

FUSION IN EUROPE

NEWS & VIEWS ON THE PROGRESS OF FUSION RESEARCH



3 | 2018



EUROfusion

Most of the illustrations in this edition are created by Paula Calleja. Read more about our incredibly talented graphic designer:



Picture: private

Paula Calleja

Age: 21

Origin: Spanish

Currently based at: London, United Kingdom

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“ I have recently graduated in Design and I am embarking on my trip in becoming a fully-fledged designer! I have always been interested in how science and technology will impact our societies and how we can communicate the latest projects and advancements to a wider audience. I believe in the power of design to speculate and enquire about our future, as well as democratize scientific knowledge and progress. ”

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EDITORIAL

This is the third 'Fusion Writers' edition and this time, it is all a bit different. Our volunteer authors did not report from their lab. Instead, we invited them to use their imaginations and envision what may potentially lie ahead. "What would a fusion powered future look like?"; "What benefits does fusion hold for society?"; "What makes fusion research so complex?" and "What is the secret of solving this big quest for mankind?" – The Fusion Writers, and Artists of 2018, in fact, delivered the answers.

Our fusion experts present results and thoughts based on their daily work – like Aljaž who is a nuclear engineer. He finds compromises in order to work out the best design for DEMO, the first demonstrational fusion power plant. But, even if fusion research is such a melting pot for sciences, there is a lot of confidence in the success. For Jason and Justin, the key to the realisation of this new kind of energy lies in the cooperation of so many brilliant minds. In the event that one of the many tasks cannot be solved, a breakthrough in another related field may just do the trick.

But, how is all of this connected, how is it managed, which road will European fusion science actually take to reach its ambitious goal? Prasoon introduces the beauty of the European roadmap on fusion. Its revision will be published in autumn this year, so he decided to take a deeper look at the exclusive features of this unique book on organising a giant scientific endeavour. In doing this, he is also combats the perpetual claim that fusion is, and always will be, 30 years away.

As Prasoon puts it, fusion energy is no longer science fiction. There are countries which heavily rely on a solution to literally 'power up' their economy. Julio impressively describes the scenarios in his home country Peru. In this edition, we also read about laser-driven fusion and introduce a story that takes us 70 years into the future, when war in Sudan is a thing of the past and fusion has become a regular energy source.

What you will find in this magazine is a melting pot of visions, ideas and thoughts. They are all nicely connected by Paula's striking illustrations. She voluntarily contributed lots of artwork and could not help but use the power of her design skills to visualise the things our authors have been writing about.

For me, it is always fascinating to work with people from many different countries who all come up with so many different ideas in order to develop one jointly-created magazine. And right before I open the doors to another world to you, dear reader, I would like to thank the Fusion Writers 2018 and artists for their invested time, their tireless efforts and their great stamina in editing their texts with me back and forth until we reached a final draft. You should all be proud of your work!



Anne Purschwitz
Editor of Fusion in Europe
Picture: EUROfusion

Designing a fusion power plant is complicated. It is not a simple, elegant, unified problem, but rather a complex mess. Yet, we see this as a reason for confidence in the future of fusion.

IF WE PERSIST, WE WILL SUCCEED



Picture: private

Justin Ball

Age: 29

Origin: American

Currently based at:

