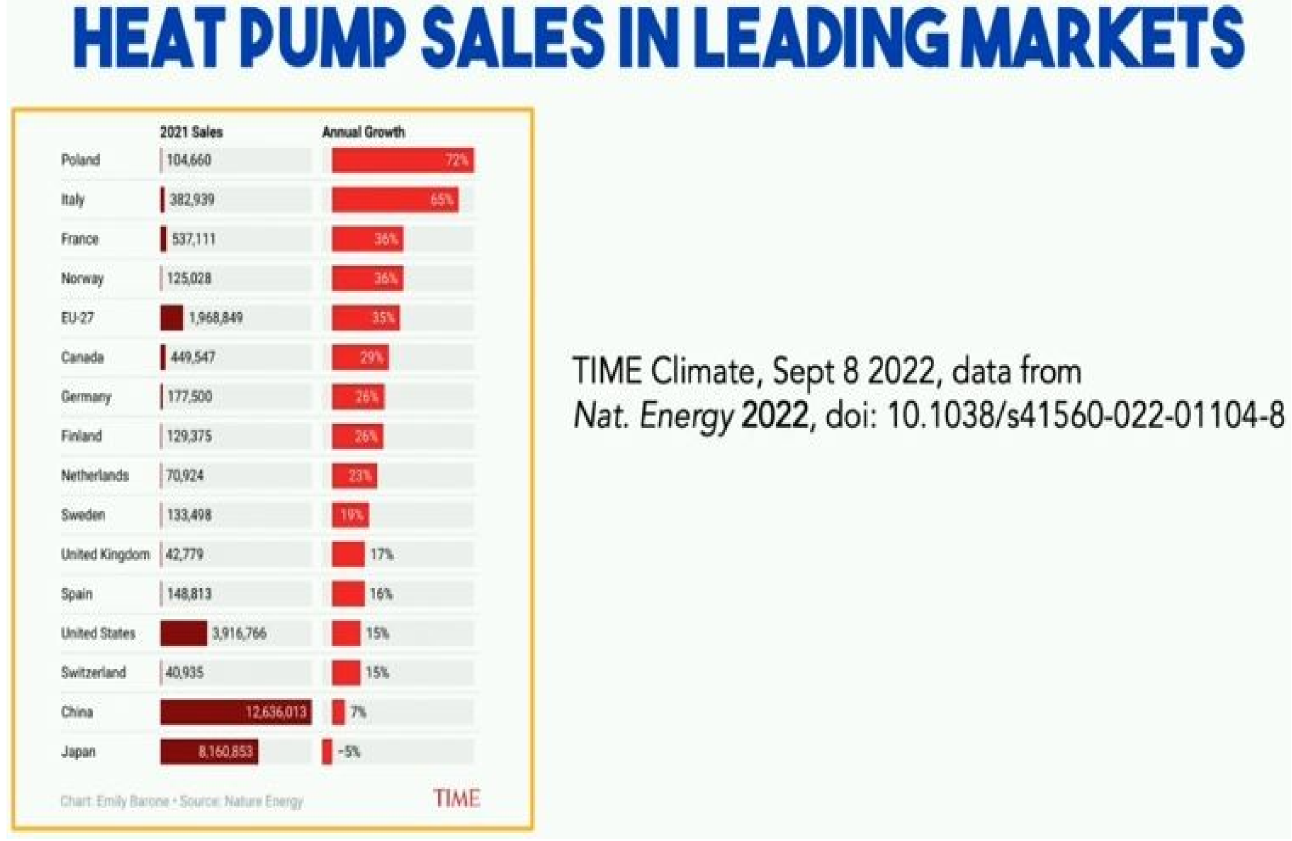


Fig. 43 – *Heat pump sales in leading markets*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Returning to Hydrogen, the molecule can be used differently for daily and seasonal storage and conservation. In fact, if we look at the profile of California in the amount of energy supplied over the course of a day - among the various sources that the State has as a dowry, between polluting sources and clean sources, together with the share that is imported - during the sunny hours, the Photovoltaic systems, installed and in operation, have an excess of energy produced, greater than the requirement required in the West Coast State, and precisely in the hours before and after the stroke of midday. Does it really make sense to waste energy like this, or even reduce production? It would certainly be better to avoid it. With what means and/or uses? The basic idea is to accumulate it and put it aside in often very large batteries - commonly known as accumulators - whose stored energy can be made available again when some intermittent sources, such as Photovoltaic systems, cannot produce energy, that is, in the hours without Sun. Accumulators are therefore a sector to invest in. The other solution is to use this surplus production for the production of Hydrogen, thus reducing the significant energy costs for the production *ex novo* of the molecule, store it - in the safest and most controlled sense of the term - and use it to decarbonize sectors where other clean and renewable sources cannot function as an alternative to polluting fossil fuels.

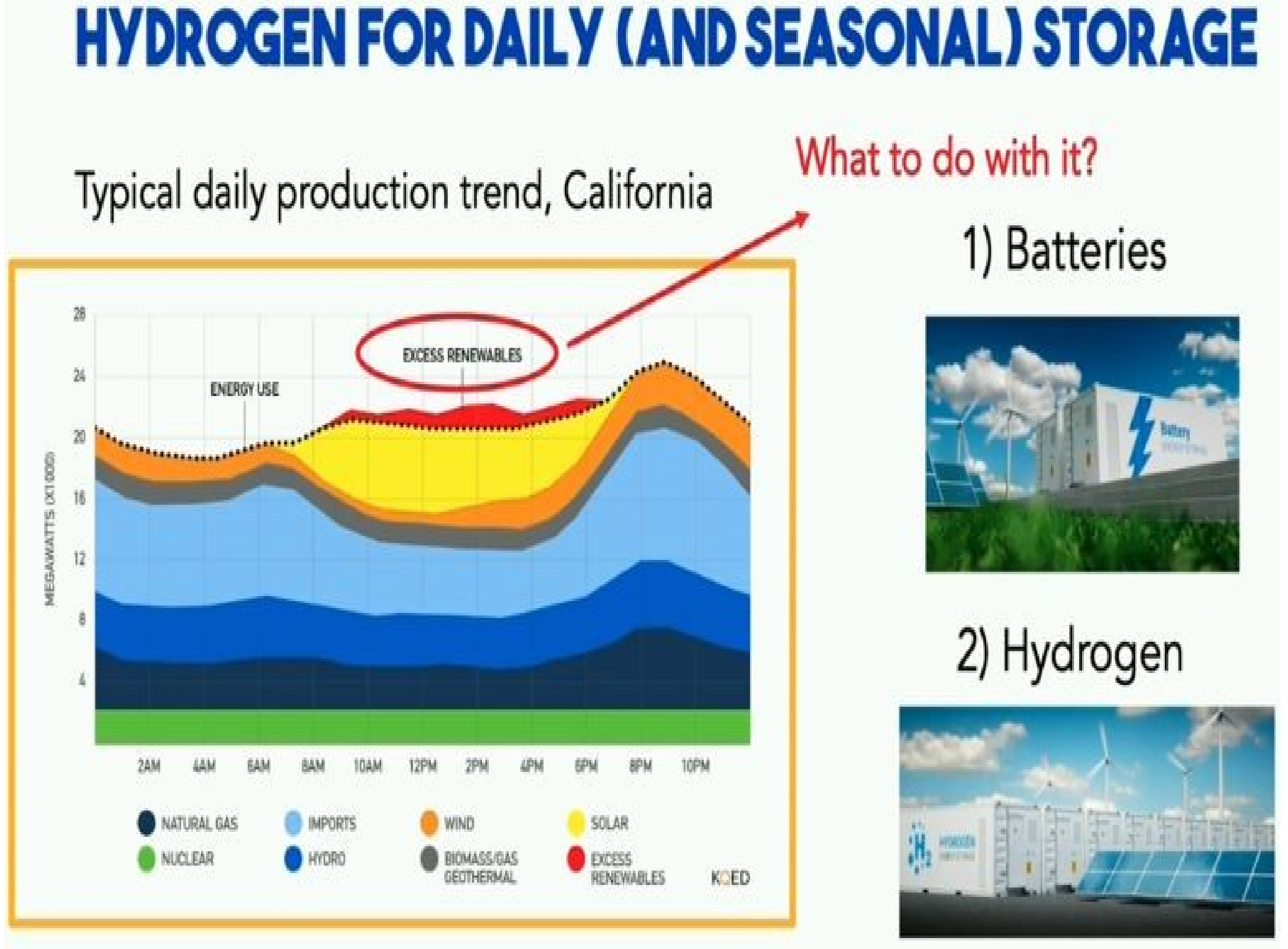


Fig. 44 – *Hydrogen for daily and seasonal storage*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

This is the true and constructive future perspective of Hydrogen, exploiting the energy overproduction of green and recyclable sources. Let's take for example an extremely significant case in Italy: the large steel plant in Taranto. It is the largest existing plant in Europe and has had, and has, very serious health and environmental problems, effects in many administrative and employment areas, for Italy, but above all for the city and the population of Taranto, due to its extremely polluting production. If, in the last twenty years, investments had been planned in the construction of renewable energy plants, first of all Photovoltaic, many of the problems that are gripping Taranto would have been solved.[2] And instead, so much, too much time has been lost. We are behind and there is still a lot of work to do, but if we finally make the appropriate and necessary decisions, both for this problem in particular and for the general context, we can arrive at solutions that were previously unimaginable. It is not a utopia. We can do it, we must do it.

II.II.6 – Can Hydrogen be used to power the transport sector? Analysis and comparison for each type of means and vehicles

On April 22, 2022, the Italian Government produced a report that explains and lists the various forms of power supply for the different types of transport in use.

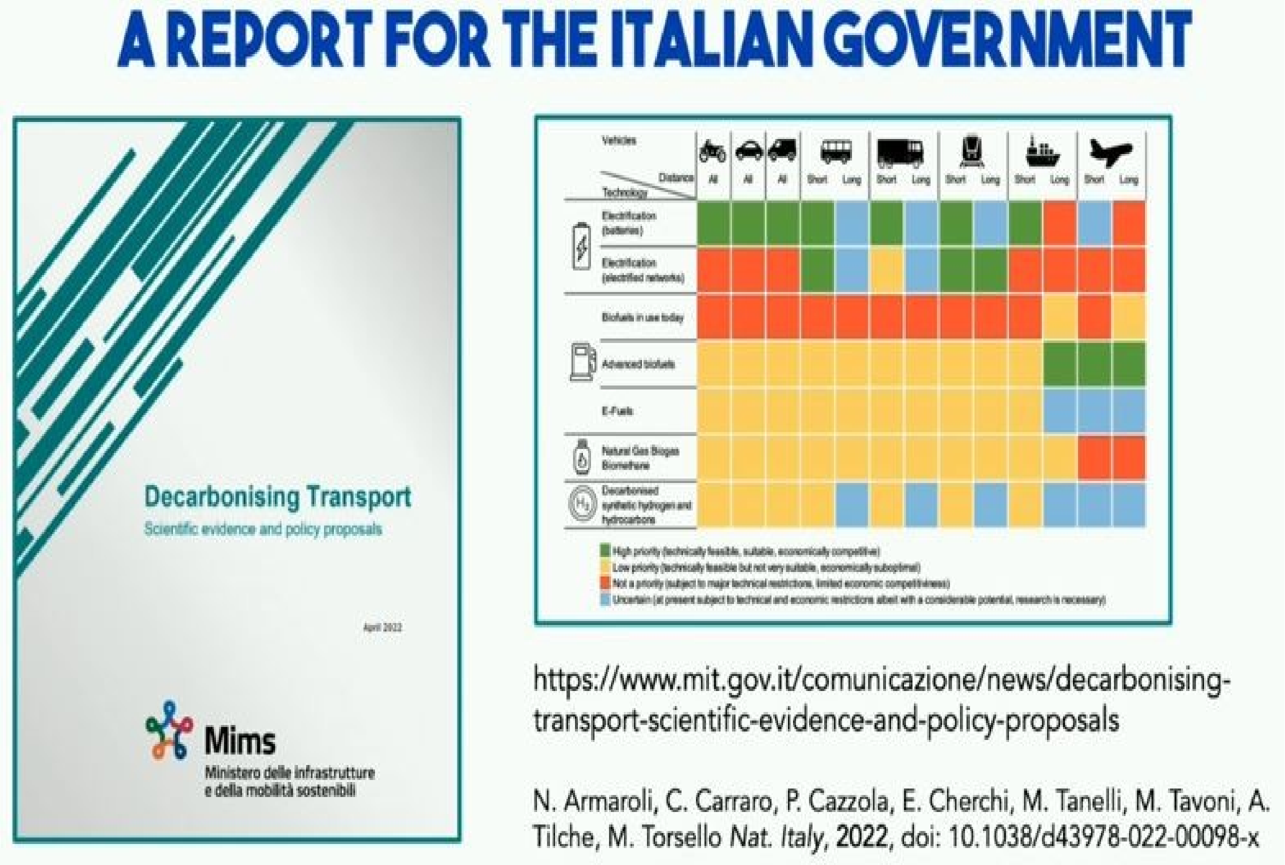


Fig. 45 – *A report for the italian government*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

[2] For more information on this topic regarding the former Ilva of Taranto, please refer to the following article from the scientific journal Nature Italy: https://www.nature.com/articles/d43978-021-00109-3

In this case too, it concerns Italy, but the data and conclusions can be applied to other European countries. In the table taken from the above document, *"Table 4: Assessment of the various technologies for different vehicle types and distances"*, the means of transport are listed, with the scope of their distances, their convenience, as well as the possible and available technologies for their operation. Let's now make some significant comparisons to have a more concrete idea about the complexity and the pros and cons of transport via Hydrogen.

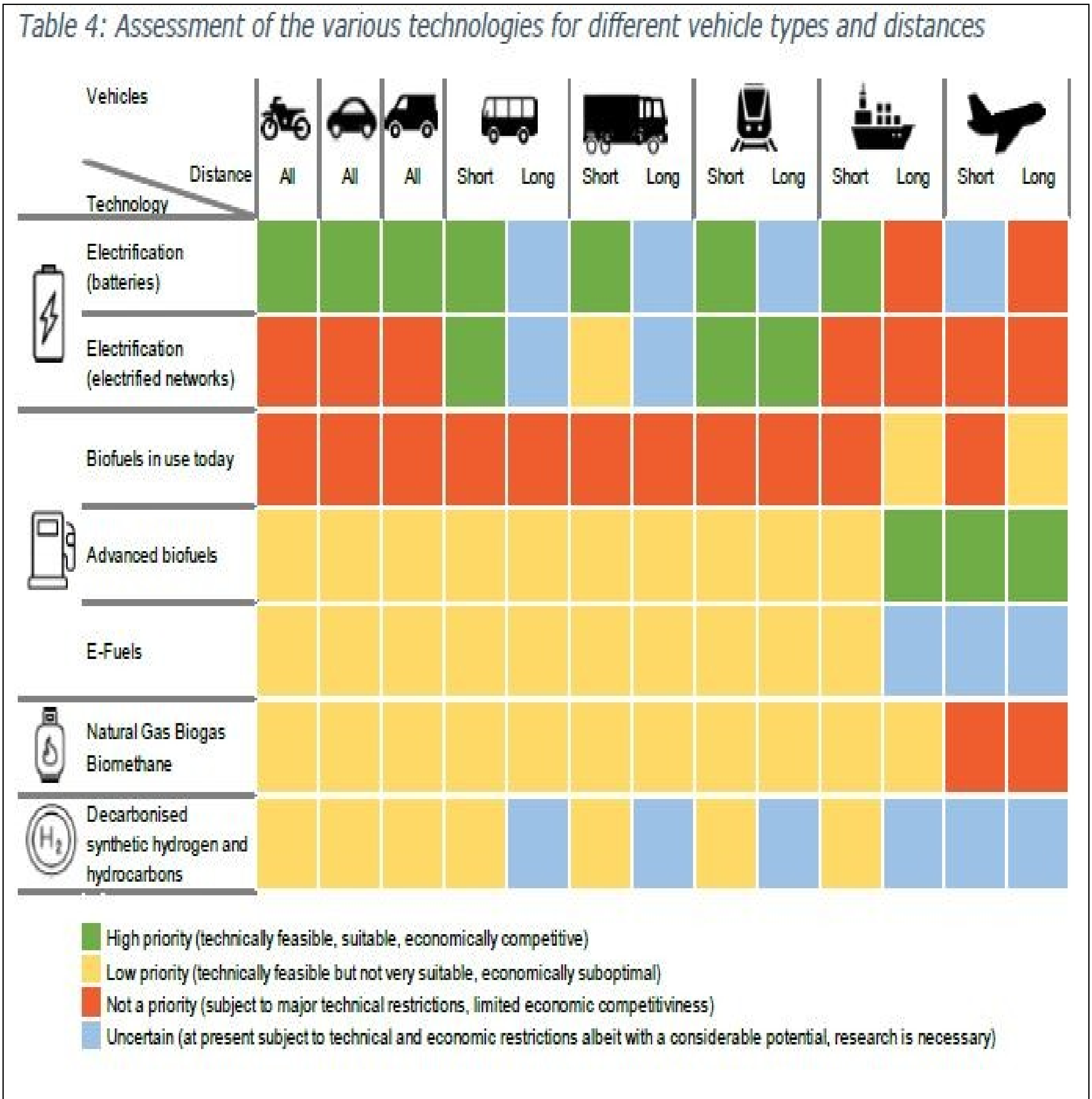


Fig. 46 – *Table 4: Assessment of the various technologies for different vehicle types and distances*, N. Armaroli, C. Carraro, P. Cazzola, E. Cherchi, M. Tanelli, M. Tavoni, A. Tilche, M. Torsello *"Decarbonising Transport - Scientific evidence and policy proposals"*, *Nat. Italy,* 2022, doi: 10.1038/d43978-022-00098-x.

Cars and light and heavy road vehicles.

What is the difference between a Hydrogen vehicle and an electric vehicle? In itself, not that much. In fact, Hydrogen cars are, as we anticipated, operated by Fuel Cells, that is, systems for transforming chemical energy into electrical energy that is then fed into the battery and, from there, into the car's engine. This car, referred to as a Fuel Cell Electric Vehicle (FCEV), is essentially an electric vehicle. It has components and a smaller battery that can be traced back to those of Battery Electric Vehicles (BEV), but also other components such as the 3 cylinders at 700 atmospheres and the oxygen capture system that make it more complicated than electric cars. Another complication: the oxygen it draws must also be purified to be functional for the vehicle. Many of these complications present in the FCEV do not exist in the BEV which is much simpler: a closed system with no capture from the outside, essentially a battery with an engine and wheels.

Fig. 47 – *A Hydrogen vehicle is an electric vehicle*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Let's consider, in Italy, two cars present on the market: the aforementioned Toyota Mirai (FCEV) and the Tesla Model 3 Standard Range + (BEV). The Toyota has a 5.6 kg H2 tank that requires more than 300 kWh to refuel, it has 174 hp, a range of 600 km, a purchase price of €67,000 and a refueling fee of €80, there are very few refueling stations in Italy, only 3. The Tesla, on the other hand, has a 50 kWh battery, 280 hp, a range of 450 km, a purchase price of €57,000 and a recharging fee of €25 that can be done in over 27,000 public charging stations or even in the home garage.

Fig. 48 – *A quick comparison of FCEV vs. BEV models*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Even more, making a technical comparison between FCEV and BEV light vehicles - even if they share the starting point, the production of electricity from renewable sources, and the end of the process, the electric motor - the intermediate processes are much more for the FCEV and with a greater inefficiency. In the BEV, the energy, after being produced, only needs to be transported, via transmission cables, and charged into the high-capacity battery. In the FCEV, after the energy has been produced it must be used to produce Hydrogen, compress it, liquefy it, transport it, consume it by burning it to transform it back into electricity to charge its low-capacity battery.

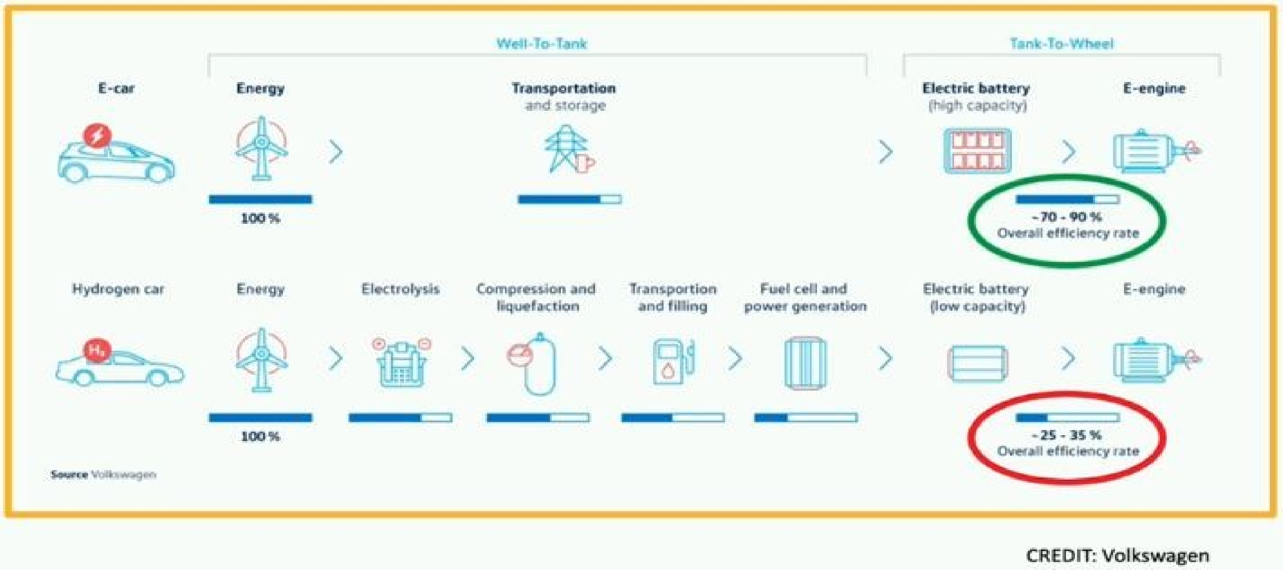


Fig. 49 – *Light duty vehicle, BEV vs. FCEV*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Figure 1: Efficiency comparison between electric vehicles and hydrogen Well-To-Tank and Tank-To-Wheel. Revision based on Volkswagen infographics - [Link]

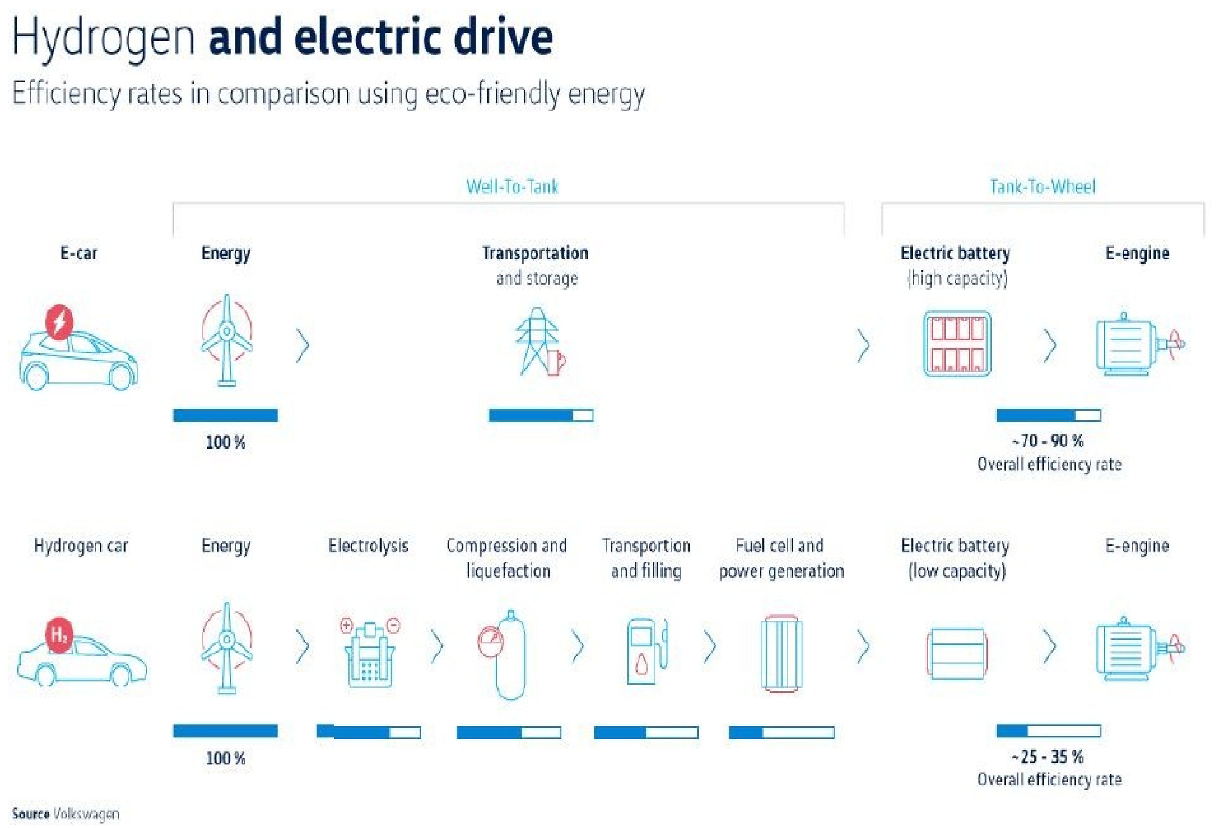


Fig. 50 – *Hydrogen and electric drive*, N. Armaroli, C. Carraro, P. Cazzola, E. Cherchi, M. Tanelli, M. Tavoni, A. Tilche, M. Torsello *"Decarbonising Transport - Scientific evidence and policy proposals"*, *Nat. Italy,* 2022, doi: 10.1038/d43978-022-00098-x.