Swiss Plasma Center, Switzerland

 JB_Fusion

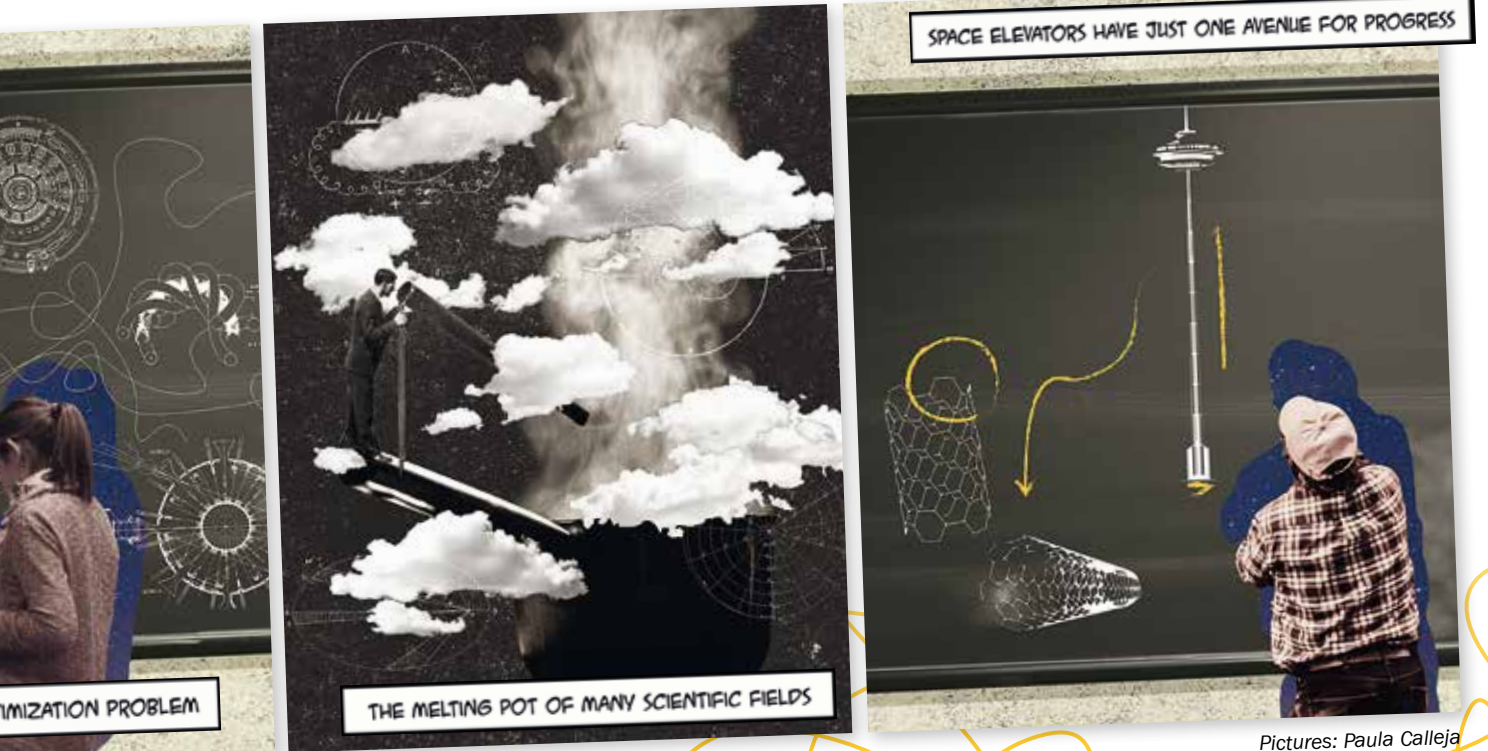
“ I am a post-doctoral researcher studying theoretical plasma physics. My research focuses on how the shape of the tokamak plasma can be optimised to reduce turbulence. In my spare time, I enjoy cooking and long walks in the mountains. ”

ONE ROAD TO A SPACE ELEVATOR

Consider the task of building a space elevator. The idea is quite straightforward: carry a cable into outer space, drop it back down to Earth, and use vehicles to climb the cable. Unfortunately, there is a flaw: we don't know how to build the cable. It must be thousands of kilometres long, but there is no material that is strong enough to even support its own weight. Hence, the space elevator is in a bad position. It has just one avenue for progress, which could prove impossible. If material scientists can't develop a material for the cable, then the space elevator can't get off the ground.

MANY ROADS TO FUSION POWER

Contrast this with fusion. Fusion is an interconnected design optimisation problem that requires balancing considerations from many different fields of science and technology. You



Pictures: Paula Calleja

want to construct robust superconducting coils to create the strongest magnetic bottle possible. You want to find clever ways of taming turbulence, which causes plasma to leak out. You want to develop ever more efficient ways to drive a steady-state electric current in the plasma. You want the solid components surrounding the plasma to be as durable as possible in order to best handle the heat and neutrons produced by fusion reactions. All of these problems are difficult, but, as you read this, scientists around the world are working on them. And when any of them make progress, it brings the whole endeavour closer to reality.

STRIKING THE RIGHT BALANCE

By tweaking the design of a power plant, progress on one of these problems can compensate for lack of progress on another.



Picture: private

Jason Parisi

Age: 26

Origin: British

Currently based at:

University of Oxford, Culham Centre for Fusion Energy, United Kingdom

jfp_fusioneer

“ I am a PhD student studying plasma theory. My research focuses on understanding turbulent instabilities in the edge of fusion plasmas in a region called the pedestal. ”

“ *There are many different potential paths to the creation of a fusion power plant, and we only need one to reach our destination.* ”

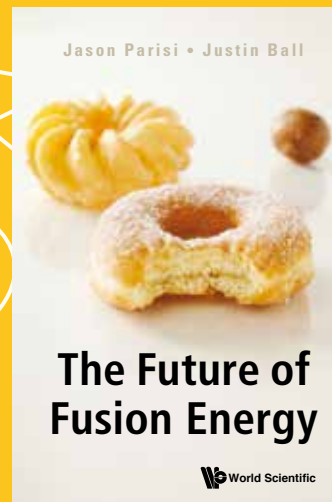
For example, let’s suppose that magnet designers are successful in using novel high-temperature superconductors to produce much stronger magnetic fields. Well, this would directly improve plasma confinement, which means that you no longer have to be as clever with your plasma physics.

Alternatively, imagine that physicists discover a way to stabilise turbulence in the plasma, but no one can figure out a more efficient way to drive the electric current in the plasma. Well, then you can just lower the electric current in your power plant design. Less current will weaken plasma confinement, but this is now tolerable because you’ve improved it by stabilising turbulence.

As a final example, imagine that material scientists are able to devise a stronger plasma-facing wall (or a cheap, easily replaceable wall). This would enable you to operate more aggressively to produce more fusion power because the consequences of the plasma becoming unstable and touching the wall are now less severe.

PERSISTENCE IS KEY

There are many different potential paths to the creation of a fusion power plant, and we only need one to reach our destination. Navigating them may prove difficult, but we can be much more confident that, if we persist, we will succeed. ■



Title: **The Future of Fusion Energy**
 Release date: December 2018
 Publisher: World Scientific
 Pages: 345

Justin and Jason have written a popular science book! It explains the fusion quest to non-scientists – discussing everything from the discovery of fusion in stars to power plant design, from the world’s biggest experiment ITER to the smallest of fusion start-ups. Accessible and fun, the book explains where we are and where we’re going.