The point is that, in the end, the overall efficiency rate: for the BEV it is between 70-90%, while for the FCEV it is only 25-35%. Therefore, to travel a distance of a given number of kilometers, a BEV, a battery-powered car, compared to the now anachronistic internal combustion cars, consumes 4 times less, while FCEVs consume 3 times less. Therefore, despite the fact that 12,000 Hydrogen cars were sold in 2022, a truly small number on a global scale, there is not a huge difference between combustion cars and Hydrogen cars. The latter are better, but not with such a large improvement, so switching from the former to the latter is not a real gain in terms of efficiency. Battery-powered electric cars therefore remain the best option in the light vehicle sector.

As for heavy vehicles such as high-capacity commercial vehicles, the issues become significantly more complex. First of all, Hydrogen is in good company. In fact, in addition to the molecule, there are several other possibilities: the aforementioned batteries, Biofuels and synthetic fuels.

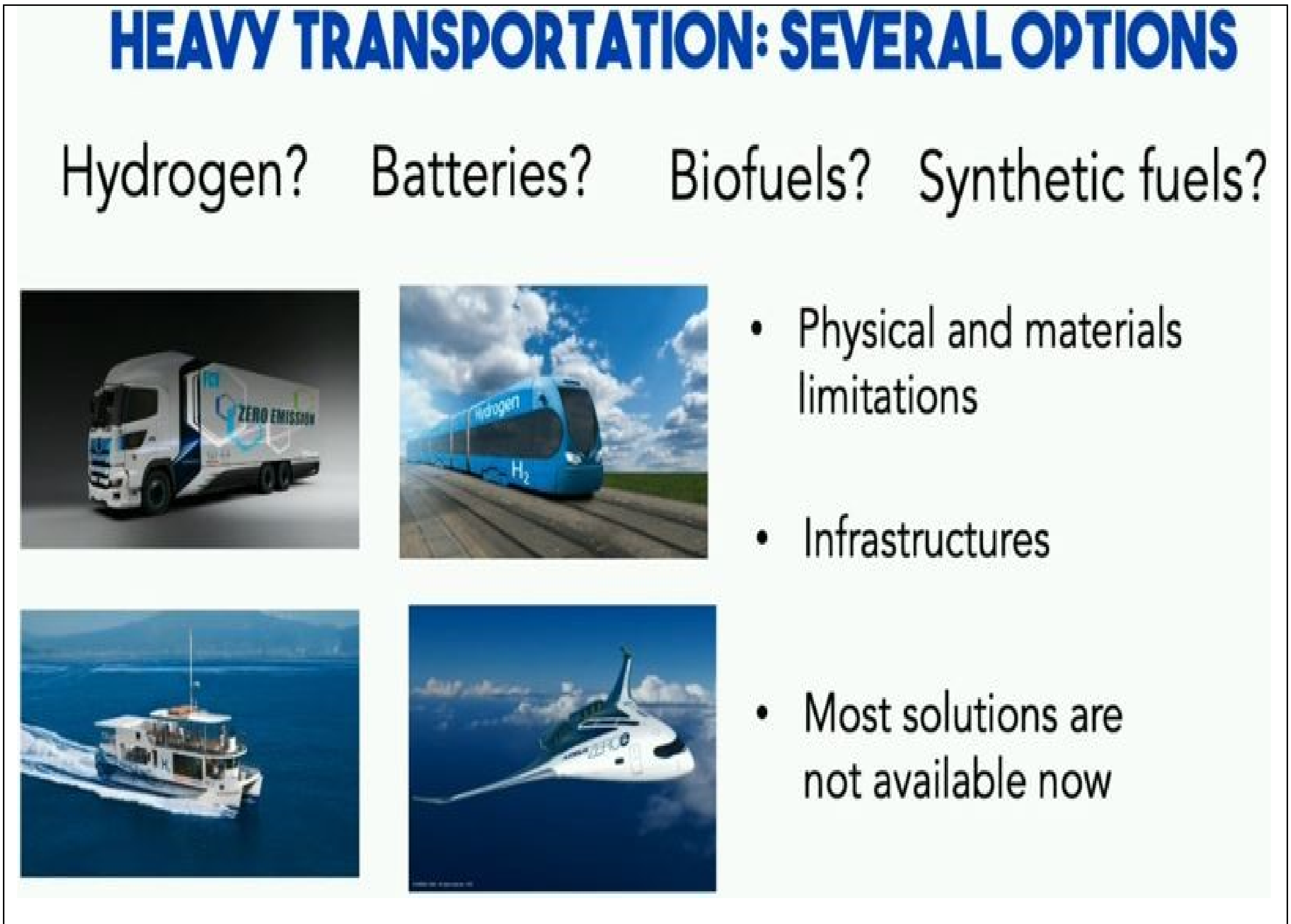


Fig. 51 – *Heavy transportation: several options*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Trying to summarize, these heavy means of transport are affected by material and physical limitations: how bulky can a battery be for trucks/lorries/buses etc.? And a Fuel Cell for trains? Perhaps too much for their current functionality and manageability. There are in fact infrastructural problems: lack of high-power charging stations, almost no hydrogen refueling facilities and, finally, the impossibility of using them, to date, in various means, such as the hydrogen airplane which is still under development.

As regards public transport, buses first and foremost, the main options available today are three: hydrogen, battery or non-polluting fuels, biological or synthetic fuels.

Fig. 52 – *Public transportation, several options on the market*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

But there is a prevalence among these: electric buses. Even in this case, battery-powered vehicles demonstrate better performance and efficiency. An example above all is that of the French city of Montpellier, where the municipality has cancelled a contract for the purchase of Hydrogen buses, replacing them with their battery-powered versions, since the cost of vehicles powered by the molecule would have been excessive, 6 times higher.

Fig. 53 – *Battery option tends to prevail the case of Montpellier*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

What is the situation for trucks/lorries? The choice here would again be between hydrogen trucks and battery trucks. According to a study by German researcher and author Patrick Plötz, here too there is too little margin for hydrogen vehicles and the electrified solution remains better from all points of view, although still being improved and perfected. It should be noted, however, that there is already an alternative solution for land transport of goods, similar to transport via the classic truck as we know it. We are talking about electric trains, sophisticated, functional and increasingly improved, and also, in perspective, alternative solutions for the electrification of motorways: such as "wired trolley trucks" powered by electricity via special electrical conduits of the infrastructure network, as happens with city trolleybuses.

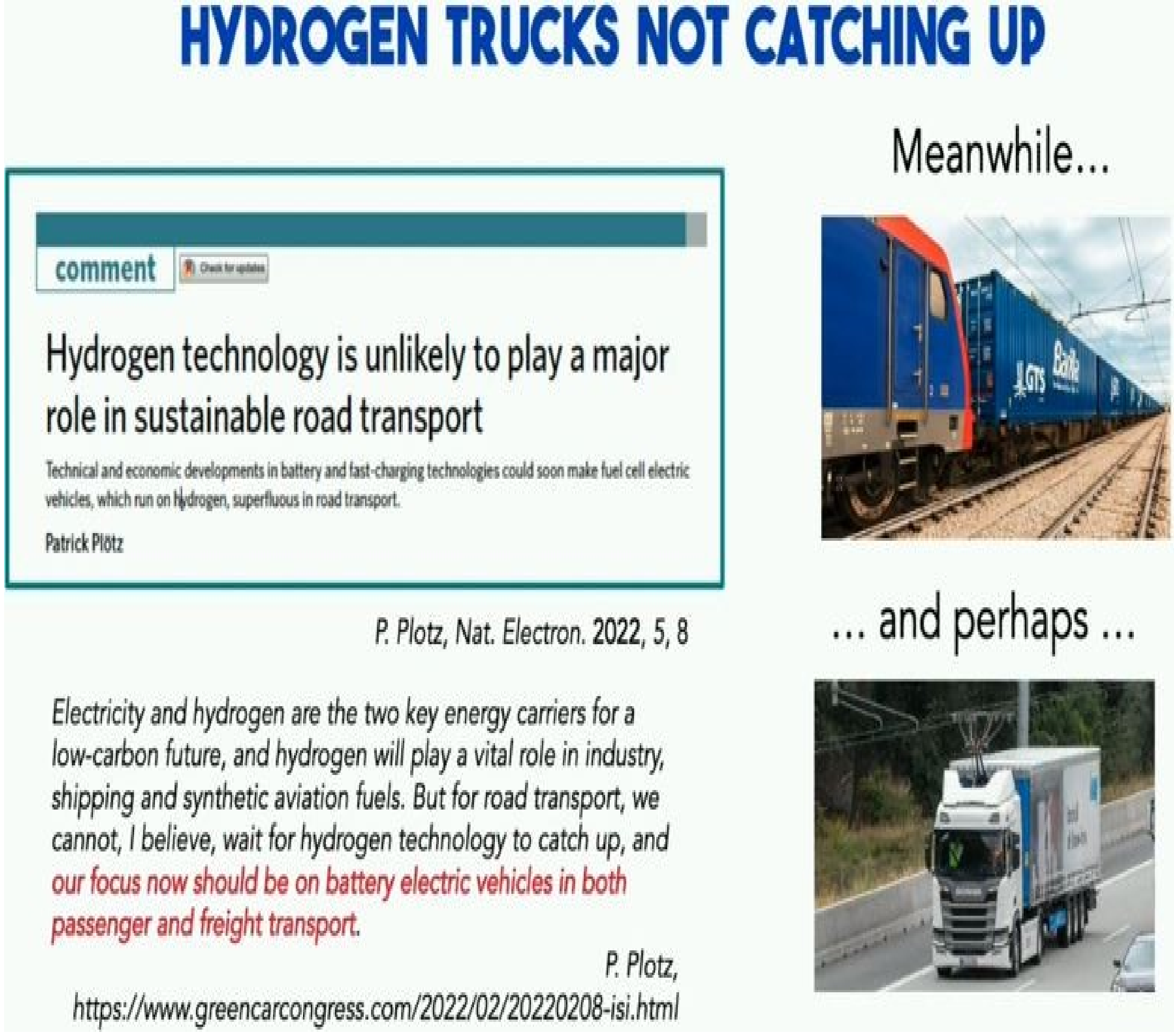


Fig. 54 – *Hydrogen trucks not catching up*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

We have mentioned trains and rail transport, let's also delve into this sector.

In Europe there are thousands of kilometers of non-electrified railway networks, in Italy there are still 5,000 km of railways without electrification, but, despite this, inevitably even in this category of transport, hydrogen-powered vehicles must compete with those powered by electricity. Hydrogen insight, a magazine focused on hydrogen, reported that according to a study commissioned by the State of the Federal Republic of Germany of Baden-Württemberg, hydrogen trains are not a valid and economically convenient option as they have an overall cost, compared to electric trains already in use, higher by as much as 80%.

Fig. 55 – *Both Hydrogen and battery trains available*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Having made these initial comparisons, it appears clear that Hydrogen does not seem to be ready and in order as regards the land transport sector in general.

Maritime vessels.

As far as ships and shipping are concerned, as long as you are dealing with small speedboats and boats, you have no problems. But when you are dealing with massive vessels for the transport of containers and goods for trade and cruise ships for the transport of passengers, things get much more difficult.

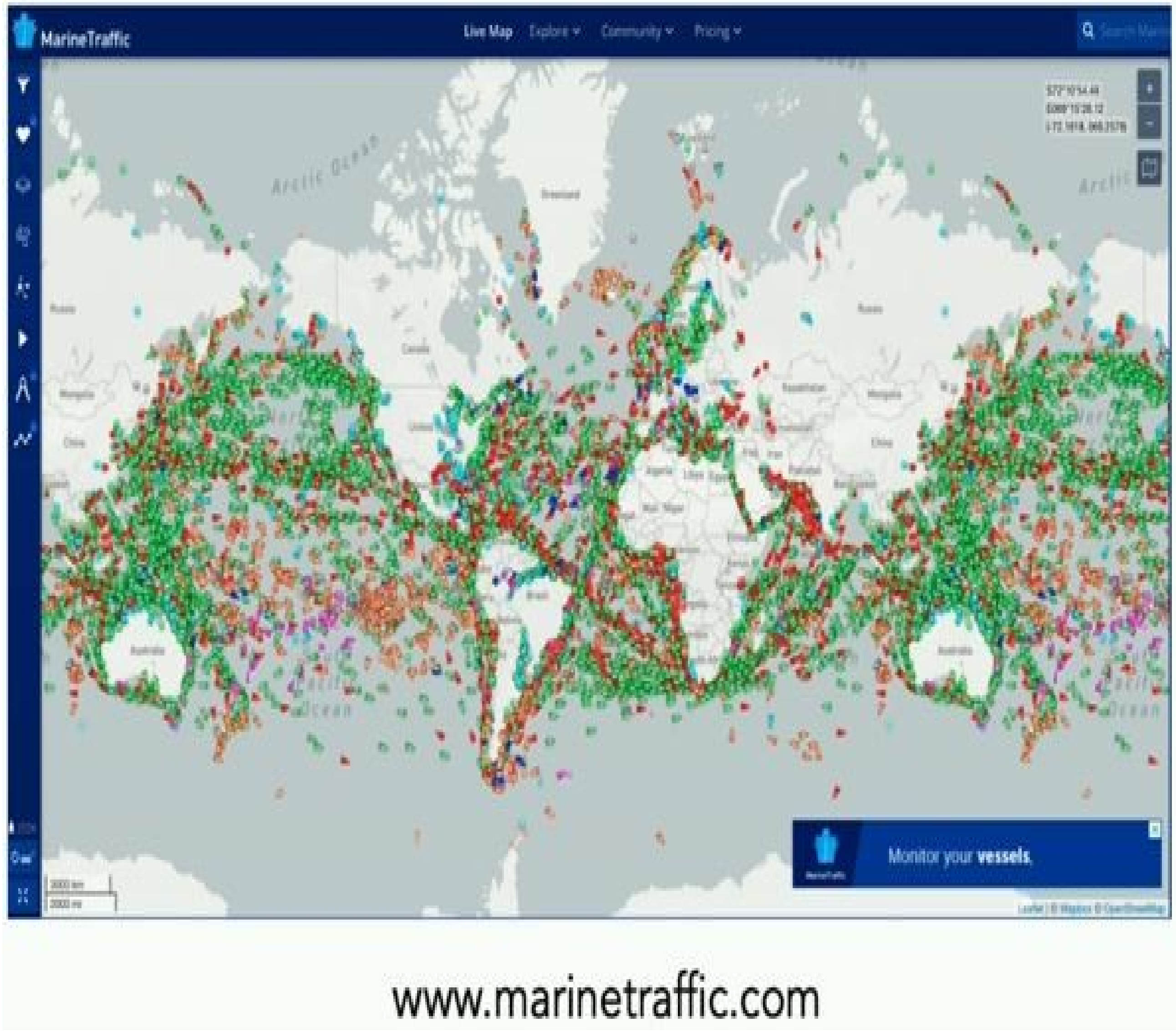


Fig. 56 – *Global shipping, we have a problem*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Let's make a quick and direct assessment and consideration of these difficulties. Let's take for example the container ship that a few years ago, due to a strong wind flow and the driving errors of the crew that was steering it, ran aground inside the Suez Canal blocking maritime traffic for days, causing an increase in the prices of many raw materials and consumer goods and delays in the production chains of various important companies. That gigantic commercial vessel can transport something like 220,000 tons of materials and goods arriving from China to Europe, loading its cargo, for example in Shanghai and, after 30/40 days of navigation, unloading their cargo in the large logistics ports of our continent such as Rotterdam and Genoa. It is a truly long journey.

How much fuel can a ship like that consume and burn for just one of these trips? A monstrosity. A single trip consumes 9,000 tons of Heavy Fuel Oil O.P.C., and let's not even talk about its emissions, which, even more, would be multiplied by the countless vessels, commercial and otherwise, that circulate the oceans of the entire globe every day. If we wanted to replace conventional vessels, changing all the ships with a version powered by Hydrogen, it would be necessary to power them, in order to travel the same trip, 3,000 tons of liquefied Hydrogen. Not gaseous, liquefied. At first glance, one might think that this is still a significant advantage since the fuel required is quantitatively lower (3,000 tons H_2 < 9,000 tons O.C.P.). However, the problem should not be seen so much in the numerical quantity, but in the volumetric quality or energy density. Here is the problem, because Hydrogen has a very low energy density per volume and therefore each ship would need a tank twice as large as that for the container ships currently in operation via O.C.P.. And that's not all for large-capacity and long-distance maritime shipments. In addition to what has been illustrated, it should also be added that the molecule, always with the Green mode, must be transformed from a gaseous state to a liquefied state, with the consequent consumption of 150 GWh of electricity, then maintaining it, for the 30/40 days of the duration of the entire crossing, at a temperature of -253°C, consuming for these processes not insignificant quantities of energy. These 150 GWh of electricity to produce this large quantity of Hydrogen are anything but small. Making another important comparison of the masses involved, the largest Electrolyzer in the world, present in Japan and more precisely, not by chance, in Fukushima, produces 10 MW of Hydrogen through a 20 MW photovoltaic park that occupies a space of about 18 hectares, equivalent to 26 football fields. But here we are talking about MW and to supply a large container ship we need GW of energy quantity in Hydrogen. Furthermore, with a plant equal to the largest in the world, like the one present in Fukushima, 3 years of uninterrupted operation are needed to produce the quantity of Hydrogen necessary to supply a single trip of a large cargo ship from Asia to Europe. Truly enormous numbers, a real brain teaser.

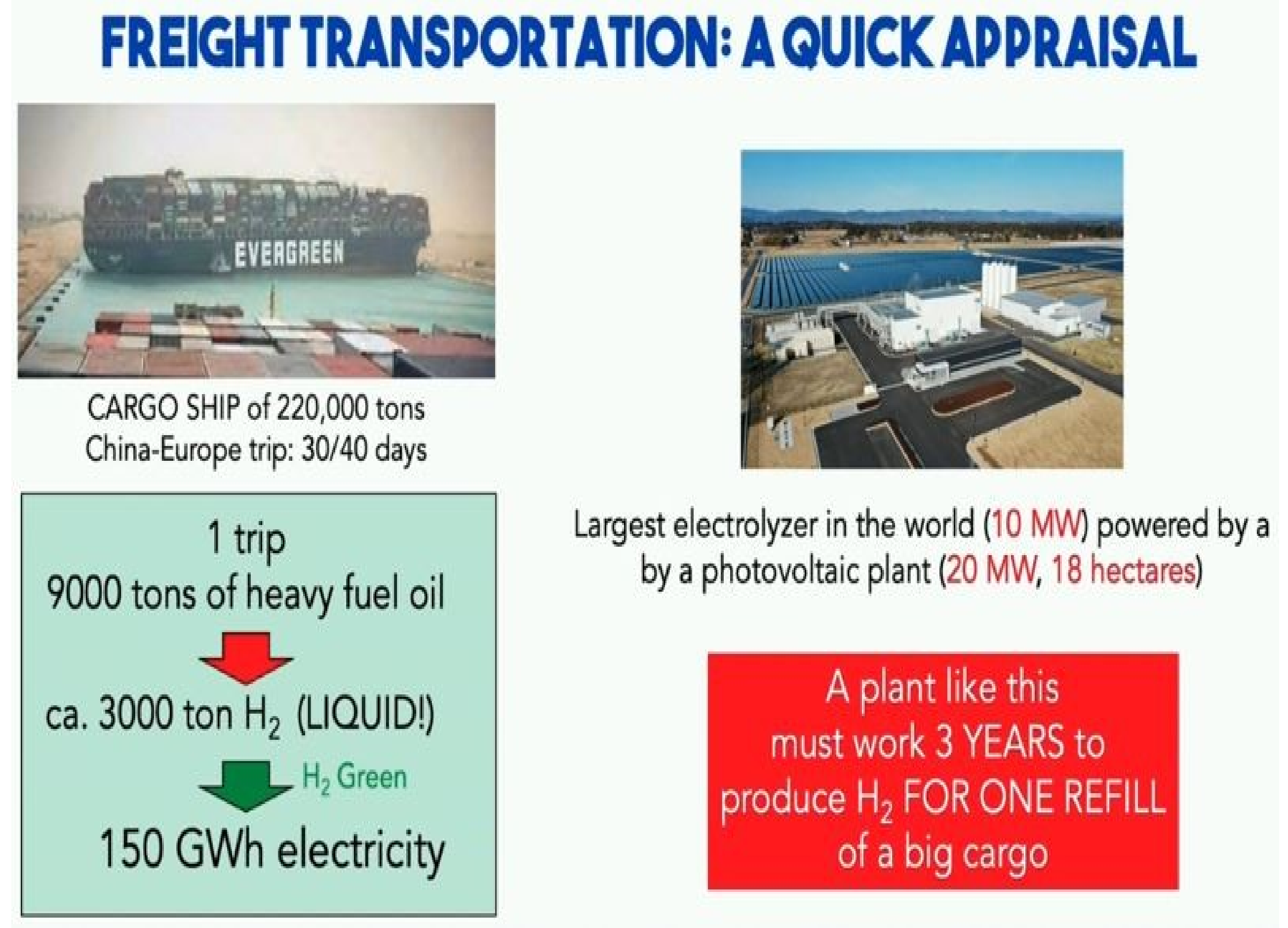


Fig. 57 – *Freight transportation: a quick appraisal*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

At this point, a crucial distinction must be made between the energy transition and the ecological transition/conversion/transformation, where the debate is more open than ever. What would be the substantial difference? In this context, to achieve the energy transition it should be enough, for example, to replace the diesel engine of boats with an engine running on an alternative non-polluting fuel and, incidentally, many of the replacement fuels are not present and available as they are still in the research and development phase. Since it is so complicated and problematic to make this substitution, it becomes necessary to aim for a direct ecological transition on this point. After all, our ultimate goal is to achieve, not so much an energy transition in and of itself, but an ecological transition through the energy one. The real goal, in the end, is this, and the way to reach and obtain it must be functional to it. For this reason, in this specific case, the dilemma is: must we necessarily reconsider, either partially or totally, the localization and/or delocalization of industrial production? This is the question we must ask ourselves given that many goods are made in other countries, often quite far away like China, for the simple fact that it is more economically convenient, ending up underestimating and then suffering the consequences of external problems like global warming, which calls everything into question. Let it be clear, acting in this way has and also had valid reasons, but today with the climate crisis it is necessary to completely change register. In fact, at the end of the day, to truly achieve the much discussed ecological transition what really needs to change is the system. The economy and human activities as we know them are not environmentally sustainable, the commercial maritime transport system that has been created is totally unsustainable. This is the incontrovertible truth that no one wants to consider. This is the real sensitive topic.

Fig. 58 – *Just an energy or an ecological transition?*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Hydrogen airplanes and aircraft.

Nowadays, a fuel that is nothing short of excellent is used for airplanes: JET A/A-1, or Kerosene. This fuel has a high energy density rate, remains in a state of liquefaction at -47°C, thanks also to the very cold temperatures present in the atmosphere, and allows flights and air routes without stops with a flight duration of more than 20 hours. For these reasons, it is really difficult to replace Kerosene for this transport sector, and it is quite unlikely to replace it with Hydrogen or even with batteries especially for long-range flights. This is given for several reasons, including issues of weight, volume and Earth's gravity.