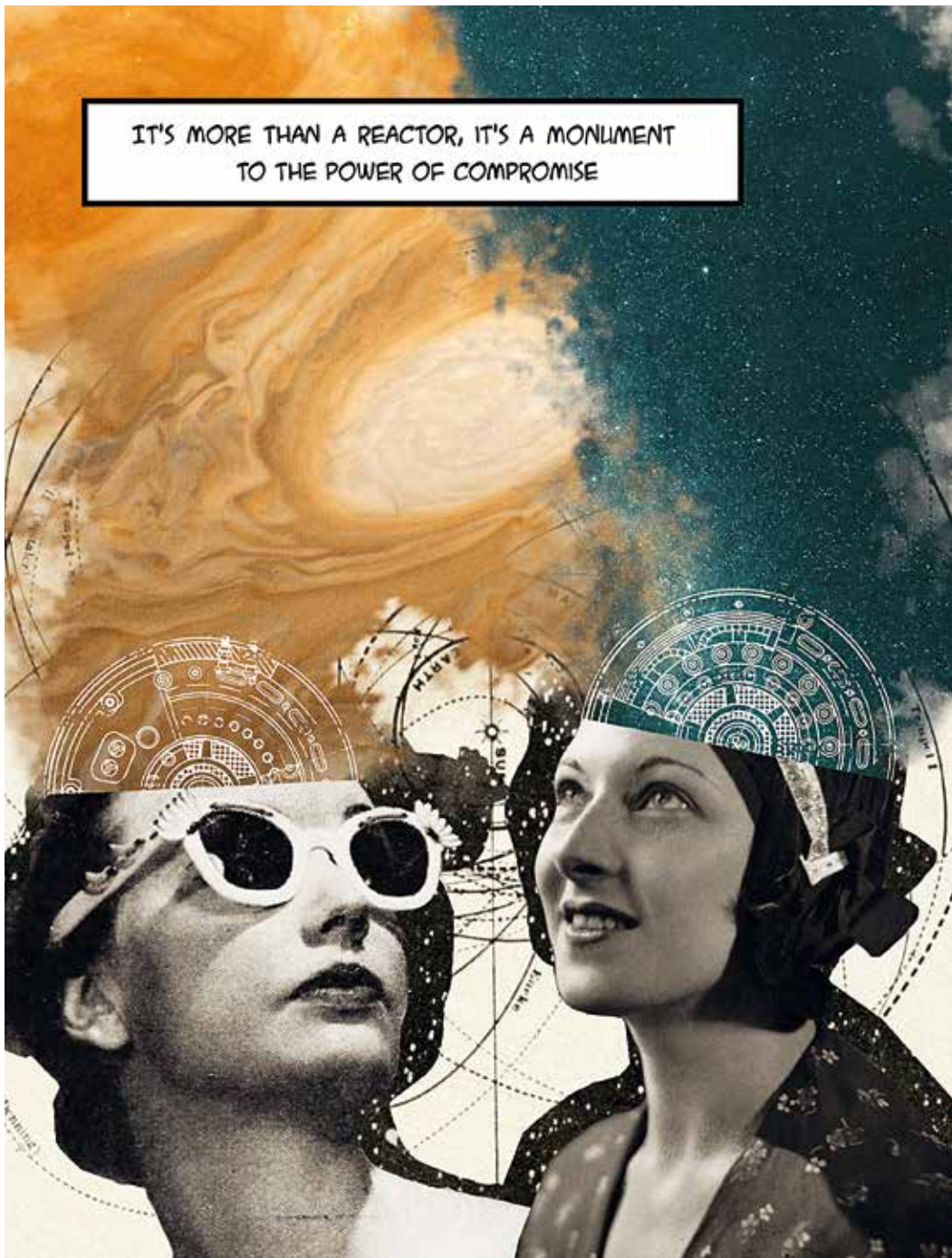
[www.amazon.com/
 Future-Fusion-Energy-Jason-
 Parisi/dp/1786345420](http://www.amazon.com/Future-Fusion-Energy-Jason-Parisi/dp/1786345420)



DEMO

A MONUMENT TO THE POWER OF COMPROMISE

IT IS A COLLABORATION WITH A VERY AMBITIOUS GOAL,
NAMELY TO REALISE FUSION ENERGY ON EARTH



The development of fusion energy is a joint effort involving many fields of science and engineering. The design of a demonstrational fusion power plant, DEMO, thus depends on progress being made on many technological fronts. Still, one of its most fascinating feats might be the coordination of the system designs and their integration into a machine that meets all of the requirements by compromising everywhere except in the final goal – the development of a safe and reliable fusion power plant.

WHY COMPROMISE?

All design and engineering challenges are defined by the art of compromise. Let's take the smartphone as an example. From this piece of technology, we expect features like a touch sensitive screen with vibrant colours, high quality cameras, a fast processor, and various connectivity protocols which allow us to listen to music, play games, access the internet, and communicate with each other.