Fig. 59 – *We use a fantastic liquid fuel…*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

A realistic solution to replace Kerosene, which is a very efficient but still polluting and harmful source, exists: liquid fuels derived from waste labelled and reported as *Sustainable Aviation Fuels* (SAF). Combustible liquids will have to be used, which must necessarily be clean and sustainable. How can these liquid fuels be created? Two fundamental elements are needed: Carbon CO and Hydrogen H2. Hydrogen and its production will therefore be fundamental to create the SAFs necessary for the future of aviation and for the sectors where sustainable fuels can serve the energy transition. Therefore, (Green) Hydrogen will be needed, but together with it, also sustainable

Carbon, which means organic waste, waste from agriculture, forests, the food sector, garbage and solid urban and municipal waste that will be synthesized through the process *Fischer-Tropsch Synthesis*. This process is carried out with the following procedure: organic waste is transformed, CO+H2 synthesis gas is produced and, through the *Fischer-Tropsch Synthesis*, thus creating SAF, which must be mixed with fossil fuel for jet fuel. Nowadays, however, SAF can only be mixed on a 50:50 scale, given international regulations, with conventional jet fuel. Furthermore, despite the fact that almost thirty years have passed, less than 0.1% of the fuel used by aircraft globally is attributable to SAF. Practically nothing and in fact among the types of transport the aircraft sector is among the most polluting in the world. Greater efforts in research and development, more significant and credible investments, as well as more enlightened and far-sighted legislation will therefore be necessary to achieve greater sustainability in this sector too.

Fig. 60 – *Realistic solution: liquid fuels from waste*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

In summary, where would Hydrogen be appropriate and relevant in the energy transition? It would be absolutely functional for sectors with very high temperature heat, that is, for types of heavy industries such as cement factories and the aforementioned steel mills, and also for heavy transport sectors, with necessary changes. Hydrogen is absolutely necessary as an intermediary for liquid fuels.

About liquid fuels, it is essential to make a further comment. E-fuels, that is, liquid fuels derived from electricity, are exactly that: fuels derived from electricity, and as such they work as we know them. The issue, even for this type of alternative fuel and system, is that they are still in a preliminary stage of development when compared to general demand; so far, there is, as a noteworthy structure, the Porsche “Haru Oni” pilot plant in Punta Arenas, in the Chilean desert. We are still in a remote phase with respect to large industrial production and this is also due to the various problems they present. E-fuels must solve the following problems: finding Carbon and Hydrogen as basic raw materials. Then to generate E-fuels, the so-called hydrocarbons are needed, which are obtained by combining these two molecules and a technology must be developed for this. The right energy and economic balance must be found and finally the impact on the ecosystem must be verified, commonly measured as the ecological footprint of a measure or activity. Furthermore, it must be highlighted that there is no improvement in this type of fuel in terms of engine efficiency. It remains substantially the same type in use today and, therefore, with a waste of the energy used, or rather of the E-fuels that we are trying to create, of a good 75% compared to that actually pumped into the engine and wheels, just as happens with old fuels such as petrol, diesel, LPG etc. In addition to this, it should also be noted that E-fuels do not bring progress and development even in the quality of air in cities and urban areas, they practically pollute in the same way as the fossil fuels that they are trying to replace.

This is as far as E-fuels are concerned, but similar considerations also apply to Biofuels, the much debated fuels derived from crops produced and from agricultural waste.

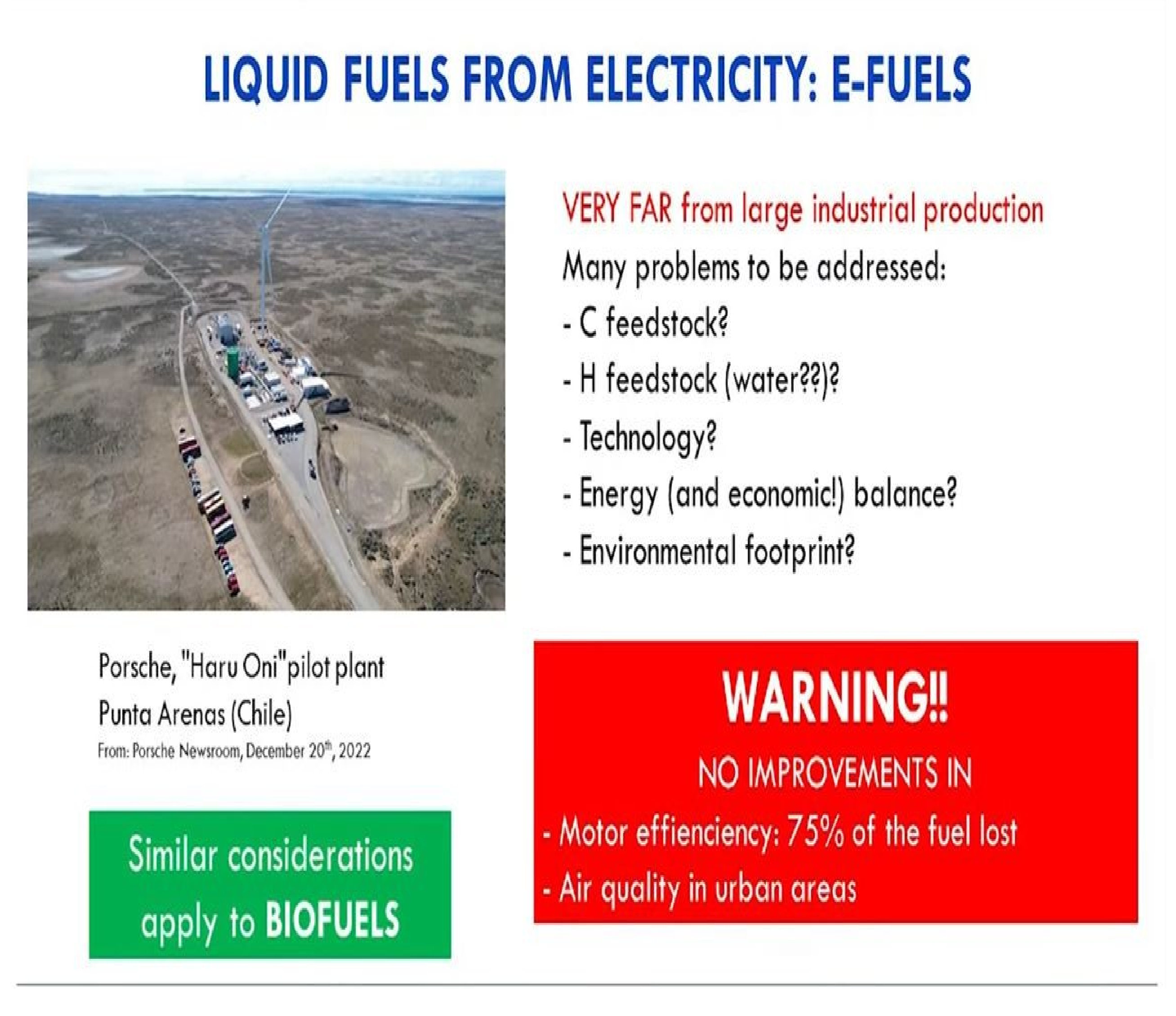


Fig. 61 – *Liquid fuels from electricity: E-fuels*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

II.II.7 – What are the interventions and policies that can be adopted by the States? The case study of Italy

After having illustrated the situations and the progress made and still to be made to reach the goal of energy transition and decarbonization both from the point of view of machines and technologies, and of the areas and multiple sectors, we come to deal, with different data and ideas, with what is being done in different countries. On September 9, 2021, scientists, researchers and scholars Nicola Armaroli and Andrea Barbieri carried out a study to reason and evaluate how much and how Italy should invest in Hydrogen.


COMMENT | 09 September 2021

The hydrogen dilemma in Italy's energy transition

Scaling up 'green hydrogen' production in Italy and other industrialized countries may clash with the goal of decarbonizing the electricity system by 2030.

Nicola Armaroli & Andrea Barbieri

Nature Italy 2021, DOI: 10.1038/d43978-021-00109-3

Fig. 62 – *The Hydrogen dilemma in Italy's energy transition*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

For what purpose? With what objectives and concrete possibilities? The purposes of this analysis are multiple and not indifferent: to identify a minimum use of Green Hydrogen for Italy by 2030, to evaluate requirements such as territory, Water, electricity, to estimate the Electrolysers necessary and feasible to achieve the completion of these works and, finally, to evaluate the resulting results by comparing them with the renewable electricity objectives indicated by the European Union.

Fig. 63 – *Scope of the analysis*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

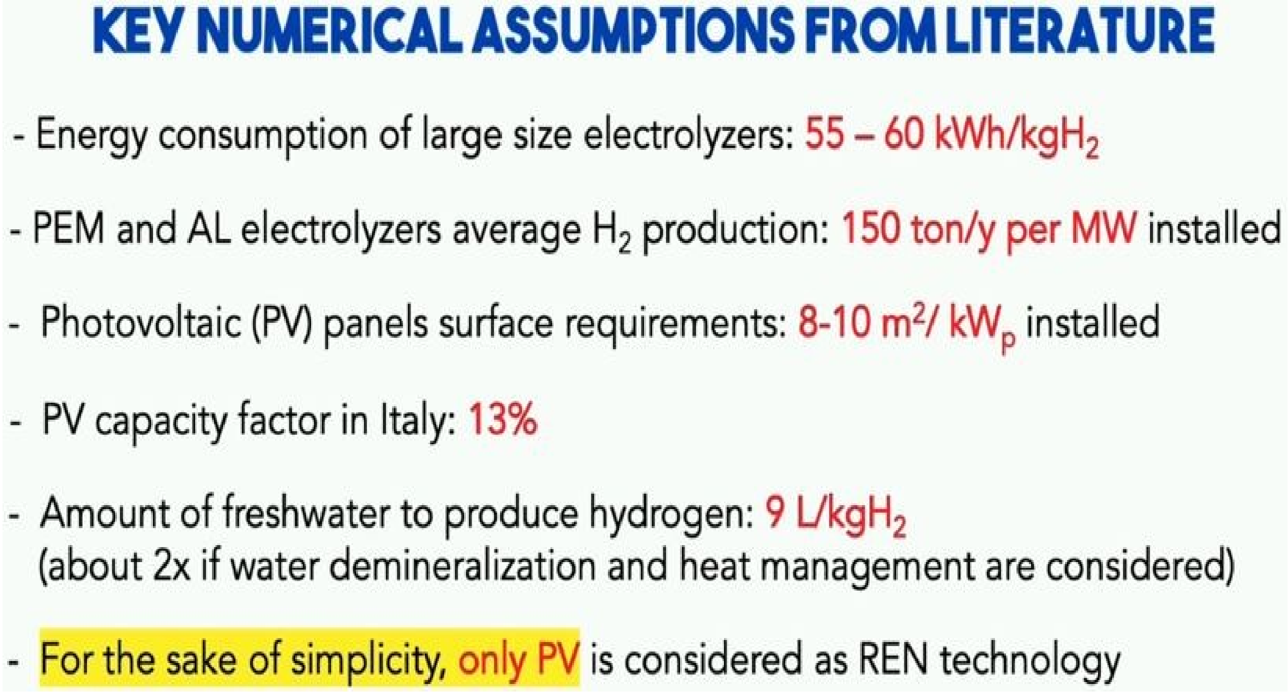


Fig. 64 – *Key numerical assumptions from literature*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Skipping the hypotheses of the study, present in the figure above and citing only Photovoltaic as a renewable source - we arrive at the central element of the study. With this study three objectives have been taken into consideration to be achieved by 2030 with which a national production of Hydrogen is realistic and sustainable. The first is to convert and replace a considerable part of the Grey Hydrogen, still in production, with Green production deriving from renewable sources, arriving at achieving as Green Hydrogen +0.48 Megatons per year. The second is to decarbonize and clean up steel production through blast furnaces, as in the case of Taranto, where the energy production need stands at 6 Megatons per year, in which case arriving at increasing the rate of the molecule to +0.3 Megatons per year. Third and last objective, based on the plan of the document of the Italian Government (*"Decarbonising Transport - Scientific evidence and policy proposals"*), increase the energy production supply to satisfy and cover the national demand by 2%, with a growth in H2 production of +0.85 Mega Tons per year. In conclusion, overall the production of Green Hydrogen to be increased in Italy is +1.6 Mega Tons per year by the end of the decade. Is it possible and realistic to reach this overall figure?

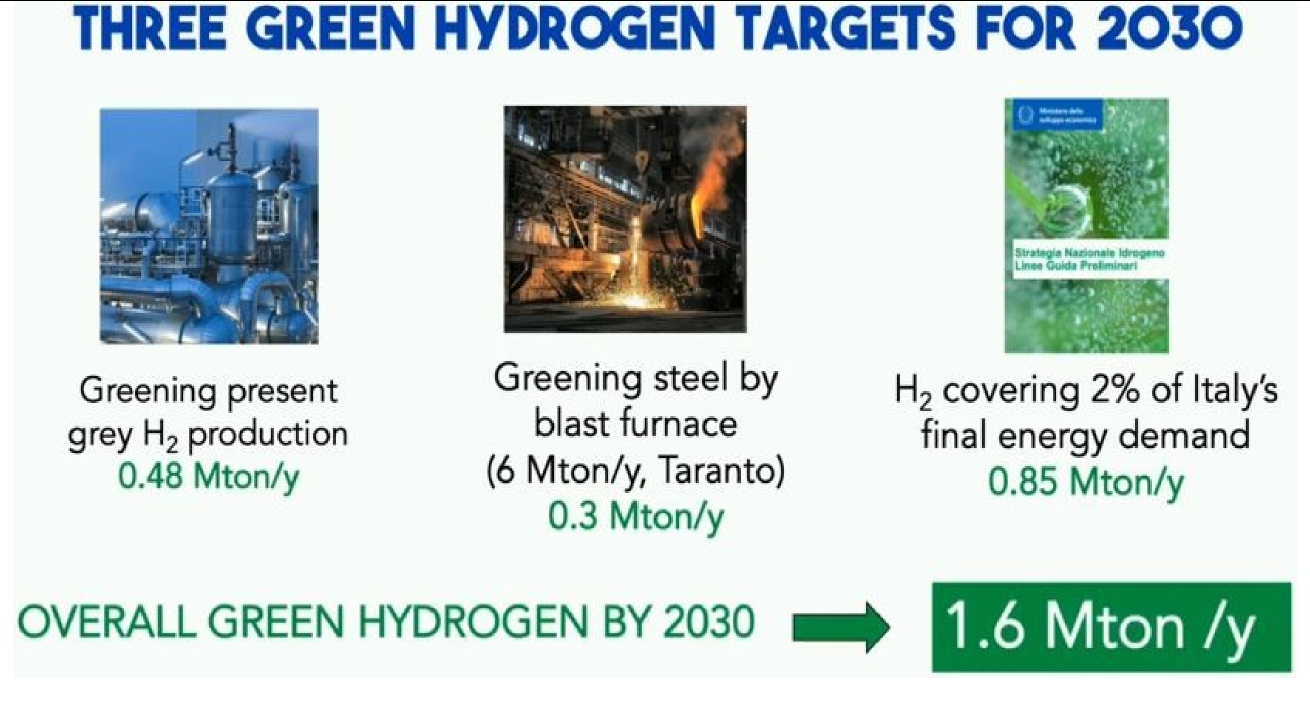


Fig. 65 – *Three green Hydrogen targets for 2030*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

To reach this substantial amount of Hydrogen, 85 TWh of electricity per year are needed. From a practical point of view, this involves several ideas to take into account. It is necessary to increase the capacity of Italian electrolysers to 10 GW and at a community level the goal has been set to exceed 80 GW of this energy form by 2030. The thing that immediately catches the eye with respect to the European community goal is that this would require a rather intense effort for a single member state but this, with effective policies, careful financing and an organization worthy of the name, makes it an obstacle that is far from insurmountable. From the point of view of space for this production, between 600 and 750 square kilometers of spatial extension would be necessary to install, more than anything else, the Photovoltaic systems for the production of energy with which to power and operate the Electrolysers together with the entire functional apparatus. It seems like a huge amount but this extension is equivalent to less than 1% of the abandoned lands and unused suitable territories. It is therefore to be considered as absolutely feasible. In addition to electricity, Water is also needed in considerable quantities. In absolute terms, the H2O needed is 30 Megametric tubes, which would seem like a lot. But even in this case, the data and information must be evaluated in relative terms. In fact, these 30 Megametric tubes are equivalent to 0.4% of the overall use of Water for industrial purposes and activities in Italy. Nothing prohibitive therefore, this too is fully feasible. We now come to the last point, perhaps the real crux of this entire plan. How much electricity should be produced through photovoltaic systems? The share here is mammoth: 75 GW of electricity from photovoltaic, which is equivalent to 3.5 times more than the current energy production installed in Italy and which must be dedicated entirely to this destination aimed at creating green hydrogen in the country. A truly impressive figure. So, how to do it?

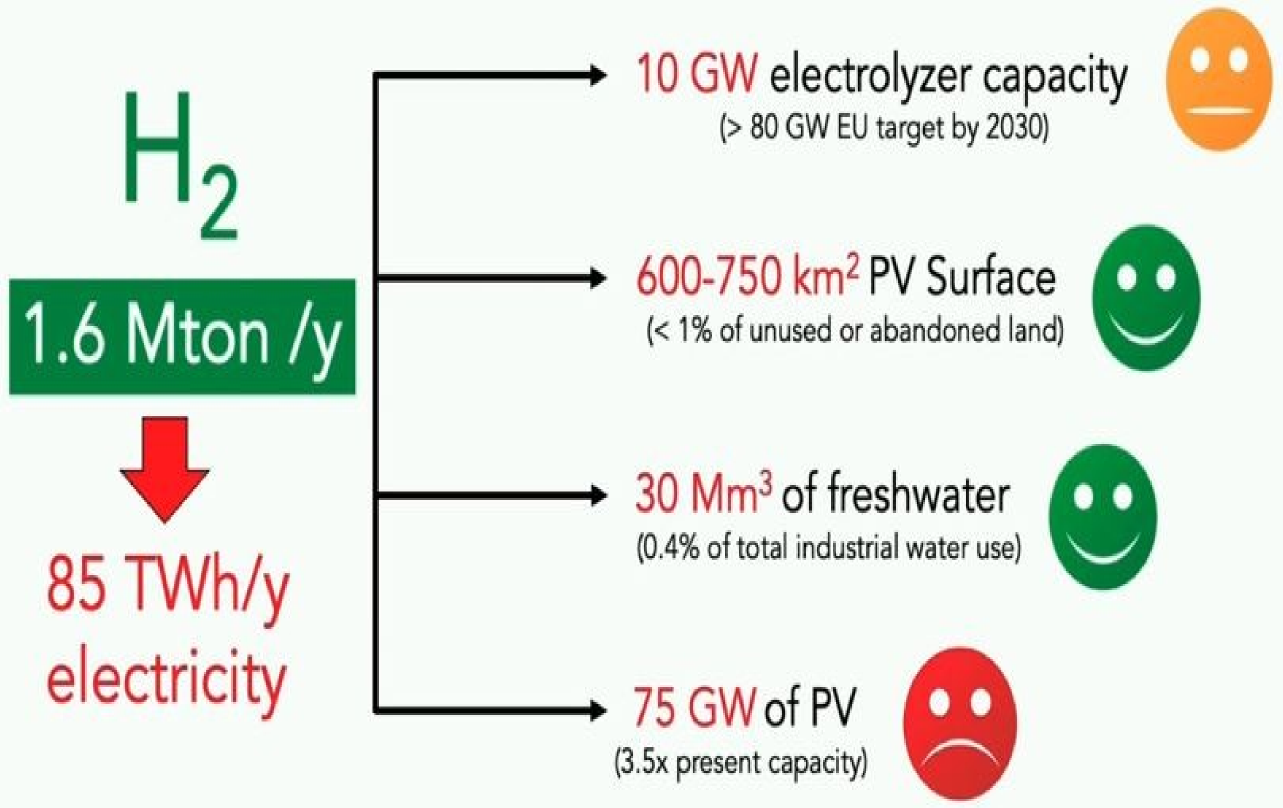


Fig. 66 – *Green Hydrogen requirements in Italy*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

It is necessary to note that in Italy the annual installation of photovoltaic technologies has always had considerable developments, first of all think of the vigorous surge that occurred around 2010-2011 and continued in the following years. Furthermore, in the same period at a global level, the growth of renewable energy, first of all photovoltaic, has had a general overall growth that is powerful and significant. This paradigm shift has occurred and has been very relevant for the topics that are being discussed here. The problem is that we speak in the past when it should now be the present, as the changes that occurred in the period 2010-2011 should have become the norm but unfortunately we did not want to continue with this energy evolution even in the years now. The exhaustion of these progresses must be traced back, inevitably, to choices of a strictly political nature that have led to the blocking of this trend and its goals achieved for a good 10 years. Today it is essential to pick up where we left off due to the needs, challenges, threats and inevitable and ineluctable transformations that the future will present us, recreating and reproducing, for years to come, the conditions that have allowed such a surprisingly remarkable leap forward. It always depends on us and the choices we make as the foundation of our lives.

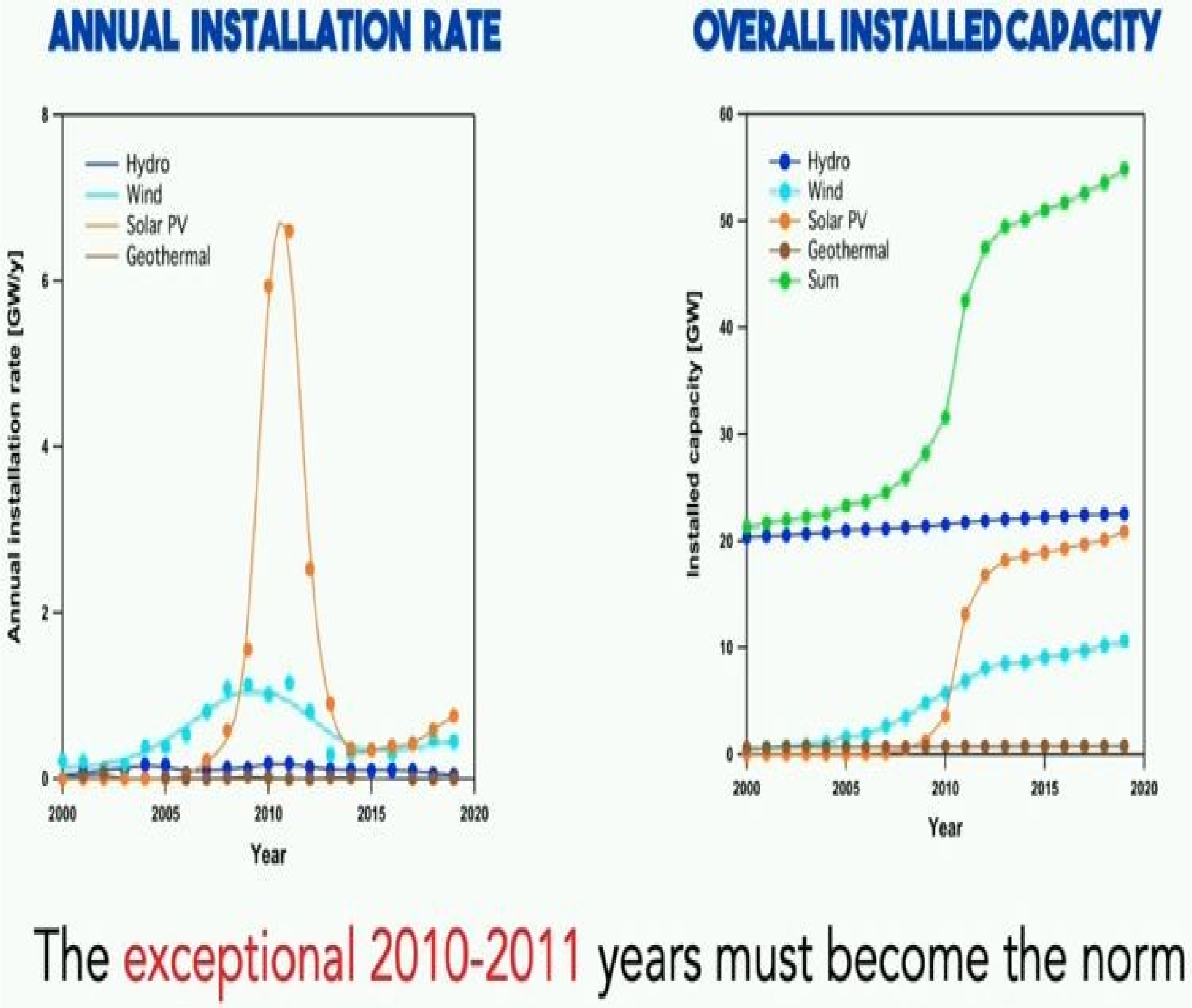


Fig. 67 – *The exceptional 2010-2011 years must become the norm*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

In the meantime, despite the Hydrogen plan and its progress, all European countries must reach a share of energy production from renewable energy from 116 TWh in 2021 to the 200 TWh of the aforementioned EU 2030 objective. In terms of quotas, this means increasing the current share of 36% of energy from renewable sources to 66%, and possibly even more, or increasing it by about a third of the total. To reach this very important goal, it is necessary to install approximately 80 TWh which correspond to 70 GW of Photovoltaic but, be careful, without allocating them to the plan for the production of Hydrogen, focusing them only to lead to the desired implementation of the European measures that, as a country, we are committed to completing.

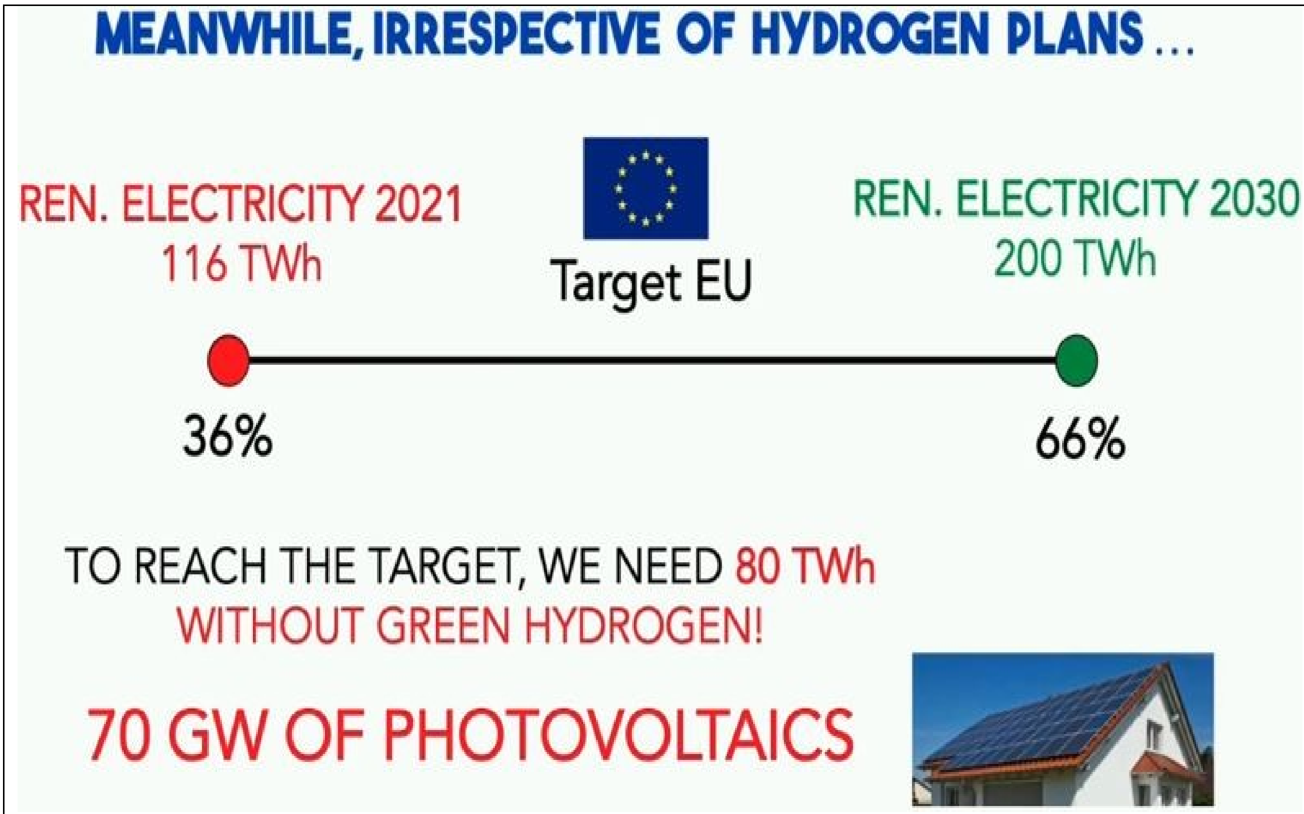


Fig. 68 – *Meanwhile, irrespective of Hydrogen plans...*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

In summary: to achieve the three uses planned in the Italian plan for increasing the production of Green Hydrogen, an electricity production of 85 TWh per year is necessary. While, on the other hand, to achieve the EU 2030 objectives on production from renewable energy sources, an increase in energy production of 80 TWh per year is essential. Rounding up, it is the same figure for two different strategies and destinations. In total, it is an energy amount of 165 TWh per year, which in turn corresponds to approximately 50% of Italy's energy consumption in the year 2021. Can it be realistic to achieve both in 10 years?

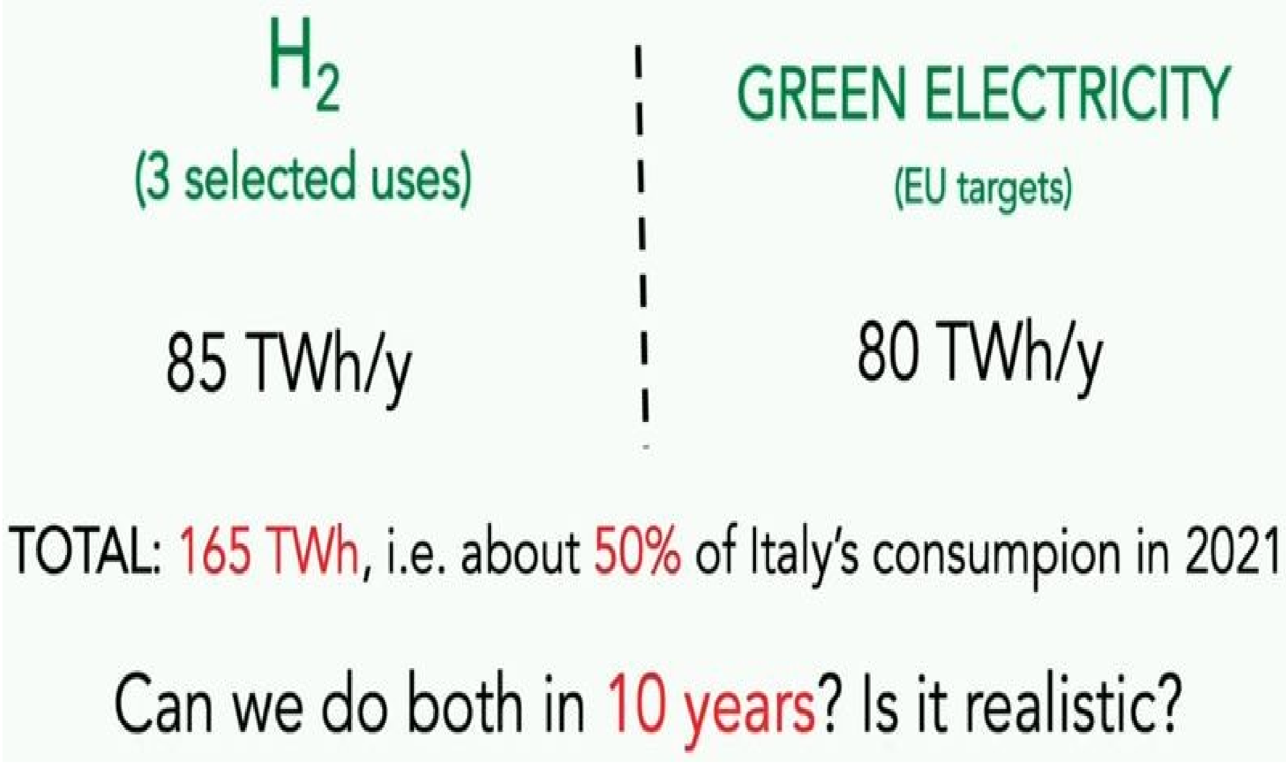


Fig. 69 – *Summing up…*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

What to do then? Returning to the 3 uses of Hydrogen in the Italian plan, it is clear that all three cannot be achieved in the next 10 years, but not all three must therefore be abandoned. We must put them on a scale of priorities and choose. But which ones should we give priority to? The first priority of all is to convert Hydrogen from the current Grey to Green type formation as, among the 3, it is the simplest and most immediately realisable. The second is to make the production of large steel mills decarbonised and sustainable from all points of view. While the third is the one concerning the production of the molecule for energy purposes, which is currently not a real necessity. Rather, it is preferable, as it is more efficient, to increase, expand and strengthen as much as possible the electrification of energy systems that are commonly used today through Photovoltaics, Heat Pumps etc.

Fig. 70 – *Three Green Hydrogen targets for 2030 priority levels*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Therefore, in the coming decade, we must first achieve energy efficiency, complete electrification, accelerating by 32.5% according to data from the European Commission, and then contribute to the energy and ecological transition through the production of Green Hydrogen.

Fig. 71 – *In the next decade first electrification, then Green Hydrogen*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Furthermore, already for 2030-2035 as starting dates, it is already possible to plan to design the so-called "Hydrogen Valleys", that is, localized districts of variable size and dimension where producers, distributors and users of Green Hydrogen are present with integrated activities, in the same territory.

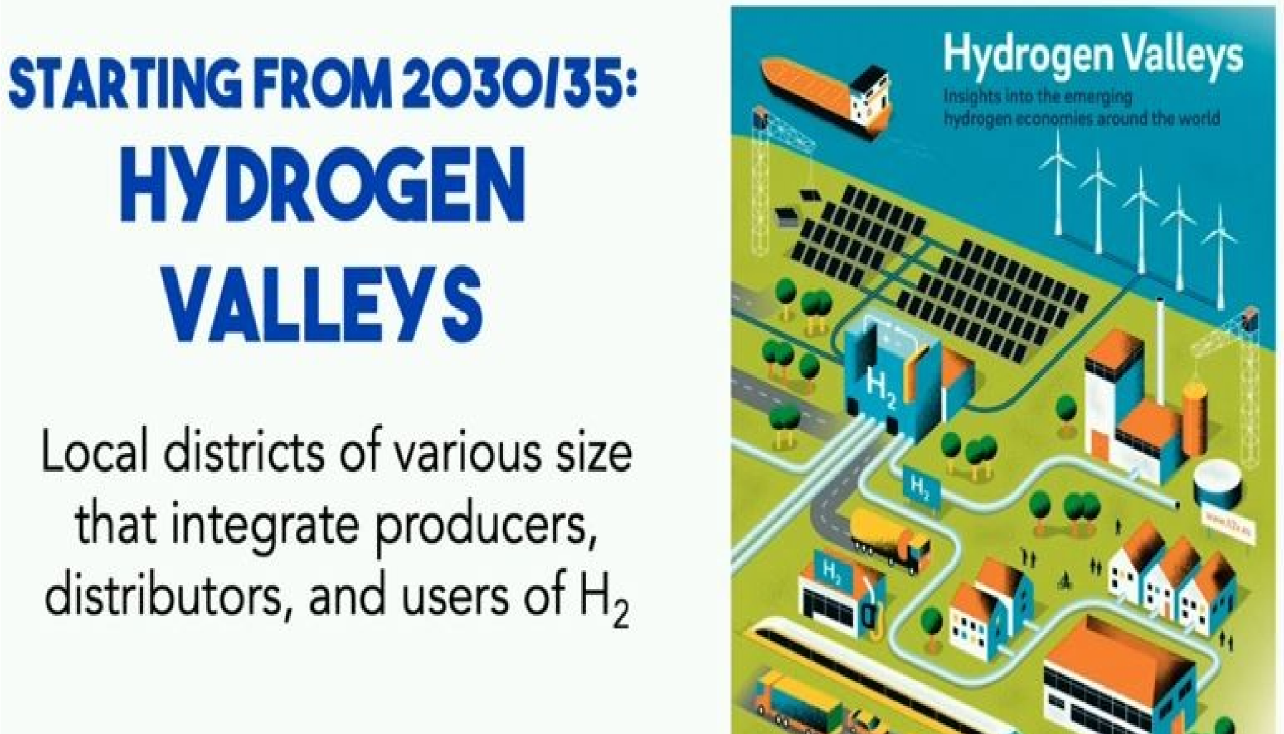


Fig. 72 – *Starting from 2030/2035: Hydrogen Valleys*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

II.III – HYDROGEN EPILOGUE: CAN IT CONTRIBUTE TO THE REALIZATION OF THE ENERGY TRANSITION AND GLOBAL DECARBONIZATION?

We therefore arrive at the conclusion of this long and intricate chapter with some final messages that bring us to the epilogue on the issue addressed so far of the energy transition and, in particular, of Hydrogen in its entirety and general complexity.

These are: today's conventional methods for the production of Hydrogen are quite efficient but unsustainable; the only sustainable, valid and existing production option is that of Green Hydrogen; Hydrogen has long been used by the petrochemical and chemical industries in general, (let's remember NH3, or Ammonia) therefore we know it and we know how to manage and use it effectively if we want but, for the topic and the energy sector, it is a very different issue from how it is commonly used; in our time we are researching and working to harness and make the most of the potential of Hydrogen in the energy sector, therefore, we repeat, it is a different sector from the original one and this requires reinventing the system and the methods used so far in their entirety; it has several problems between physical properties, which cannot be dealt with or negotiated, energy-intensive and expensive production, problems and complications of transport and storage not yet at advanced levels.

The molecule is certainly a valuable and very precious resource that, for this very reason, must be used only and exclusively when there are no valid alternatives to it: it cannot be used for light transport vehicles, on the contrary it is a valid possibility for heavy massive industries and it can perhaps also be used for large-scale heavy transport vehicles.

In short, Hydrogen is a great opportunity that requires equally great attention and care and an even more important, clear and realistic vision.

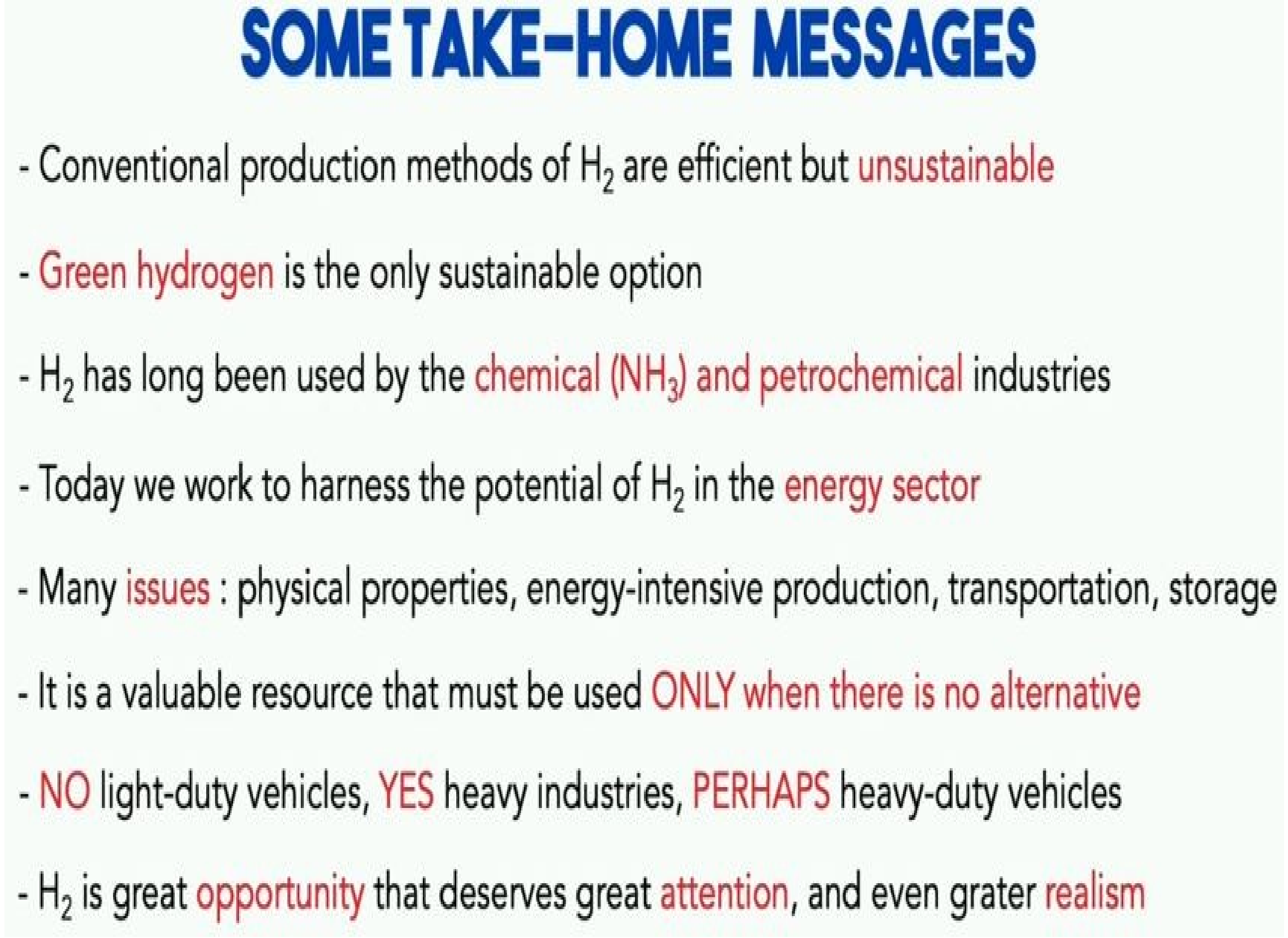


Fig. 73 – *Some take-home messages*, N. Armaroli, *The Hydrogen Dilemma* Enrico Fermi Lecture, Nicosia, 2022.

Returning to the general energy transition, changes have taken place and others are still in progress.

CHAPTER III

THE PROGRESS OF THE ENERGY TRANSITION: THE OVERALL EVOLUTION OF CLEAN AND RENEWABLE ENERGY SOURCES AS A WHOLE

"There is nothing to fear about life. We just need to understand."

Marie Skiodowska Curie

III.I – THE ESSENCE OF THE ENERGY TRANSITION: CHANGES IN END-USES AND ONGOING SUBSTITUTE TRENDS OF ENERGY SOURCES

Bearing in mind the previously illustrated global data for 2022 regarding energy uses among the main modes of use in the three end uses (Heating and Cooling, Transport & Energy/Electricity), it is evident that they have, over time, significantly improved in their use and in their share of renewable energy used. In continuity with them, the situation, in 2023, of the three main energy carriers - in this context the energy carriers and not the end uses mentioned above - is as follows: Heat (48.7%), Fuel (28.6%) & Electricity (22.7%). Within each of these quotas, the amount of renewable energy used and in function for these three energy vectors, on the total quota used for each single area, is as follows: (Heat) 9.9% Renewable Heat, (Fuels) 3.7% Biofuel & (Electricity) 30% Renewable Electricity. Discussing these data in more detail and connecting to the final uses mentioned above, it can be stated that almost half of the energy supplied is used to generate heat, for buildings, industries etc., almost 30% is used for fuels - such as liquid fuels used for transport - and last but not least, the remaining quota is used to generate electricity. Even in this context and time period, in the share of the use of renewables, despite being the quantitatively smaller measure, it is always the Energy/Electricity part, with 30% of the total energy vector, that has the most advanced portion of the others, throughout the world. In Italy it has reached 40%, a very positive and encouraging figure. For the other two vectors, however, the necessary shares are still too modest and insufficient. Consequently, the energy transition can be summarized in making these shares increasingly abundant and significant, in the fastest and quickest rate of speed of their growth, and continuing in their overall electrification.

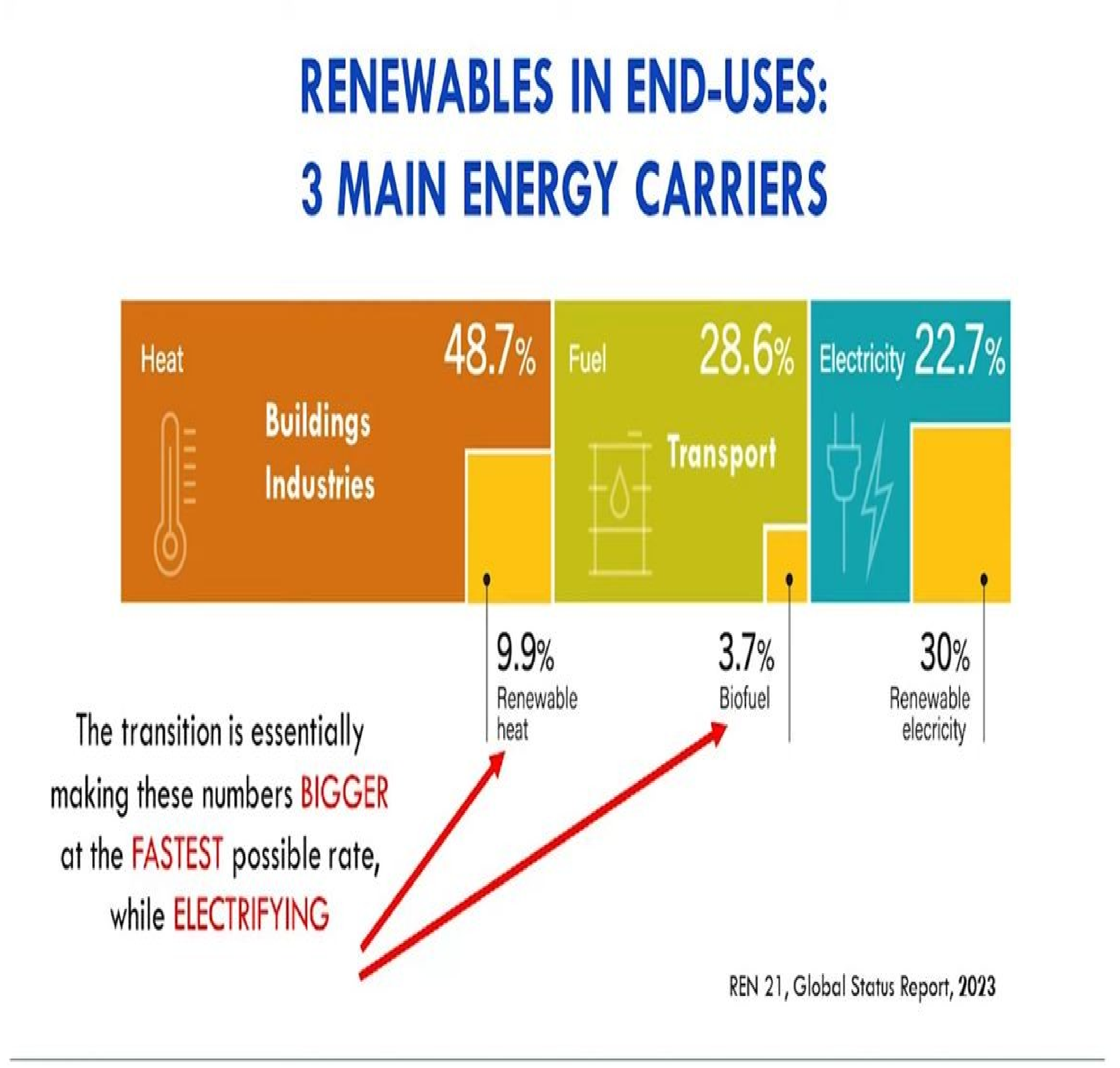


Fig. 74 – *Renewables in End-Uses: 3 main energy carriers*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

III.I.1 – Recent and contemporary energy changes, paths and trends

Let's now look at the energy trends that have occurred in recent years. The trend in electricity production worldwide that has materialized over the long period, from 2012 to 2022, shows a staggering increase in energy demand of as much as +30.7%, almost a third more, an enormity for a single decade. But this period also brings good news: although there has been an increase in absolute terms, in relative terms, in comparison between shares, compared to the previous decade, the amount of use of fossil fuels on total energy production has decreased, going from 68% to 61% of the total.

This must, or perhaps it is more correct to say should, make those who claim that energy production from fossil fuels, such as Coal extracted on a large scale by countries like China, is increasing more and more and that consequently any action aimed at reducing polluting energy sources in progress is useless and inconsistent. This is not the case at all. In this regard, another noteworthy figure is that concerning the electrical energy deriving from renewables, in particular from the power generated by Solar and Wind. These have in fact gone, both in absolute and relative terms, from less than 3% to over 12% of the total in a decade. A real revolution in progress which, despite everything, is gaining more and more traction.