At the same time, the phone must also work for extended periods of time between charging, fit in a pocket, be light enough to be carried around, and affordable enough to warrant our purchase. These constraints mean that there will always be better stand-alone cameras, brighter screens, faster processors and connectivity options, and computing devices with longer lasting batteries. It is also important to realise that, while smartphones are commonplace today, they consist of smaller pieces of advanced technology that were not available just decades ago. These subsystems had to be sufficiently developed by way of gradual improvement in order to enable the creation of the whole well-rounded package – the smartphone.

DEMO: A FUSION REACTOR, A POWER PLANT, AND A NUCLEAR SYSTEM

Similarly, designing a functioning fusion power plant requires the development of many individual systems. DEMO will be a giant, complicated fusion reactor. There is no way around it. The systems for plasma heating, control, and diagnostics must fit together with systems for maintaining vacuum, injecting the fuel, and extracting the side-products. This need for integration leads to hard choices and difficult compromises. What is more, instead of developing subsystems individually, the entire machine has to be taken into account and the reactor built from the ground up with strict nuclear requirements in mind – neutrons and gamma rays must be contained. Thick walls will provide shielding, and containment structures surround the systems, in order to allow safe operations. But as some systems will need to access the reactor for fuelling, reactor control, and maintenance, labyrinths and dog-leg shaped entrances will be used to balance the shielding capabilities with

access to the reactor's interior. All in all, the ultimate aim is a well-rounded system that performs well while adhering to all requirements.

EMBRACING THE COMPROMISE

Designing the fusion power plant is an exercise in planning work and development in coordination with many teams made up of different professionals. It is a collaborating with a very ambitious goal, namely to realise fusion energy on Earth. The only way to get there is by way of compromise. For me, it is a thrilling experience to work on such a challenging task. Every decision made for one system will affect the design and performance of another. All EUROfusion contributions to DEMO must be carried out in a coordinated fashion and often a series of analyses is required to determine suitable compromises. However, my job as a nuclear expert is also to find out whether the proposed solutions are capable of meeting the strict nuclear requirements. If not, I have to re-think, re-discuss, and re-analyse a solution until the safety requirements are met. While we are required to compromise in most aspects, there may be no compromises when it comes to safety! ■