Another figure similar to this representation of the energy sector just illustrated, is the new generation capacity.

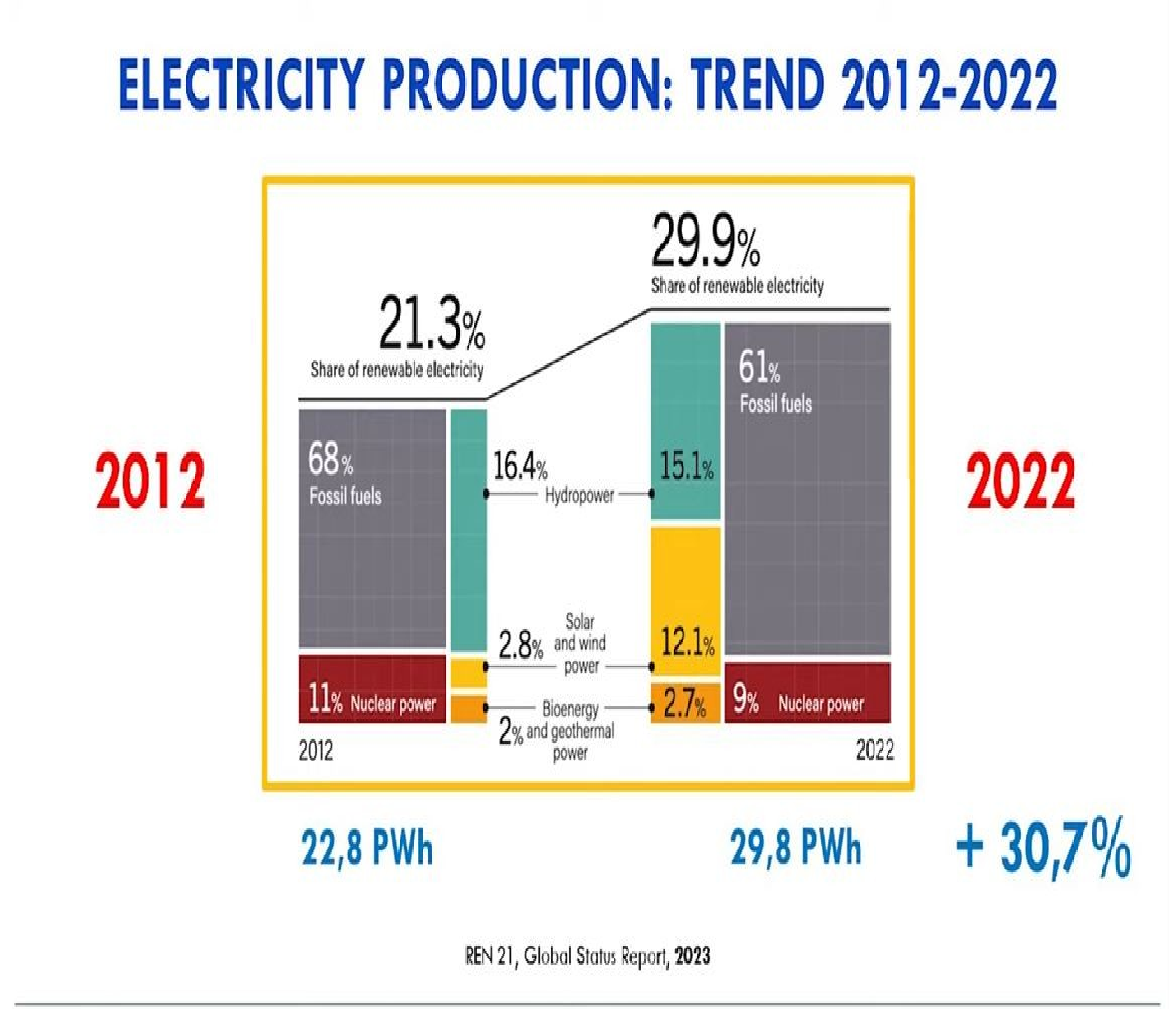


Fig. 75 – *Electricity production: trend 2012-2022*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

This quantitative scope, which has grown more and more over time (in this specific context it concerns the period from 2011 to 2021), concerns the two sectors that we have mentioned repeatedly and often together: Photovoltaic (PV) and Wind. These two, in the ten years examined, have significantly expanded their level and now, in more recent times, the electrical energy derived from wind turbines and photovoltaic panels represent, approximately, something like 80% of the total new electrical capacity of the global energy system. This is also a fact that should make those who express, often and willingly showing off without knowing exactly what they are asserting, reflect and reconsider the inconsistency of these two technologies that are now, in fact, dominant.

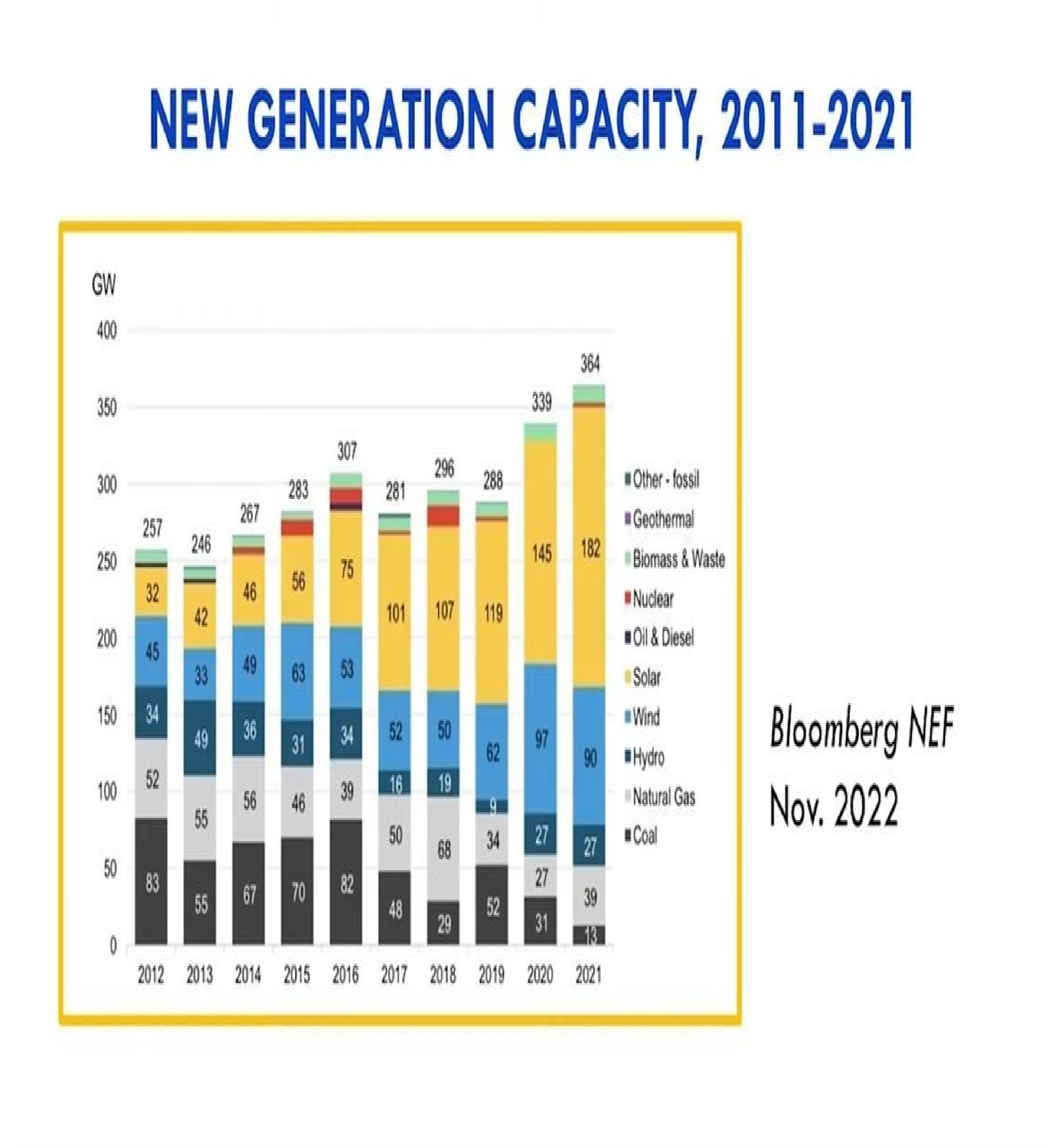


Fig. 76 – *New generation capacity, 2011-2021*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Even more, there is also a new singular news that is very recent and of considerable relevance. The International Energy Agency has declared that in 2024 renewable energies will generate more electricity than Coal in its entirety, at the PetaWh level, therefore at the widest levels. Therefore, renewables will very soon be, globally, the absolute predominant energy sources.

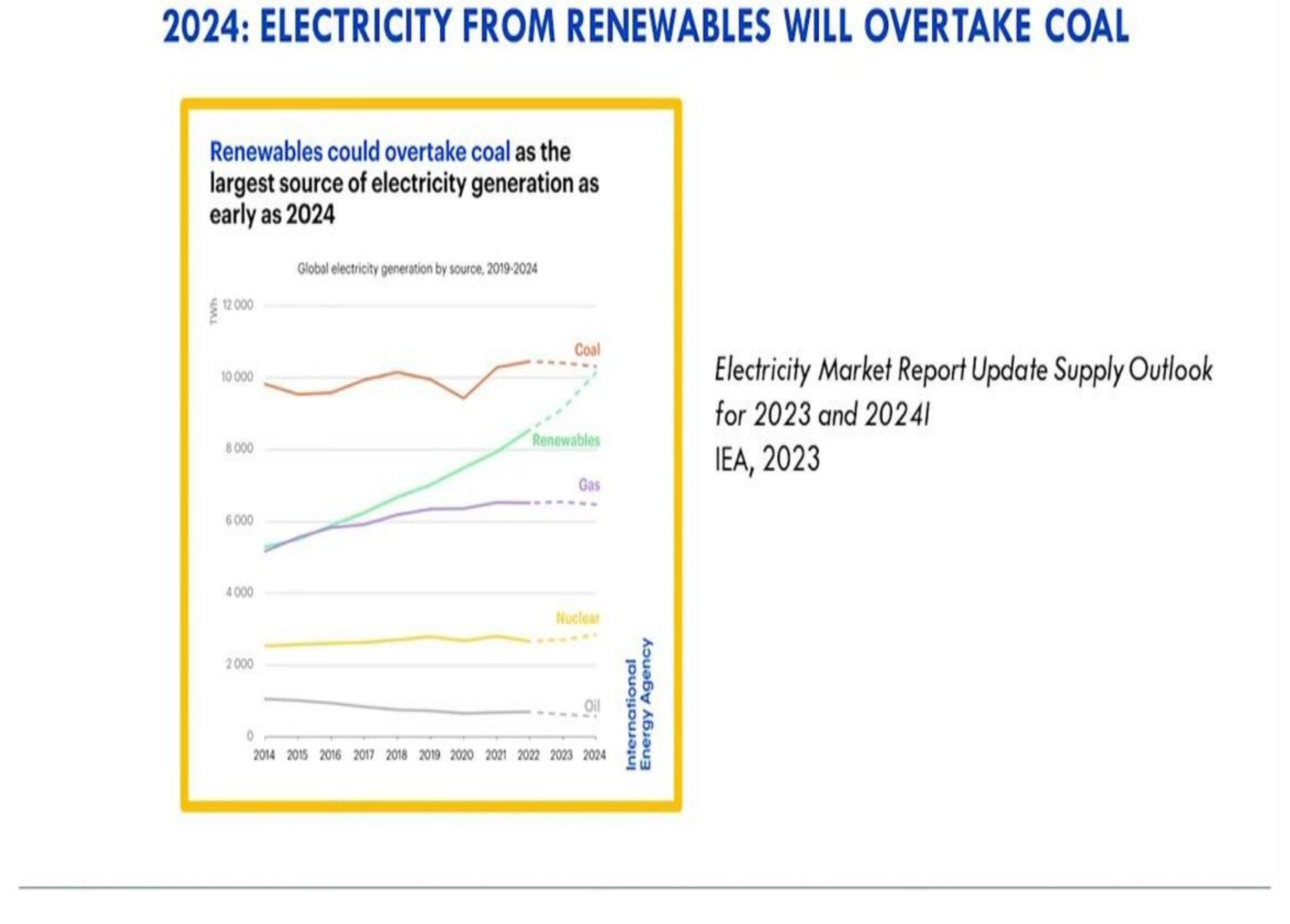


Fig. 77 – *2024: electricity from renewables will overtake coal*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

For these reasons and with this evidence of fact, despite all the problems posed in the past and the wrong decisions made, the installation and implementation of renewable sources have an unstoppable increase, with the two prevalent types, Photovoltaic and Wind, having the roles of leaders and trailblazers in this longed-for Watershed progress. As we have underlined, from 2012 to 2022, these two sources have grown, both in terms of installation rate and energy yield, more and more, year after year, reaching together 2 TWh: to be precise: 0.906 TWh for Eolic and 1.185 TWh for Photovoltaic. It should also be remembered that 1 TeraWatt per hour corresponds to 1000 GigaWatts for each hour, which correspond, in total, to a thousand billion Watts per hour. However, there is a consideration on the data that should not be taken for granted and should always be taken into account: it is not so much the number of installed plants that should interest us but rather how much energy they originate and generate. Every new plant installed is good news, but obviously if these do not produce at all or in a poor way, everything ends up being in vain. Therefore, in conclusion, how much electricity do these two sources actually produce? Is it really such a sustained and consistent energy creation in general? Always on a global level, at the end of 2022 and taking the average world capacity factor, the energy production, made and realized by both Wind and Photovoltaic, is not only equivalent, but is higher than that emitted by 600 Coal power stations, or the equivalent in Nuclear plants, with a power of 1 GW each. Therefore, the two renewable energy sources equal and surpass one of the most important polluting fossil fuels together with the other source, which is based on the Atom but which is highly critical and controversial, on a total energy creation of 7 TWh per year, always on a global level.

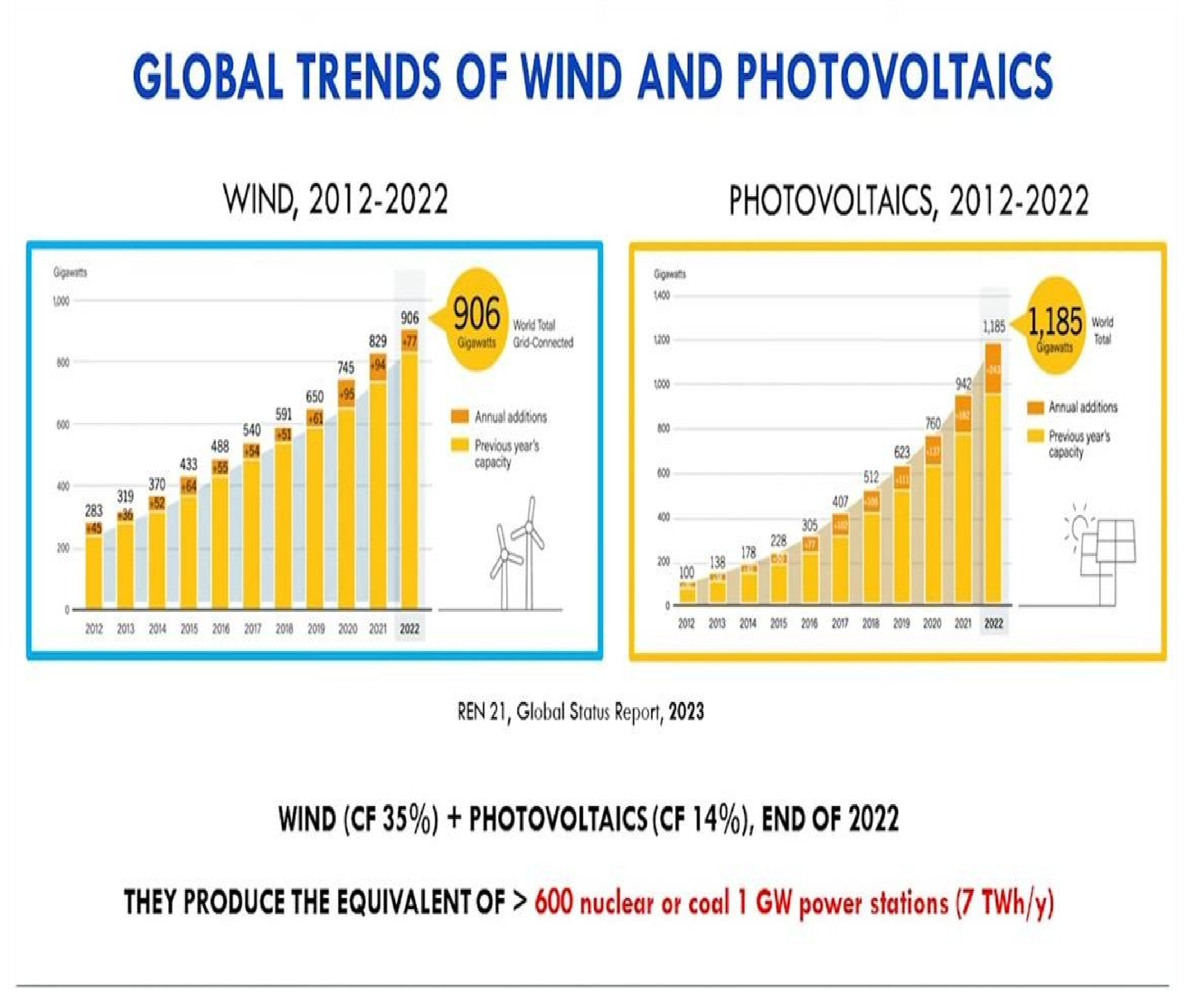


Fig. 78 – *Global trends of wind and photovoltaics*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Therefore, if, regardless of their still very significant use, we take into account the damage caused by energy production, through the extraction and combustion of an energy source now obsolete such as Coal, or we calculate the exaggerated costs and the immense technical problems caused by Nuclear - in economic, social and ethical terms, in terms of safeguarding human and natural health, internal and geopolitical politics, the environment and landscape - this is a fundamental step, often dreamed of and sought after, to overcome the catastrophic damage of the past, finally settling accounts with it, and finally moving forward towards a better future.

III.I.2 – A practical and emblematic case: Italy between Nuclear and Renewable Energy

Going deeper, let's take a concrete case, taking as a point of reference the country that we have already taken as an example on several occasions, also valid for other countries and contexts: Italy. In 2022, our country produced, through its installed photovoltaic production, the energy amount of 28.2 TWh, which corresponds to a good 10% of the national amount of energy produced. A tenth of the total. This is not a small amount for a single energy source. Furthermore, according to the latest updated data, in the following year, 2023, thanks to the new 30 GW plants built and put into operation, this energy amount has grown, over the course of this last year, and as an annual quota, to 35 TWh. In the meantime, looking at the other reference sector of renewables, energy deriving from wind power, again in 2023, has reached the infrastructural capacity of 12.5 GW, generating an energy share of 21 TWh for the public needs of the Bel Paese. It is certainly not a very structured capacity despite the potential that could be expanded and that the Mediterranean country has available. But in any case, the energy capacity generated last year, in Italy, adding together the two types of clean energy, results in a total of: PV 35 + WIND 21 = 56 TWh. This data brings to mind, for those who have experienced it, the period 2009-2011 in which there was extensive debate, of a plan of the Italian government in which they wanted to produce energy with new nuclear reactors. The energy production of this plan, based on the fission of the Atom, was planned through the construction of 4 large reactors, equivalent to 50 TWh. How many reactors have been built and put into operation since then? None. At the time there was a lot of discussion about it, but nothing was done, also due to the results of the referendums that led to the ban on the construction of nuclear plants in Italy. In the meantime this praiseworthy and commendable result has been achieved: 56 TWh from clean, safe, renewable and sustainable sources from all points of view. This is also a fact that deserves to be remembered.

Fig. 79 – *A practical case: Italy, 2023*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

III.II – PARADIGM SHIFTS, NEW MODELS, FALSEHOODS AND MYTHS TO BE DEBUNKED: THE OTHER RENEWABLE WORLD OF THE FUTURE

Let's add other significant data and information, often unknown to most. In 2022, in Europe, the energy production of the Photovoltaic & Wind duo has reached and surpassed, with a marked margin of difference, also Methane Gas. All the more reason, therefore, what is being illustrated is not an uncertain possibility, a desirable hope, a daydream, an illusion or a utopia. It is a project, a work in progress that is being put into practice and materialized day after day and that, with this continuity, will be completed in the next 20 years. But quick actions are necessary, accelerating and intensifying the efforts because time is running out and being defenseless is self-destructive.

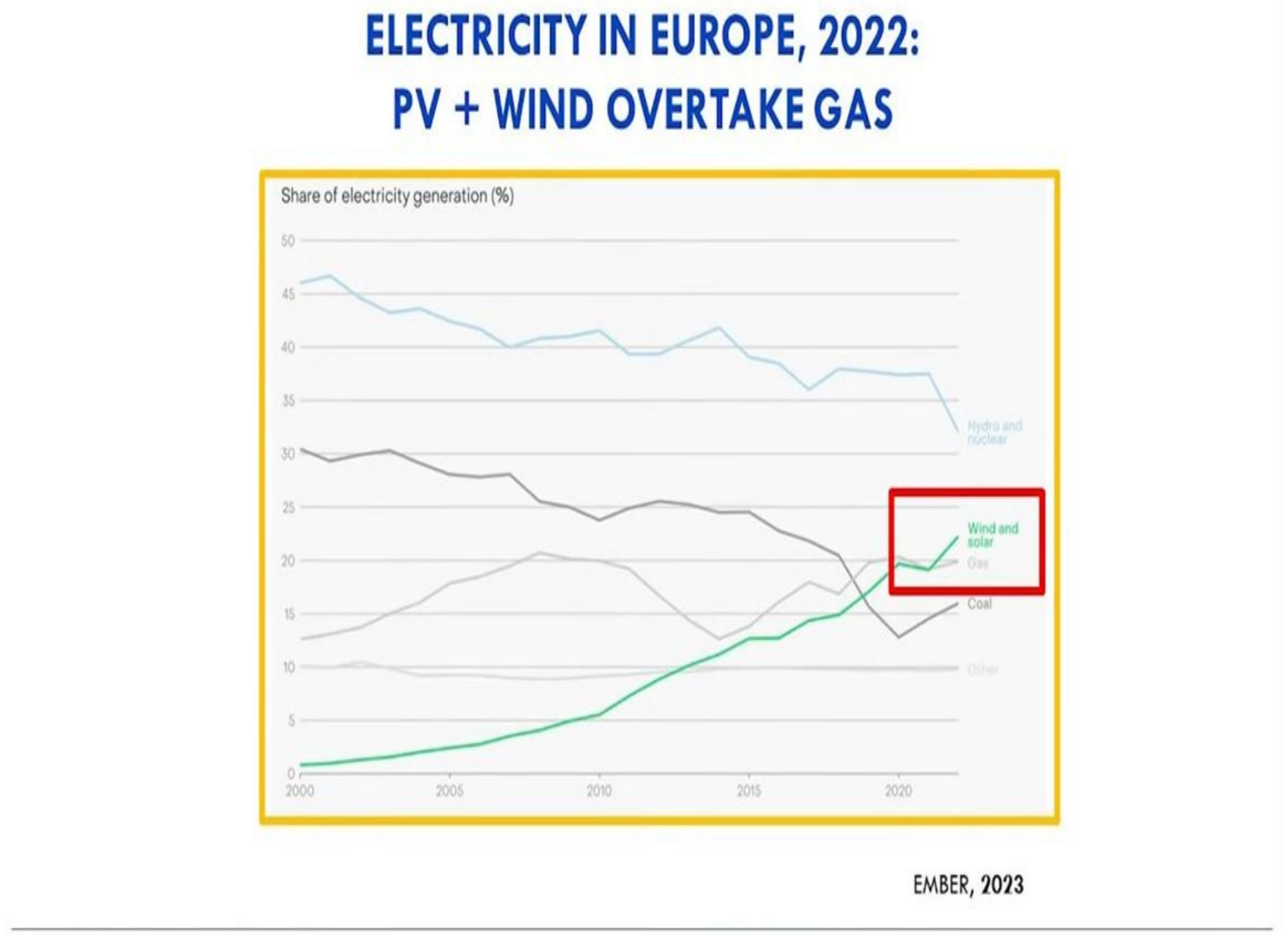


Fig. 80 – *Electricity in Europe, 2022: PV+Wind overtake Gas*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Having come this far, we can establish that, ultimately, with absolute and indisputable certainty and reasonableness, the turning point and the keystone of the energy transition, which is in turn functional to the ecological transition, is the technology of Photovoltaic Solar panels and systems for the production of energy.

In short, Photovoltaic (FV/PV) is the true winner of the decisive process underway. Unlike other technical typologies, such as the aforementioned Hydrogen or Nuclear, it has a much simpler and more immediate technology that makes it very easy to install and put into production. This simplicity of creation and ease of installation has been its fortune compared to other sources, and has decreed its success.

To be even more precise, returning to a global time graph made by the International Energy Agency, in 2010 the installed capacity of Photovoltaic was practically inconsistent when compared to the others. Nowadays the exact opposite is true.

The panels that capture and transform sunlight into electrical energy have had an unstoppable and dizzying growth reaching an indisputable leading position. Even more, it has been calculated and announced that in 2027 Photovoltaic will be the technology, in terms of capacity implanted and structured, most installed and used in the world, thus managing to overcome the large and long-lived presence of Coal, which still leads. All this, not so many years ago, was commonly considered unimaginable, but now it is pure reality, making this a simply extraordinary change.

A dozen years ago no one, not even the scientists, researchers and scholars who dealt directly with these matters, would have bet a penny on a paradigm shift and such an astonishing, unexpected and surprising evolution.

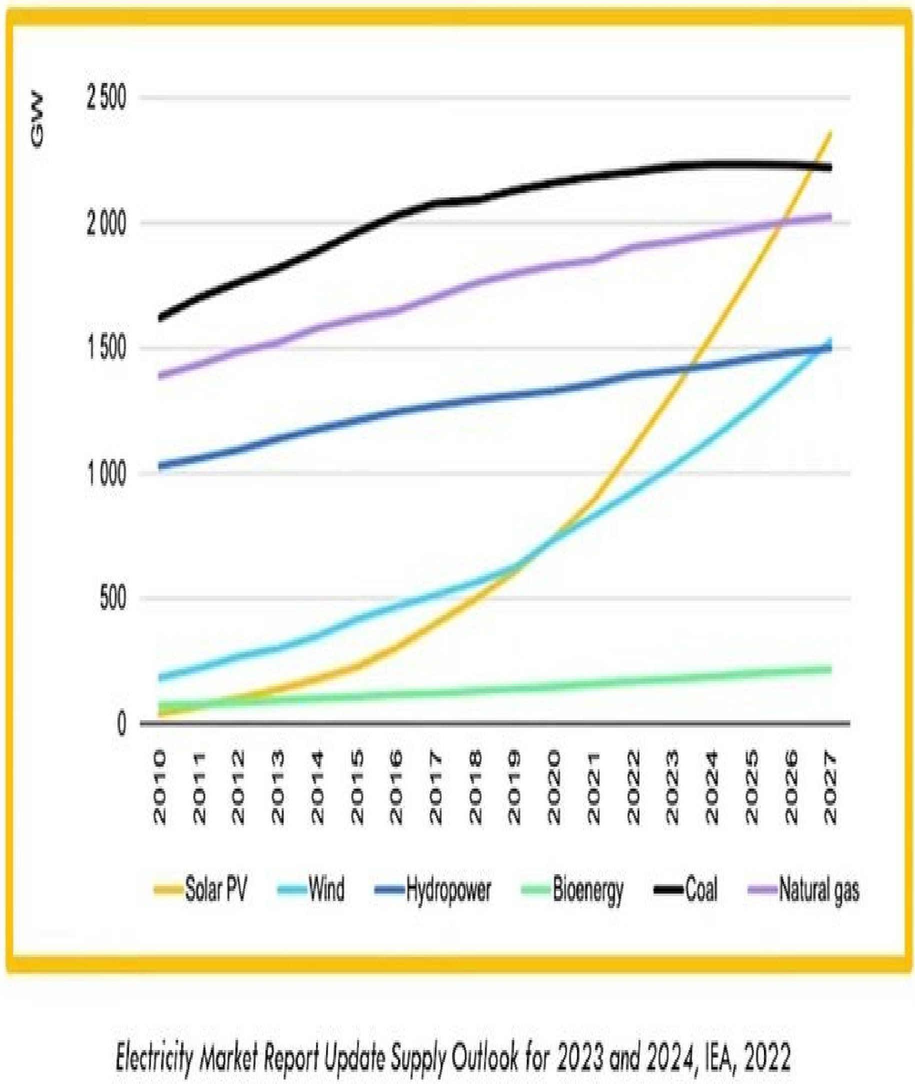


Fig. 81 – *2027: PV #1 electricity technology in terms of capacity installed (just amazing...)*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

This transformation in the energy landscape must have reasons that attract the curiosity and desire to know of many people. Let's therefore delve into these aspects of this new energy technology, answering questions that have inevitably been asked. What, how and why did all this happen? And in particular: why will Photovoltaic be so dominant? This is due to the fact that this panel technology provides answers and feedback that combine with a long and heterogeneous list of factors. In summary, the factors that create these fortunate, profitable combinations can be listed and illustrated as follows.

Photovoltaic panels:

- They have a standardized production and recycling. Unlike other technologies, the panels are essentially always the same and identical to each other wherever they are produced.
- They are modular. It is the same “tile” regardless of their power (from 2 KV, 2 MW or 2 GW) or where they are installed: a pergola, a roof of a large building or a vast and extensive structure in the desert.
- They have a cost, still today, constantly decreasing, making them accessible for every budget and every market, we are talking about millions if not billions of customers and/or users who can be involved.
- They have a low and contained risk of supply of critical materials.
- They are easy to transport and functional. They can be loaded practically anywhere and transported by any means: from the most mammoth vehicles, such as large container ships, to the most minimal and rustic animals such as camels).
- They are also easy to install. They can be set up and placed anywhere (from the smallest villages to the most monumental metropolises, this is a unique feature compared to other technologies).
- They have installation platforms that are immediately available and usable: pergolas, surfaces, walls, roofs, hooks of various types and types, etc. For other energy sources, this is one of the fundamental problems; in the case of panels, for their positioning, you are spoiled for choice.
- They do not require highly qualified specialized workers to function and this is a considerable advantage.
- They have no moving parts or components: it is a single piece, it may seem banal and obvious, but this is a simplification that is far from indifferent, and it is also long-lasting and reliable, and it also requires little maintenance.

- They can be combined with another modular technology, which is the electric energy storage batteries, which are also fundamental for the transition in progress.
- Finally, they are socially accepted in a transversal and extensive way.

For these reasons, this prodigious leap has taken place and there is no similar technology that connects, combines and unites all this. Here's why.

Faced with all this data, inevitably, it becomes necessary to do some *debunking* arriving at clarifying and amending points left in the dark and usually manipulated.

There is a theory which assumes that, if all these facilities are built and placed, we will end up invaded and submerged by them within a few years.

Yet another absurdity.

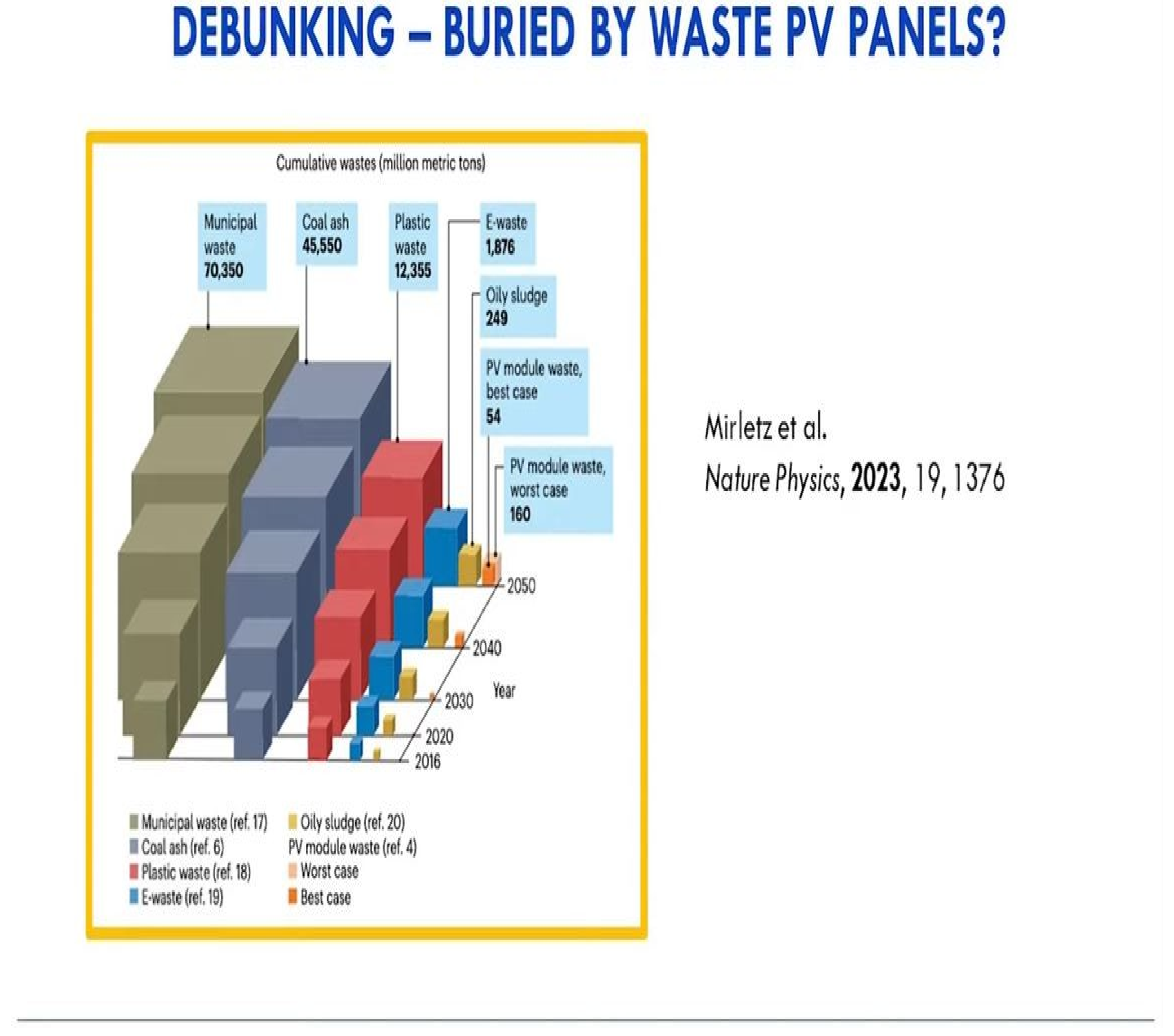


Fig. 82 – *Debunking - Buried by waste PV panels?*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

According to a study from *Nature Physics*, waste from Photovoltaics, in the most serious and poorly managed scenario, is in a much lower measure than waste, emissions and scraps from Plastic, Coal and municipal and city garbage in general.

In any case, it is evident and well known that even renewable sources, as well as many other means, tools and devices in use today, require the exploitation of mineral resources deriving from mining and not only.

The light of the Sun and the relative flows that it transmits to us, as is well known, are an extraterrestrial input superabundant for our Planet Earth that has allowed us life as we know it. But, received as it is, it is unusable as a means for human energy purposes.

Ergo, just as happens with plants - which serve as food for animals - they take Solar energy to transform it into nourishment and organic energy for themselves. To have this vital source of sustenance, we humans must use intermediary means such as converters and accumulators of Solar flows. In turn, to produce and create these instruments, the mineral resources that our Planet makes available to us are needed.

This is the method we have available to carry out and exploit our technological "chlorophyll photosynthesis" and to be able to obtain an energy yield directly from the source of our life: the Sun.

This necessarily brings us to one of the most pressing questions regarding the transformation in progress: do we have a sufficient and adequate measure and quantity of mineral resources for the energy transition?

There is a well-curated and illustrative infographic made by McKinsey in 2022, where the different resources are listed on the lines such as the various useful and used metals and relates them to the columns of the multiple technologies, moving from the left, from the more traditional and conventional ones, to the right arriving at the more recent ones that are more up-to-date and innovative.

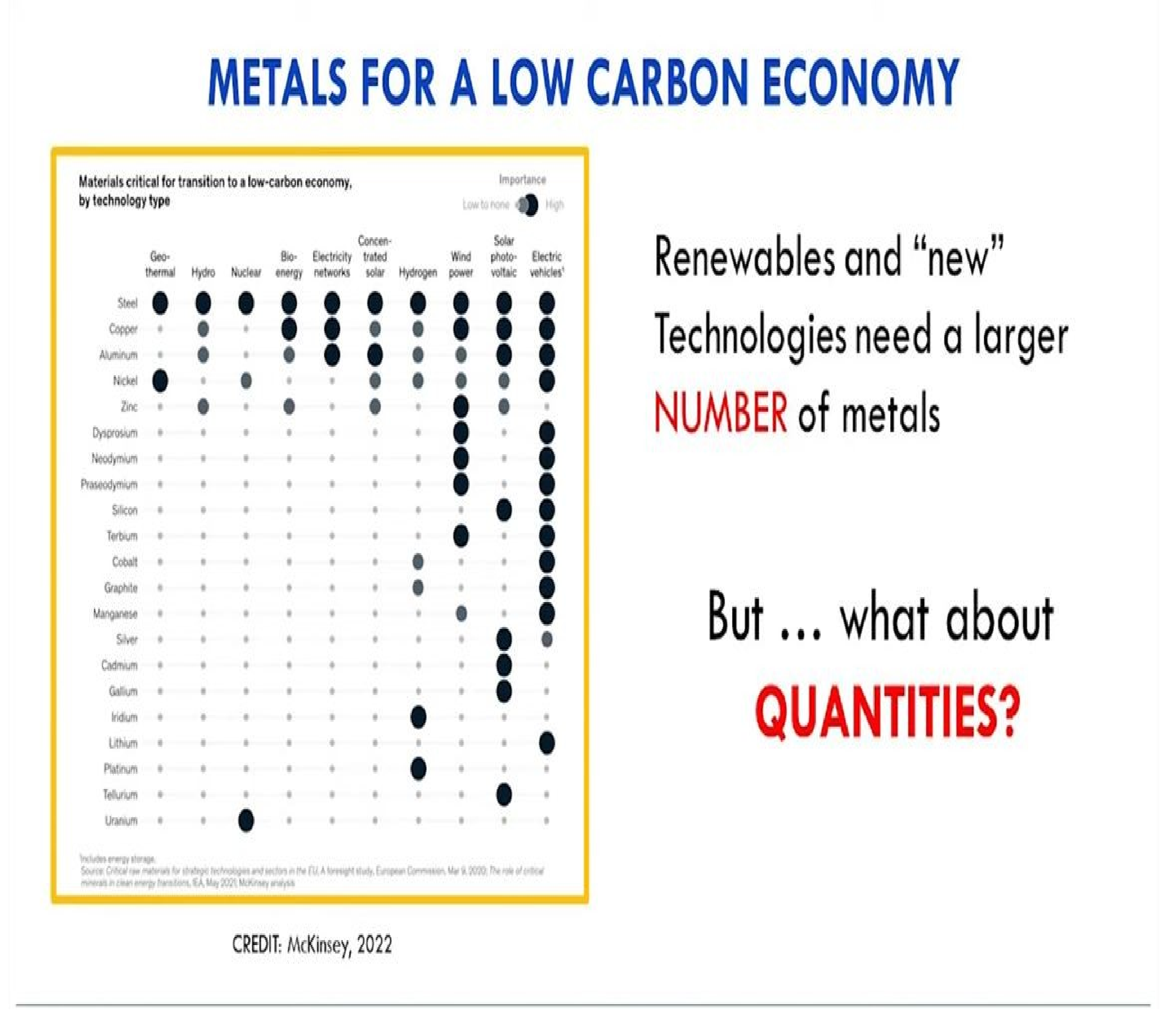


Fig. 83 – *Metals for a low Carbon Economy*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

This table shows that, while older techniques (Geothermal, Hydroelectric, Nuclear etc.) require limited and smaller quantities of mineral materials, the more you look and move towards more modern and contemporary technologies (Wind, Photovoltaic, Hydrogen etc.) the more the number of types of materials and resources needed expands and increases. But be careful, this only concerns the number of ranges, the list of types, metals and materials needed and not so much their quantity. Therefore, renewable sources and modern technologies require more types of resources. But what about their quantity? Essentially, renewable sources require an indisputably smaller quantity of resources and materials than other technologies. To give a concrete example, a 1 MegaWatt

Photovoltaic system built on the ground originally requires 200 Tons of material. In absolute terms, this is a truly massive and bulky quantity. But again, we must look at and interpret these data in relative terms. In fact, if you want to produce, for a period of 30 years, the same amount of electricity as this type of large plant, with Coal you would need 14,000 Tons. 70 times more materials. A comparison of approaches as markedly unequal and different as it is merciless. Even more, it should be remembered that the resources and materials of the Photovoltaic plant are recyclable and reusable with the appropriate measures, while the residues of Coal and fossil fuels in general are only GHG emissions that end up in the atmosphere and stay there, with all the damage and consequences that we end up receiving in exchange and that we are suffering and will have to face more and more in the times to come.

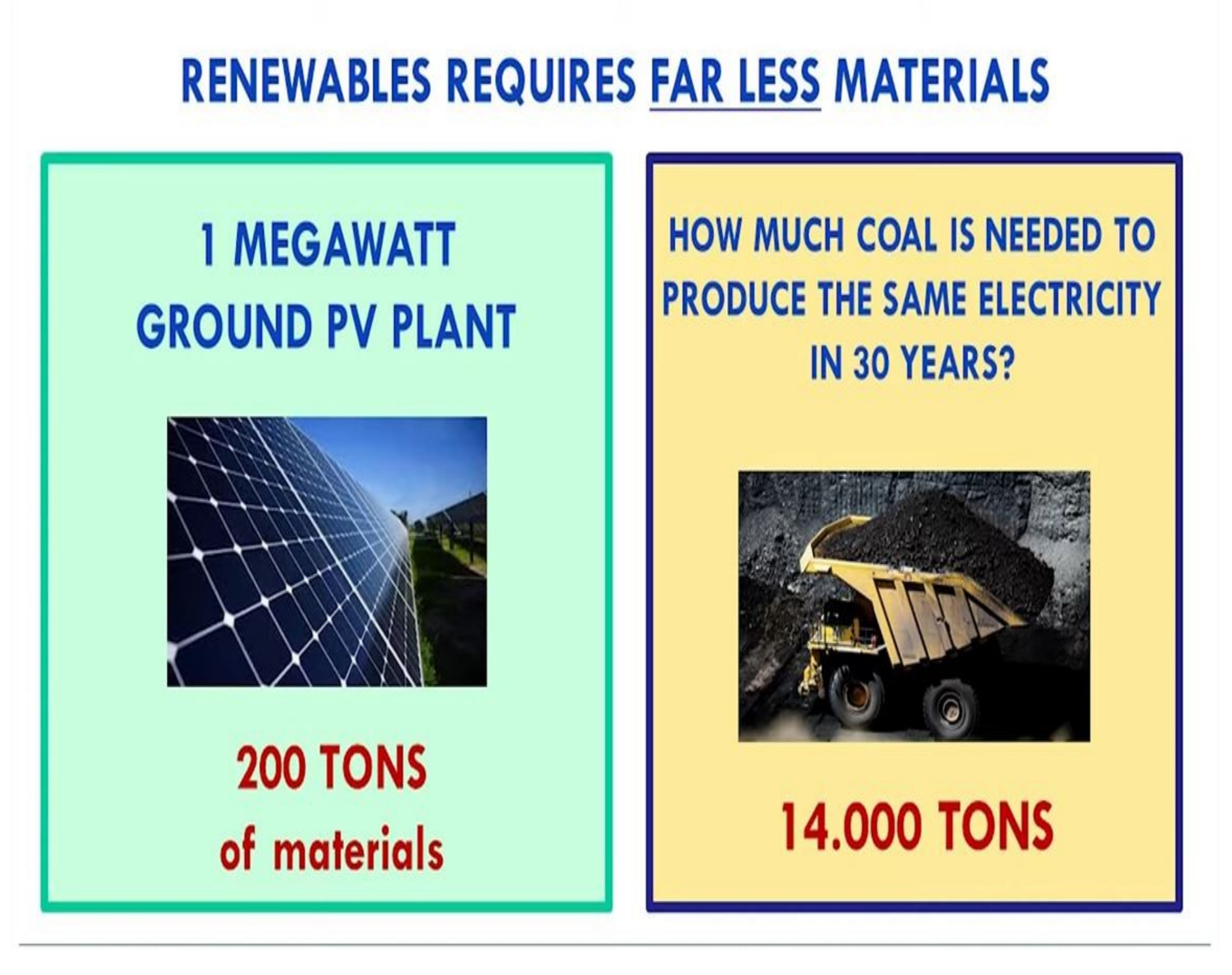


Fig. 84 – *Renewables requires far less materials*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Let's go back to a topic that we have already touched on with the in-depth analysis on Hydrogen. Let's delve into electric mobility as a whole and, with it, let's take a look at the aforementioned BEVs, or Battery Electric Vehicles. From a strictly practical point of view, those who drive a BEV for a 300 km journey on the motorway consume approximately 50/51 kWh of electric current which, in turn, correspond to 5.7 litres of petrol. If you were to drive, travelling along the same road at the same speed and with the same distance of 300 km to cover, a car/vehicle of the same comparable type but powered and set in motion by an internal combustion engine (defined as an *Internal Combustion Engine* car, ICE) you would consume not less than 6 liters but 30 liters of gasoline. This is the fundamental reason, in addition to the issue of emissions and other environmental reasons, why electrified mobility is clearly better and superior to the now anachronistic mobility based on internal combustion. With mobility based on electric current, you consume, for the same route to travel, 3 to 5 times less than with previous conventional cars. This is the most important point of all: same travel route, same speed, or at least comparable, consumption clearly and incomparably lower.

Further debunking, one of the biggest lies concerns BEV vehicles. They are often considered unreliable and dangerous by many, as they tend to have greater risks and cases of short circuits and, with that, end up catching fire due to spontaneous combustion in many cases. Among the many, this is the most elaborate, widespread and considered most truthful manipulative lie by public opinion. But, once again, data and research say the opposite. A study was recently produced by an association of US insurance companies that shows that not only do BEV vehicles not have particular risks of spontaneous combustion and short circuits that make them so dangerous, but that they are actually much safer and more reliable than their hybrid and conventional combustion engine ICE counterparts. Further journalistic research supports what was found compared to what is most believed to be true.[3]

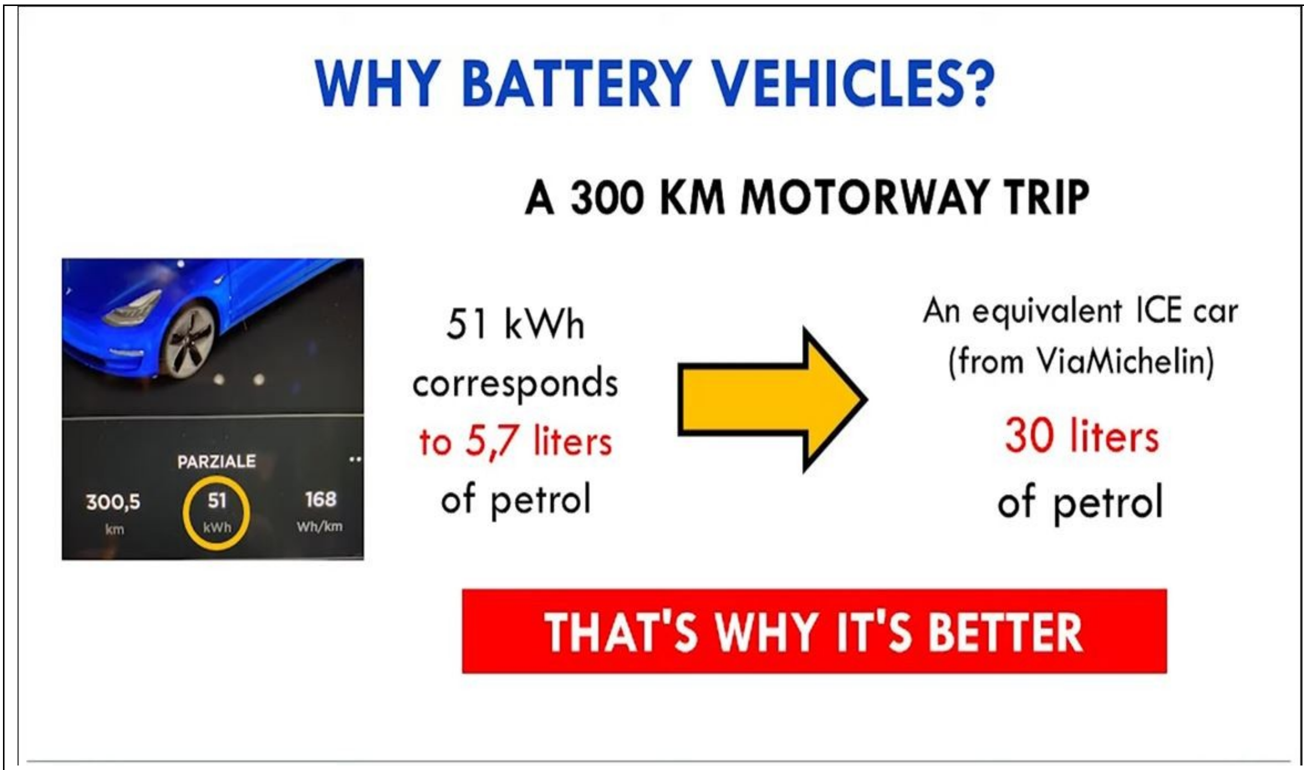


Fig. 85 – *Why battery vehicles?*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

There is a very marked difference between conventional automobiles and Battery Electric Vehicles. Conventional automobiles are still commonly used today. The *Internal Combustion Engine Vehicles* (ICEV), require for their power and for the functioning of their motorization a material input, Petrol, Diesel, Methane, LPG etc., a very simple product to recognize and tangible, while the residual waste, as we know, is dispersed into the atmosphere, CO2 and other GHGs. In addition to this, it must be taken into account that one of the problems regarding pollution in general is that it often escapes our senses, it is imperceptible - it cannot be seen, it cannot be tasted etc. - who can

[3] Link to US study: https://insideevs.com/news/561549/study-evs-smallest-fire-risk/
Link to Guardian article on the topic: https://www.theguardian.com/business/2023/nov/20/do-electric-cars-pose-a-greater-fire-risk-than-petrol-or-diesel-vehicles

care about something that we do not have the awareness and direct perception of? - if not for consequences of another type connected to it such as the climate crisis and extreme events.

On the other hand, however, BEVs are powered and operated by electric current which is immaterial that can be drawn and created for our purposes through, a now rhetorical example, renewable energy sources and, an important characteristic, you can generate more and more of them with the increase of these energy sources.

From this we can further see that electric cars will become more and more capable, more efficient, more functional, more useful and comfortable, therefore overall better as time goes by. Of course, it should be remembered that there are various complex materials of various types inside BEVs, first of all for the batteries, but in this case there is no dispersion. The full load of the already illustrated metals and materials is carried out only the first time, when the vehicle is purchased, but from then on they are always the same ones present and used in the vehicle.

Summarizing and synthesizing this part, while ICEVs need, function and are characterized within a Linear Economy that continually requires new resources to be extracted and eradicated, BEVs are instead distinguished by being included within a Circular Economy where the resources obtained from the environment are reconverted, reused and recycled repeatedly tending towards infinity. A person, for example a mother or a father, who buys and uses a battery-powered electric vehicle for their needs and travel, will be able to give as a dowry and in succession these vehicles and components, with their internal materials, such as Lithium, to those who will come in the future.

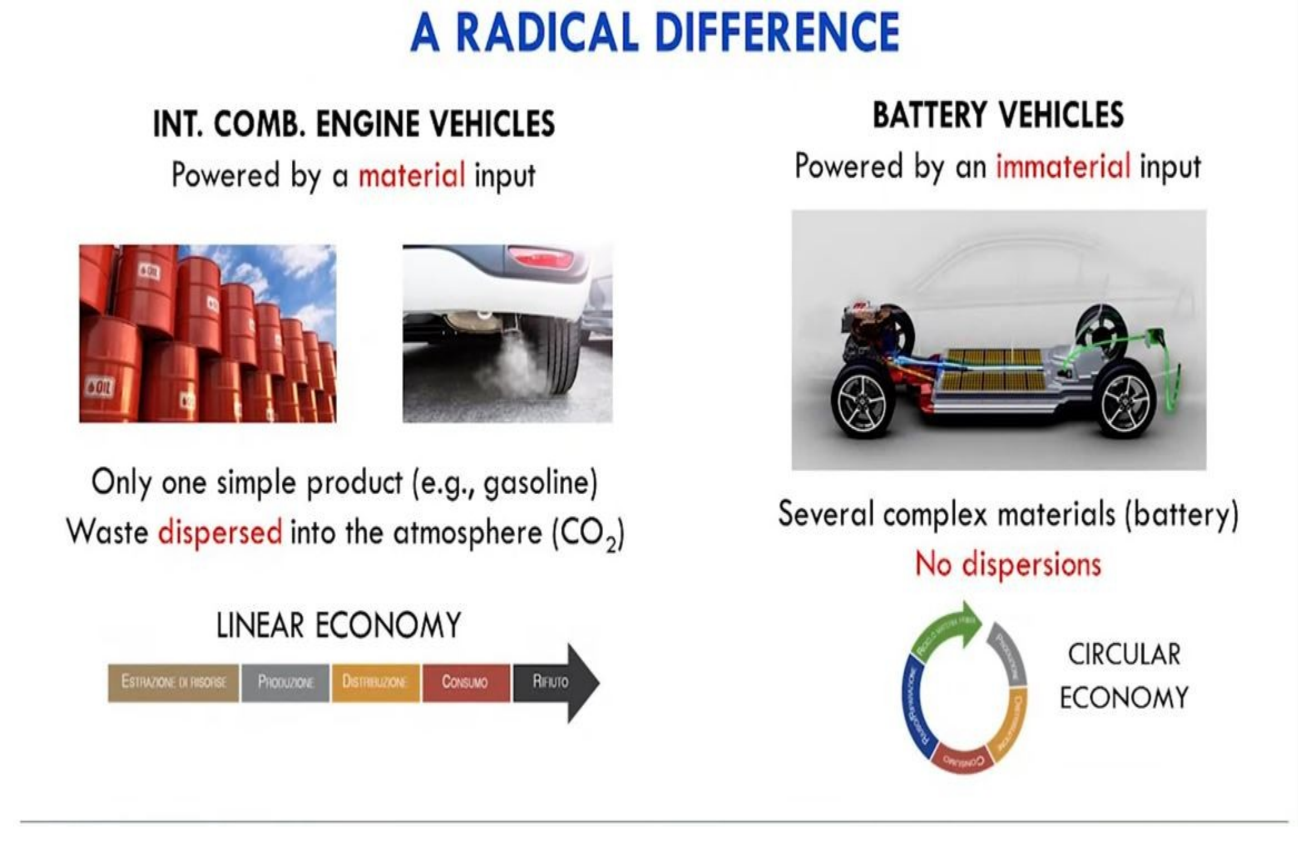


Fig. 86 – *A radical difference*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

But attention! In this section we talk about battery-powered vehicles and, usually, these are Lithium Ion batteries (or more simply Lithium batteries). But not all Lithium batteries are the same! There are different types of components and, therefore, there is a risk of confusion and communication errors. To give an example, there are batteries with the same and common energy capacity (50 kWh) but with different and unequal cathode chemistry, in this case, let's take the NMC 523 as a starting point, comparing it with the LFP. In the first case, the NMC 523 contains Nickel, Manganese and Cobalt - which are Rare Earths and therefore often critically important in their supply - with a total of almost 50 kg of these three types of materials. While in the second case, the LFP, made of Lithium, Iron and Phosphorus, does not have any of these three critical materials and has within it almost 40 kg of Iron and just over 20 kg of Phosphorus, both materials that are much more available, accessible and therefore not particularly problematic in their supply and accumulation.

MATERIALS CONTENT, A COMPARISON (in kg of metals)

	50 kWh NMC 523 Ni-Mn-Co	50 kWh LFP Lithium Iron Phosphate
Lithium	5,5	4,9
Cobalt	9,5	/
Nickel	23,5	/
Graphite	44,0	59,4
Manganese	13,5	/
Copper	17,0	23,2
Aluminum	29,0	39,4
Iron	/	37,3
Phosphorus	/	20,7
TOTAL	**142,0**	**208,1**

Fig. 87 – *Materials content, a comparison (in kg of metals)* , N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

III.II.1 – Quantities of resources, rare earths, bottlenecks and future possibilities: the topic of batteries for the energy transition and beyond

Let's now talk about one of the most discussed essential materials regarding batteries for our many electronic instruments and not only and also, obviously, for electric energy accumulators and for electric vehicles in general: Lithium. What can be said about Lithium? Is there enough of it available? We cannot do without this fundamental mineral element, both for the energy transition and for other development issues and sectors such as the technical, economic, scientific and technological ones. It is extracted from mines, as currently happens in Australia, and in particular brines as in South America. According to the US Geological Survey of 2023, the lithium resources estimated about ten years ago, in 2013, corresponded to 23 Megatons. The new estimates made recently in 2023, however, bring the amount of lithium available globally to 98 Megatons, that is, more than 4 times as much as the previous estimated quota. One might ask: but how is this possible? Because, over time, as it was established that Lithium was increasingly useful and necessary, we began to progressively and extensively search for and find it and in the end, in current times, the resources available and usable for our purposes have increased from the original 23 Megatons. From this last quota searched and identified, at the present time and in economic terms, 26 Megatons of the aforementioned mineral are currently exploitable and employable, which are available as reserves. Given all this, given that something like 8 kg of Lithium are needed for each motor vehicle, how many BEV cars can be built and produced with these 26 Megatons available? The figure is impressive: 3.2 billion vehicles can be built between cars and VANs. They are also a mammoth and exaggerated quantity if we then take into account that nowadays the motor vehicles present worldwide are something like 1.4 billion cars and vehicles. In the end, these numbers are not as markedly distant and unreal as one might believe and suppose. So, is it possible and feasible to have the ability to transform and make possible the complete electrification of the global car and vehicle fleet? To make every vehicle, present and manufactured, an electric vehicle? And how? The answer to these questions is, however, rather uncertain: it all depends on multiple and diversified factors and variables: how much Lithium will be discovered and brought to light, how much Lithium will be recycled, reused and put back into circulation in the economic and production chain? Or perhaps we should say, more accurately, in the resource cycle, since we are still dealing with a Circular Economy system. However, other types of lithium-free batteries are being researched and developed: such as Sodium and Nickel batteries or Sodium only batteries, also referred to as Salt batteries, and even Sand batteries! Projects with these different types of materials are being developed and researched, but it is still too early to consider them complete and achieved in their ability to be usable. In the future, batteries will be smaller, flexible in use and modular, given that, for the most common and daily uses, they do not necessarily need large batteries but smaller ones are more than enough.

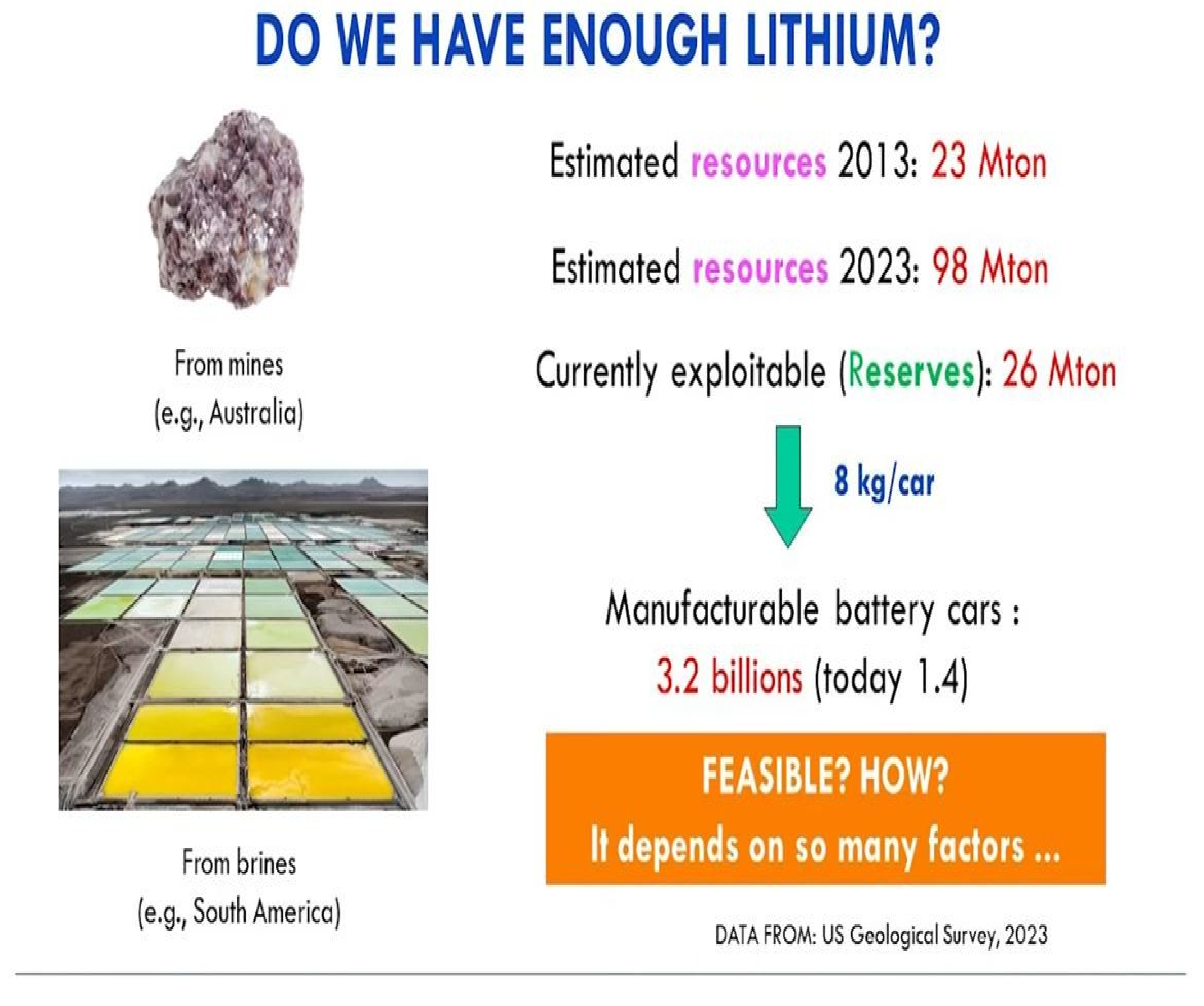


Fig. 88 – *Do we have enough Lithium?*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Another current issue, very present and discussed in the public debate, is the problem of Rare Earths such as Cobalt, which can be exploited precisely to build new batteries, as we have just seen with the NMC 523 battery, where the C stands for Cobalt. The extraction of Cobalt is a harbinger of very serious violations of Human Rights. It often happens that, if you declare that you own an electric car, other people such as friends, relatives etc. come to criticize and reproach you because the battery for the vehicle you own ends up fueling exploitation, slavery, abuse and violence (for example in Africa) on people who work to dig and extract this precious material, perpetrating heinous crimes such as the exploitation of child labor. These crimes and abuses, to name one case, have been discovered and brought to the light of international public opinion in the

Democratic Republic of Congo, where these minerals are very present and where, unfortunately, these abuses of Human Rights are all too frequent. The absurdity of this criticism and this reproach is that it is aimed not only at batteries for BEVs assembled with Cobalt, but also at those batteries where Cobalt or other Rare Earths are not present, such as LFP batteries. However, this is surprisingly ignored with regard to other small products and devices on the market, and commonly employed and used, where Cobalt is also present, often even to a greater extent, in consumer goods and articles such as lawnmowers, automatic robotic vacuum cleaners, PCs and, first and foremost, smartphones and other digital devices and instruments.

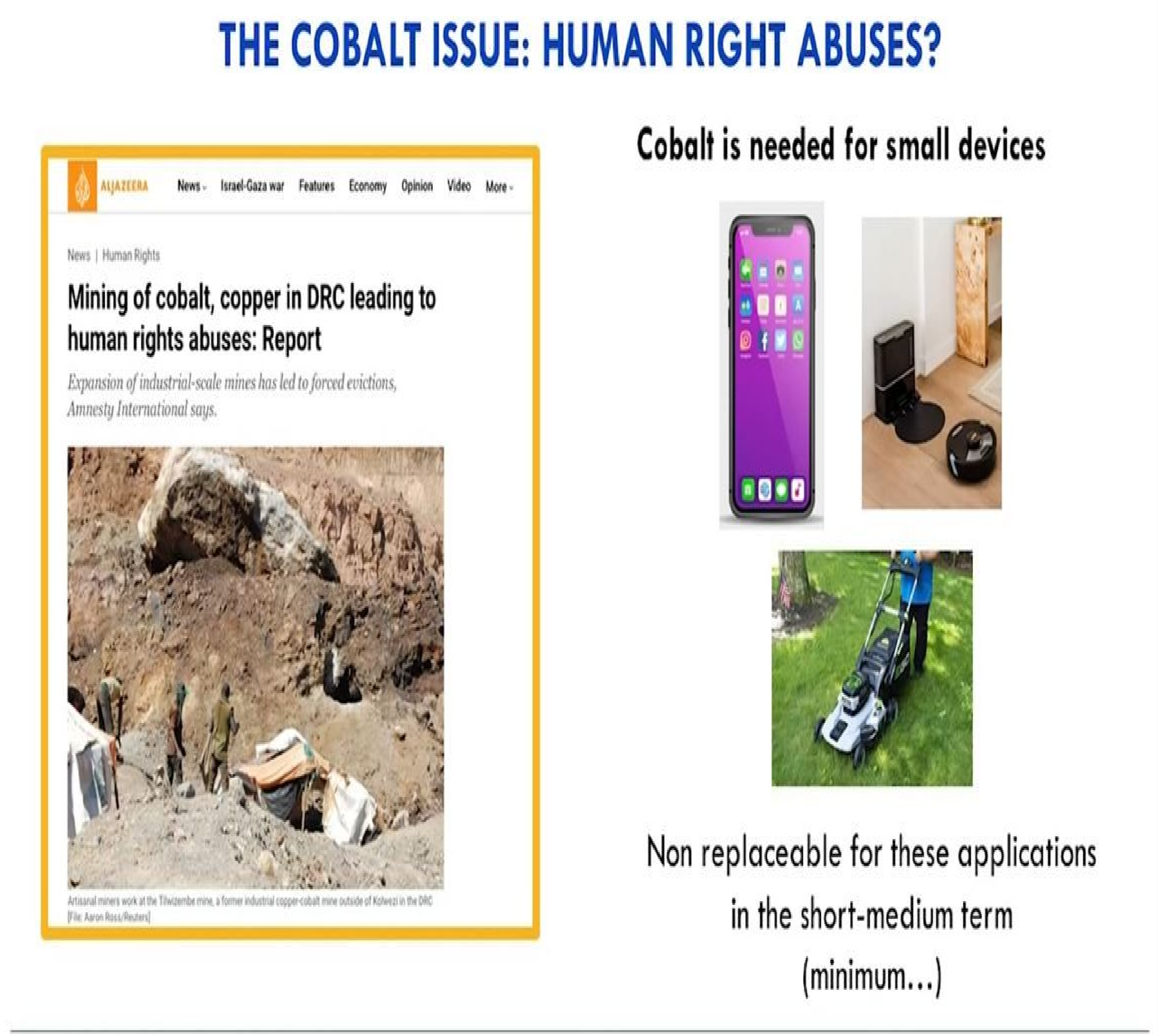


Fig. 89 – *The Cobalt issue: human right abuses?*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

In these goods and products Cobalt is absolutely necessary and cannot be replaced by other materials at this time, but research is ongoing. Let's now look at the numbers and general data regarding Cobalt to have a broader and more concrete context and vision.

The largest global supplier of this material is the Democratic Republic of Congo (DRC), with 145 KiloTons produced in 2022 and an overall share of the total world production of 73%. It has been estimated that of this very important share of the DRC, approximately 20% of production derives from probable violations and abuses of Human Rights.

Approximately 40% of Cobalt is used for batteries in the automotive sector and therefore only 5.9% is the share of Cobalt extracted that ends up in the electric vehicle sector to which crimes and offenses against Human Rights can be traced.

This is yet another example of how certain myths/hoaxes, which are believed to be true, after having viewed the data and compared the information, prove to be only mere insinuations, manipulations and disinformation without any real basis in reality.

Fig. 90 – *Supply and use of Cobalt*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

We continue with this analysis of the availability and supply of materials and minerals useful for batteries and for the energy transition as a whole, arriving at another crucial question: are the overall mineral resources available in sufficient and adequate quantities to produce the necessary batteries? There are numerous projections from different sources in this regard, but let's take a reliable source such as the International Energy Agency as a point of reference. In fact, according to a projection from this institutional source, it is estimated that the necessary growth in the productivity of the various materials and materials, to maintain and contain the growth of global temperature within +1.5°C, is to have and supply 42 times more lithium, 25 times more graphite, 21 times more cobalt and more. These are also very large quantities. But are there enough of them? Do we realistically have these large quantities available? The answer to this fateful question is yes. It is positive, not only because the quantities requested compared to the available ones are quantitatively satisfiable, but also because the need for mineral materials, requested in the quantities just described, is significantly reducing over time thanks to new innovations and efficiencies that allow us to request ever smaller quantities to make the goods and products requested work. The real question that must be asked and addressed does not lie so much in the quantitative availability, but in the implementation bottlenecks for its achievement. These limiting bottlenecks are essentially the following: exploration, permits and consents, implementation extraction in and of itself, refining and manufacturing of the product. Understandably, we are led to think that the missing piece of the mosaic that hinders this process is the amount of resources and their possibilities for use, resources that, instead, our Planet possesses in abundance. Instead, in the end, the real knot to untie, the real challenge is: are we fast enough and capable enough to create, in the best possible way, the production chains for the production of batteries and other devices and equipment necessary for the necessary transition still underway? This is, once again, the real determining focal point: time. This is the real problem to face and solve.

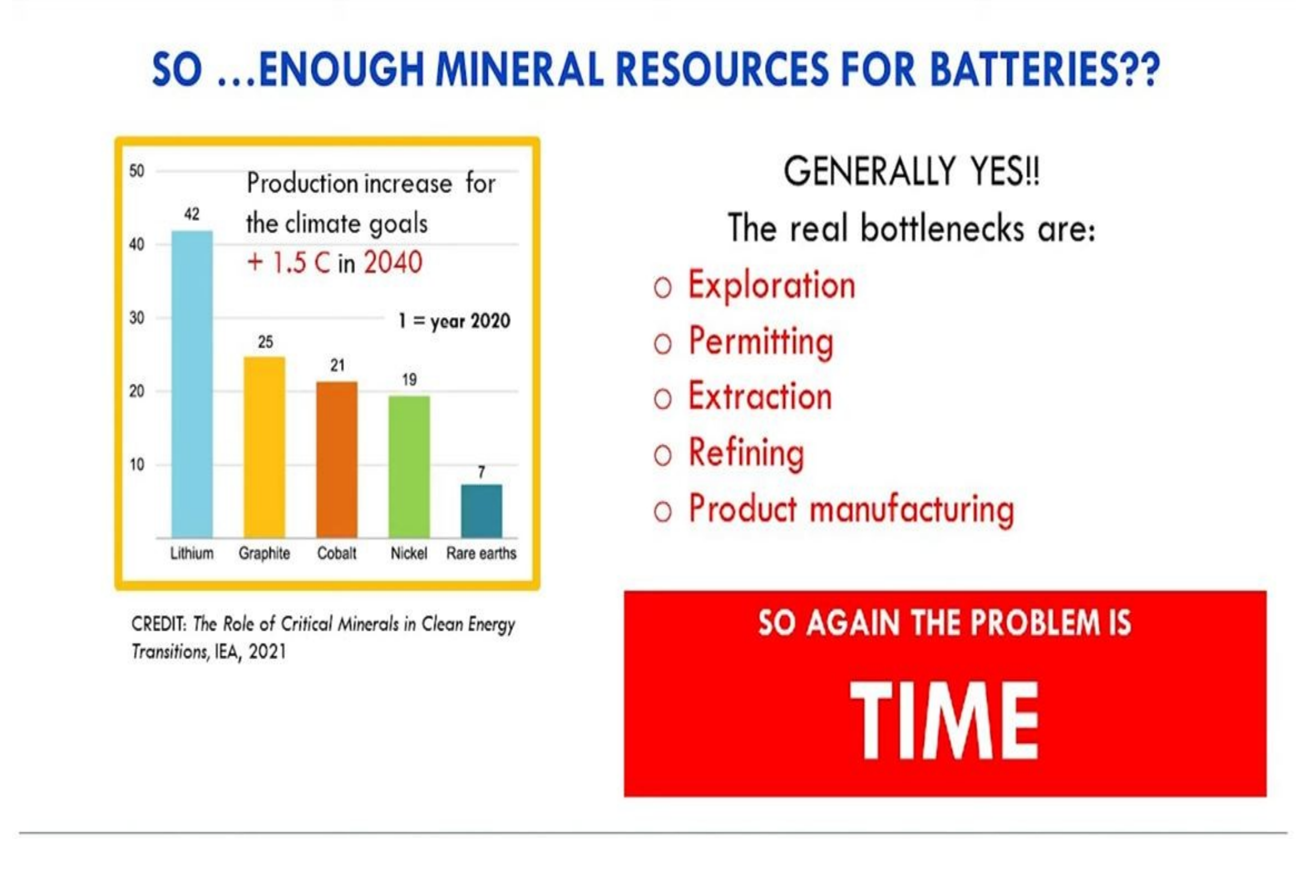


Fig. 91 – *So... enough mineral resources for batteries??*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Speaking of batteries and the materials needed to build them, let's take a look at one of the types of batteries that was previously mentioned and that, as anticipated, can represent a real turning point that can potentially change the landscape and times in this race to electrification: Sodium and Nickel batteries, better known as Salt batteries. This type of accumulator is still in the research phase, but it can really change everything. They have a lower energy density due to physical limits and, as a consequence of this, given that in the current circumstance the volume is not a problem, if they are actually implemented they would have an impact first and foremost on the renewable energy sector. Even more, the excellence of these Salt batteries comes from the fact that the Sodium they are made of, as is easy to imagine, can be extracted and collected anywhere and, furthermore, it can be combined and combined with the desalination of Ocean Salt Water, for example for the conversion from Sea Water into drinkable Fresh Water, through purification and potabilization systems.

In our complicated and chaotic world, one of the biggest problems on the agenda and increasingly present in the international scenario is that of the supply of clean Water. Therefore, desalination processes for the creation of clean and drinkable Water can be combined with the production of these plausible types of accumulators. In fact, these produce, as a waste from the Water purification process, brine that can be used to produce sodium for both table salt and the aforementioned batteries under development. Here is another possible example of a potential Circular Economy that would allow us to solve even more problems. However, we repeat, this is an eventuality still in the research and development phase and making predictions is rather difficult. Therefore, we can only wait and stay updated for any progress and news on this possibility.

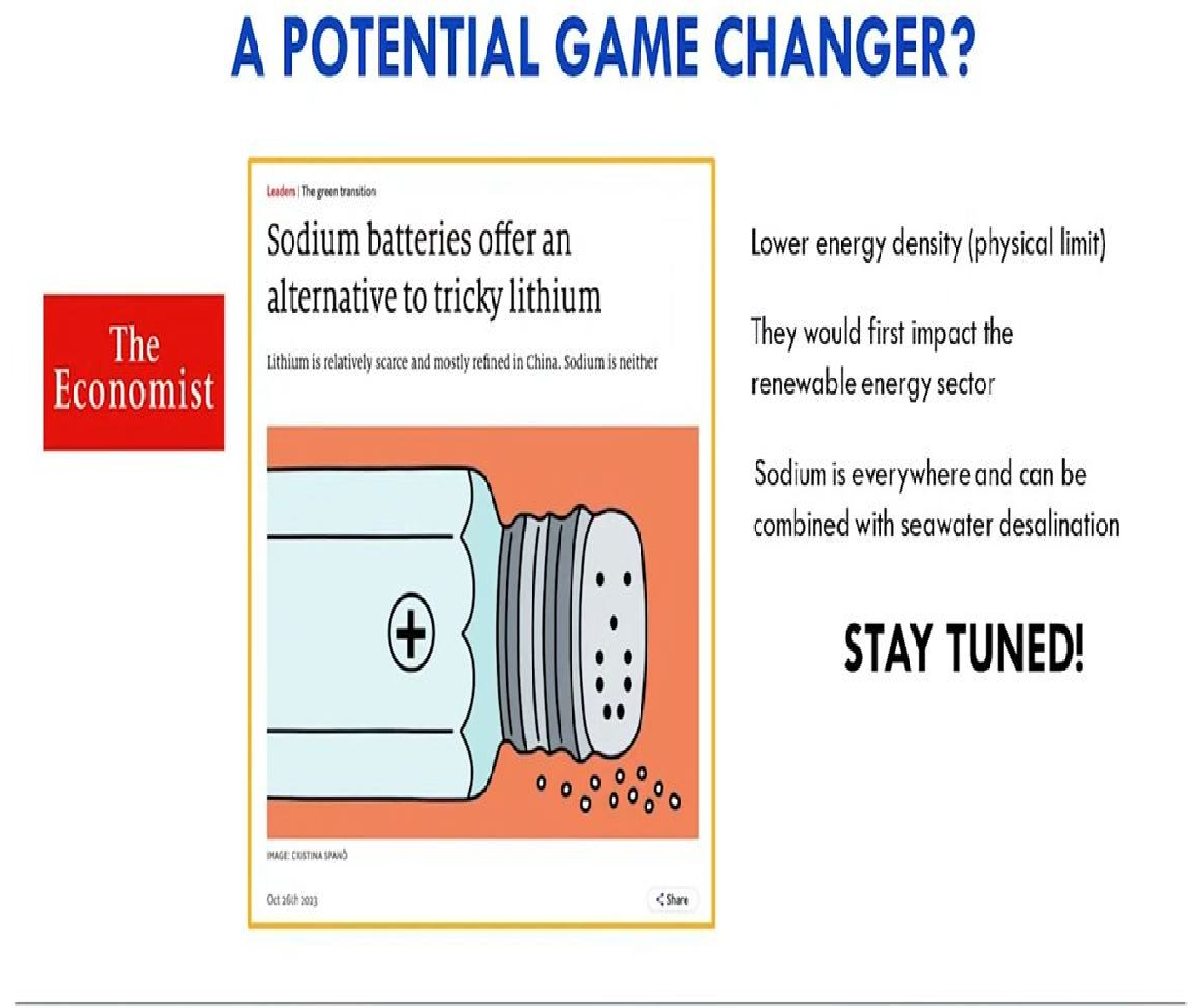


Fig. 92 – *A potential game changer?*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

III.II.2 – What can be done in one's own small way? How to decarbonize our lives

The question is: can I decarbonize my life? To answer this question, after having illustrated, analyzed, compared research, progress and the various goals to be achieved, the example that the aforementioned Professor Nicola Armaroli has directly realized is enough.

The example of Professor Armaroli, concerns the electrified house, where he has lived with his family for about 2 years, which is equipped with a 10 kWh photovoltaic system installed and another solar thermal system for the absorption and storage of heat for common domestic purposes such as domestic hot Water. Attached to this there are also, as you can imagine, a storage battery to store the excess electricity produced by the system and also a Geothermal heat pump as a general source of heating and cooling for the house.

The concrete data is its energy balance: from January 1, 2023 to December 11 of the same year, the Professor's house produced 11.6 MWh of electricity, while it consumed 10.2 MWh, thus producing much more energy than it actually consumed. Furthermore, almost 25% of the energy collected and transmitted was fed into and loaded into the public electricity grid, a fact that, in addition to generating revenue for the good supplied, can be integrated with energy communities that allow social, as well as environmental and economic, collective and interconnected benefits. The house is also equipped with a 1200 kWh electrical outlet for charging its BEV car and approximately 40% of its supply comes from home self-production. All this, among other things, was not done in a region or territory with abundant sunshine like Sicily or other islands or territories of Southern Italy, but rather in the gray and foggy Po Valley. These results can be even higher and more powerful in other territories of Central and Southern Italy and in other Mediterranean countries such as Greece, Spain, Portugal and so on.

Summing up and defining it all: this way of life is increasingly growing and has a huge space for expansion and enlargement given the millions and millions of independent buildings and structures existing in Europe and beyond. A real gigantic sleeping colossus, just waiting to be awakened for the transition, supply and public and collective energy security aimed at the energy independence of both States and families, and more generally of society and peoples.

Fig. 93 – *My electrified house, with Solar thermal*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

CONCLUSIONS

Finally coming to the conclusions, let's pick up where we started: the energy transition is the greatest challenge in the history of humanity. This is because we have to complete this test in less than 30 years, with a transformation and remodelling of our economy and our lives with all that it entails. We have been, for too many years, within an energy transition that lasted over 2 centuries, such as the transition from Wood to Coal which took 1 century. But we now have to do these crucial steps in less than 1/3 of the same time. A huge challenge. But we must not give in to discouragement, resignation, guilt or despair. In fact, the good news and the positive side of this gigantic challenge as human beings is that the key technologies, the means and the necessary tools already exist and are widely available. We must therefore not wait, or hope for a miracle, a futuristic technology or a fortuitous and providential event. We have photovoltaic and thermal solar panels, we have accumulator batteries, heat pumps of various types and uses, hydroelectric sources, biomass and so on. This is, in essence, what we have and what we will have to use to have the future we want for ourselves, for others and for those who will come. These are the solutions for 90% of our climate problems (and not only), they are solutions that exist, are immediately available and, in particular, are simple and easy to use in the vast majority of cases. The remaining 10% of the problems to which answers depend on Science, on the crucial developments in progress and on the precious technical-scientific research as a whole. This will take time and, as we have seen, we do not have that much of it available. But, at least for a good 90%, this challenge can certainly be won.

Fig. 94 – *Key technologies for the transition*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

Returning to numbers, trends, data, we see how these technologies are having exponential growth rates and indices. Wind, Photovoltaic, Heat pumps, storage batteries, electric vehicles and so on are increasing and are being distributed throughout the world. For all these reasons we must ask ourselves: what spaces and areas of use and applications can other types of technologies have that often remain polluting and therefore are not zero-emission in the next 10/20 years? Technological types that are characterized by being more expensive, burdensome, uncertain and controversial? This must be asked given that, while renewable sources grow exponentially without blocks, relapses, stumbles, stalls or crises within them, on the other hand other technologies have substantially flat growth and perhaps will not produce noteworthy results and fruits. But what sense does it make to focus on the latter with all their problems while we already have the tools we need right away, in their various forms, which are growing and improving more and more? The money and funding are there but they are not unlimited. Given the current knowledge, we must consciously and seriously choose this paradigm shift.

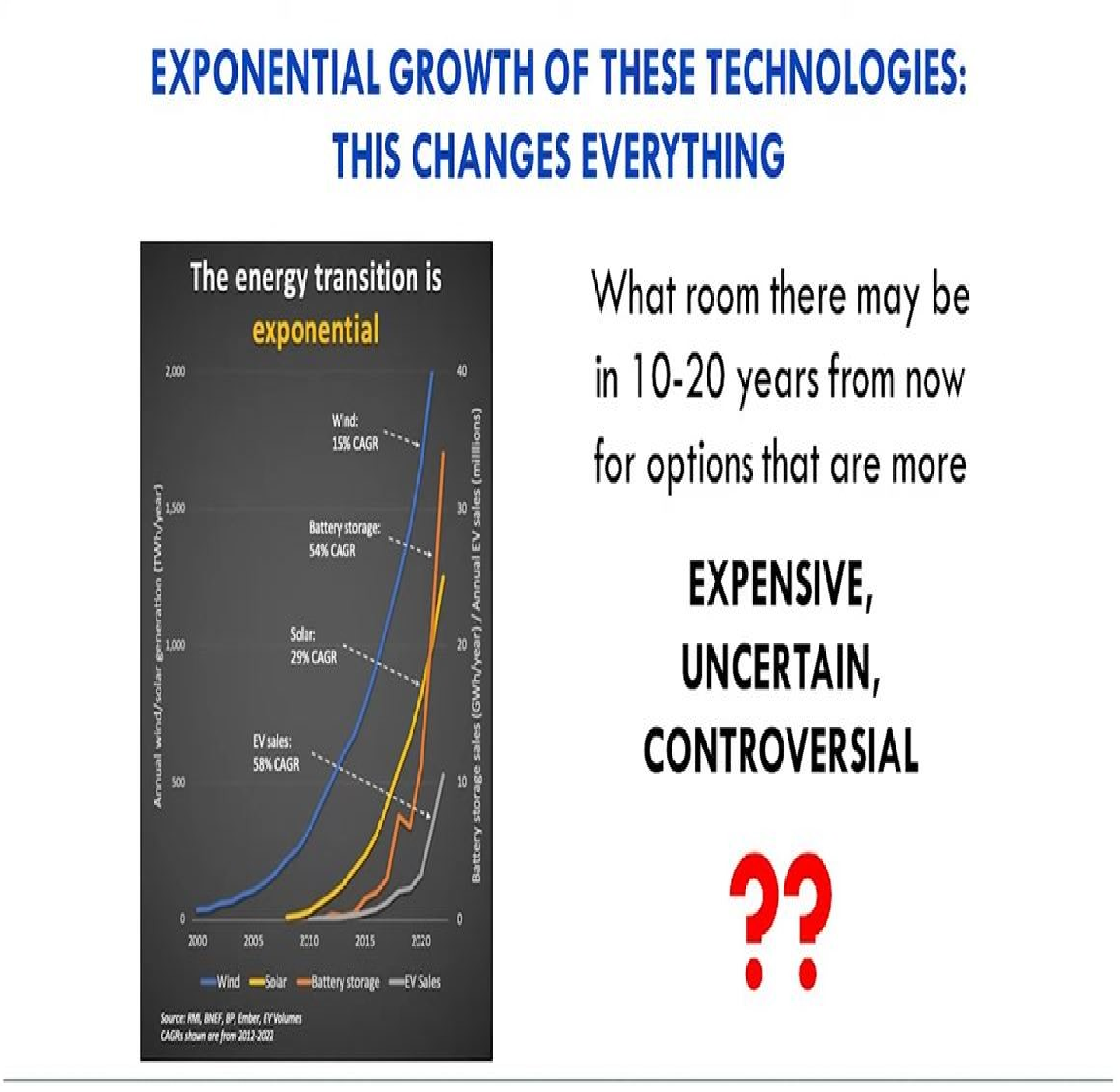


Fig. 95 – *Exponential growth of these technologies: this changes everything*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

One thing is certain: renewable technologies are changing everything. When there are exponential growths like this, everything, inevitably, changes. Time is our enemy and speed of execution must be our obsession.

Fig. 96 – *Time is our enemy speed must be our obsession*, N. Armaroli, *The Energy Transition: how can we made it?*, Atlante Days Event, Milan, 2023.

The most varied debates have been ignited on the energy and ecological transition, all too often with arguments that are quite questionable if not blatantly unfounded. For example, many criticize the fact that the materials and resources needed for the energy transition are in turn excessively impactful and harmful to the Planet and that therefore the transition should be made milder or even stopped. Those who push and insist on such positions must be provided with a clear figure: in 2021, the extraction from the Earth, at a global level, of Lithium, Cobalt and Rare Earths useful for the energy transition was 0.5 Megatons. In the same period of time, however, the extraction of fossil fuels including Coal, Oil and Methane Gas was 15 Gigatons (Giga, not Mega). Who knows which is the most impactful? The numbers speak for themselves, but too often in the debates on these topics the emphasis is placed on the impact of the extraction of minerals useful for the transition, ignoring, sometimes shamelessly, the damage that has been done, and continues to be done, with the extraction of now obsolete and harmful fossil fuels.

It is understandable and reasonable to worry about the availability of Rare Earths and other resources for the energy transition, but no one ever says anything about the immense and impactful amount of resources extracted every day from our Planet. The evidence of the climate crisis we are experiencing is also called into question. It would be useful and necessary to remember that, in any case, the economic system as it is currently structured is not sustainable in the least, let alone for a future population, on our Planet, of 10 billion people.

A quote among many that can be made in this regard is: "The rich country is not the one that allows poor people to have a car but that allows rich people to have public transport". Taken alone, Science and technology cannot guarantee us a rosy and dignified future worthy of the name. We must therefore consume less and more efficiently, with more responsibility and care, and we must inevitably act politically in this direction. This is a necessary premise that often must necessarily be made: moving from a system of mere quantitative growth (GDP), tending towards an unrealistic and illusory infinite consumption, which ignores and does not take into account the balance of resources and natural cycles, to a logic of sustainable development, where the growth of per capita income and GDP are the result and fruit of qualitative changes and transformations of a structural and cultural nature in society. Only this can lead to the reduction and progressive elimination of poverty, to the increase and collective improvement of the quality of life, to environmental sustainability and, in general, to personal fulfillment.

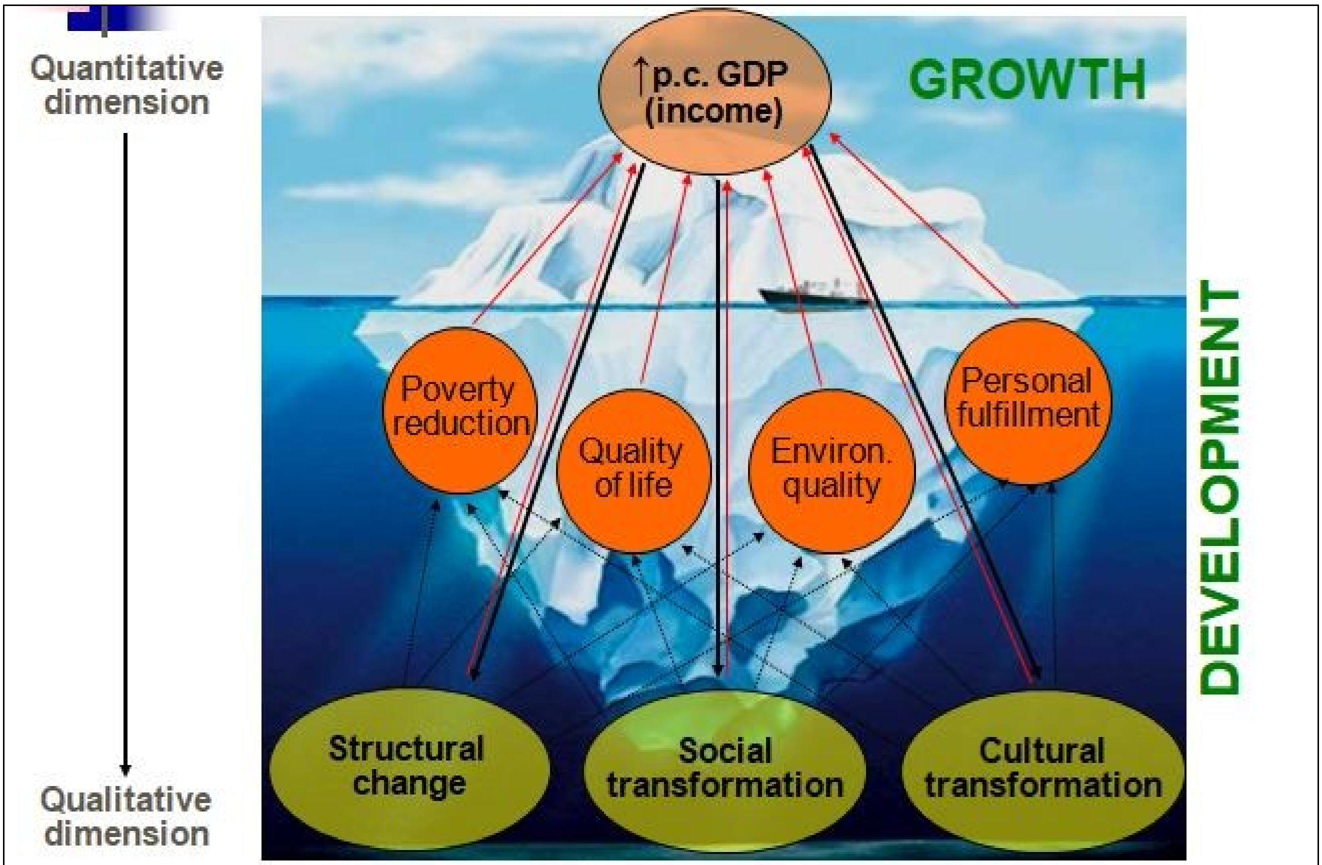


Fig. 97 – *From growth to development*, R. Esposti, Slides of *Economics of Environment and Natural Resources*, Faculty of Economics “Giorgio Fuà”, Ancona, 2020.

On the other hand, with great responsibility and attention, we can ask the fateful question that, presumably, each of us has asked ourselves: can we do it? Can we successfully complete the energy transition? It is impossible to say yes with certainty, we have not been and are not yet capable and able to make clear and accurate predictions on the energy transition underway, on the technologies to be implemented and executed and so on, as there may be unexpected and unpredictable events and changes, even very positive ones, as has already happened. In truth, every more specific detail of the energy transition is essentially unknown to us and no one can predict the future. Certainly, however, tools such as economic and fiscal interventions can change the energy world and beyond. Remember that the IMF, the International Monetary Fund, has calculated, using 2022 data, that 7 trillion euros/dollars are spent in the world in direct and indirect subsidies to polluting fossil fuels. Being able to shift and redirect a considerable share, if not all of it, of these funds towards clean and renewable energy would certainly make a difference. It is a political choice, which concerns each of us and for which each of us is inevitably responsible. What is equally clear is our objective: to progressively eliminate fossil fuels and not to gradually reduce them, as is attempted with the policies of the most recent COPs. A quote that deserves and we must keep in mind, is that of the great French writer Antoine de Saint Exupéry: "As for the future, your task is not to predict it, but to enable it". Make it possible. Let's work hard, together, with great strength and unshakable determination to finally make it possible.

BIBLIOGRAPHY

* N. ARMAROLI, *"UN MONDO IN CRISI"*, Edizioni Dedalo, Bari, 2022, Volume of pages 152.

* R. ESPOSTI, *"Course on Economics of the Environment and Natural Resources"*, PowerPoint Slides, Ancona, 2020.

* N. ARMAROLI, C. CARRARO, P. CAZZOLA, E. CHERCHI, M. TANELLI, M. TAVONI, A. TILCHE, M. TORSELLO *"Decarbonising Transport - Scientific evidence and policy proposals"*, *Nat. Italy,* 2022, Volume of pages 96, doi: 10.1038/d43978-022-00098-x

* P.PLOTZ, *"Nat. Electron."*, 2022, 5, 8.

SITOGRAPHY

 # Enrico Fermi Lecture 2022: The Hydrogen Dilemma

https://www.youtube.com/watch?v=uAW19I3-SKI&list=WL&index=880

 # The energy transition: how can we make it? Nicola Armaroli's speech during annual Atlante Days event

https://www.youtube.com/watch?v=rtM3Rrv0xUk

 # Presa Diretta Rai 3 – Puntata 09/10/2023: "La scossa elettrica" di Fabrizio Lazzaretti e Alessandro Macina

https://www.raiplay.it/video/2023/10/La-scossa-elettrica---Presa-Diretta---Puntata-del-09102023-a0ea5d78-4a2d-41d6-9d89-35e54f82d619.html

 # Presa Diretta Rai 3 – Puntata 08/04/2024: "A tutto Idrogeno" di Fabrizio Lazzaretti, Marianna Demarzi e Alessandro Macina

https://www.raiplay.it/video/2024/04/A-tutto-idrogeno---Presa-Diretta---Puntata-del-08042024-59a5bed6-49cb-44f6-b687-9486e3842edf.html

 # The hydrogen dilemma in Italy's energy transition

https://www.nature.com/articles/d43978-021-00109-3

 # Study: Hybrids, ICE Cars Far More Likely Than EVs To Catch Fire

https://insideevs.com/news/561549/study-evs-smallest-fire-risk/

Do electric cars pose a greater fire risk than petrol or diesel vehicles?

https://www.theguardian.com/business/2023/nov/20/do-electric-cars-pose-a-greater-fire-risk-than-petrol-or-diesel-vehicles

Erisittone (tessalo)

https://it.wikipedia.org/wiki/Erisittone_(tessalo)

Decarbonising Transport - Scientific evidence and policy proposals

https://www.mit.gov.it/comunicazione/news/decarbonising-transport-scientific-evidence-and-policy-proposals

P. Plotz

https://www.greencarcongress.com/2022/02/20220208-isi.html

Hydrogeninsight.com / October 20, 2022

www.marinetraffic.com