Picture: private

Aljaž Čufar

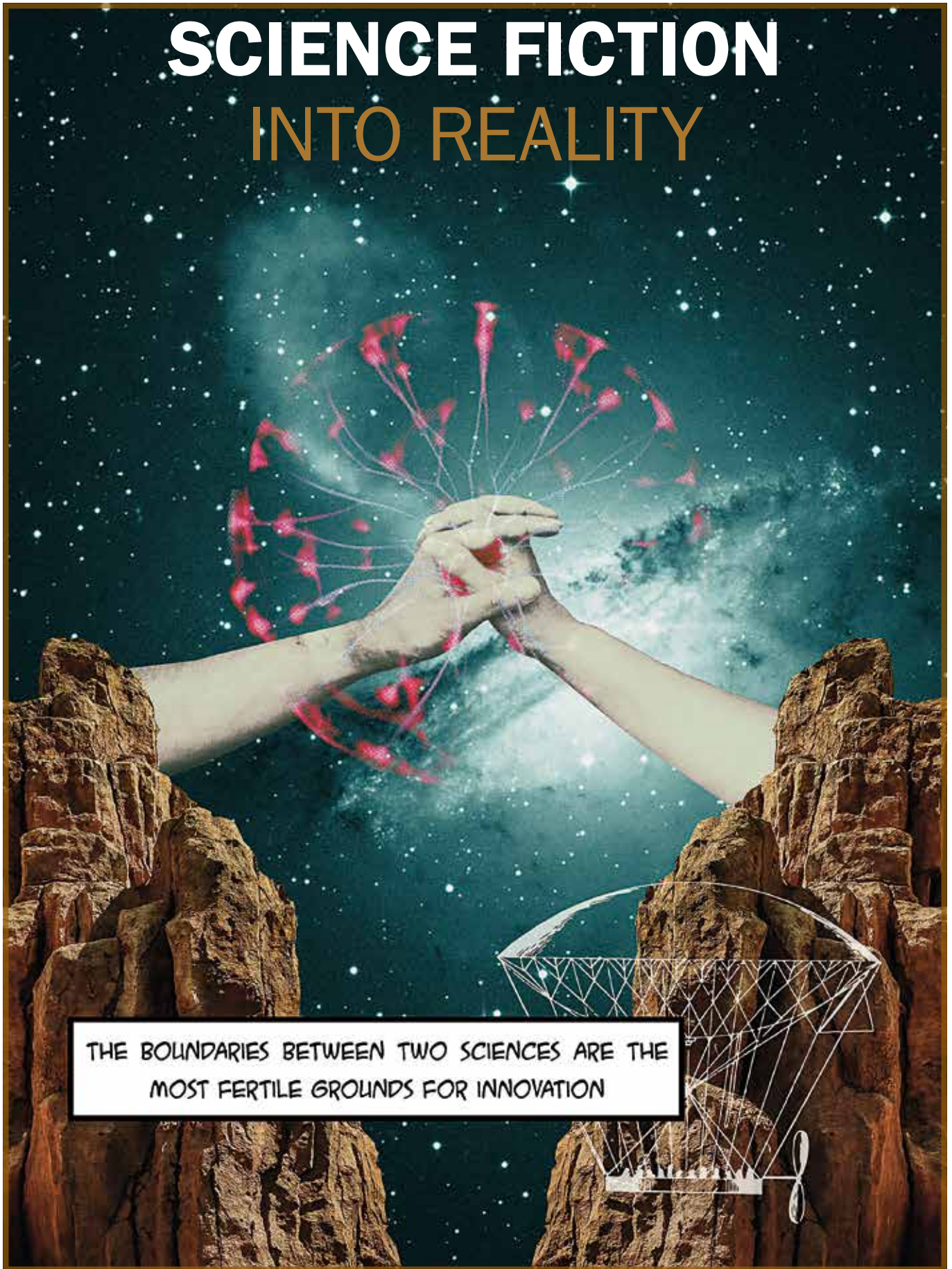
Age: 29

Origin: Slovenian

Currently based at: Jožef Stefan Institute, Slovenia

“ My fascination with nuclear technology goes back to my early teen years. It was a scary but fascinating world of powerful forces and seemingly infinite amounts of energy. The more I learned the more I saw it as an opportunity rather than a threat. I realized that cracking the fusion puzzle would elevate us to a new level in terms of energy production. I just had to be part of it! ”

TURNING SCIENCE FICTION INTO REALITY



THE BOUNDARIES BETWEEN TWO SCIENCES ARE THE MOST FERTILE GROUNDS FOR INNOVATION

Pictures: Paula Calleja

The first edition of “Fusion Electricity – A roadmap to the realisation of fusion energy” contains Europe’s blueprint for nuclear fusion. Since the European Fusion Development Agreement (EFDA) published it in November 2012, the field has seen sizeable progress. The roadmap, which is under revision this year, proves that fusion power is everything but science fiction. In its 60 odd pages, over 50 distinguished scientists and more than 10 industrial experts showcase the scholarly vision and the exhaustive planning of this the European fusion venture. Apart from investing billions, Europe has advanced fusion within sincere time and the budgetary constraints.

WHO SAID FUSION IS ALWAYS 30 YEARS AWAY?

Europe adopts a fast-track approach to land in the era of commercial fusion power plants (FPP). ITER is the linchpin of the plan, the largest share of money and personnel is devoted to its construction, operation and exploitation. A full-scale demonstration power plant, DEMO, will build on the lessons learned from ITER. It is designed to close the gap to the successful design of FPPs. The tasks, spanning over 35 years, are packaged into eight missions, converging the diverse competencies of more than 30 institutions and several companies from across the continent. The grading of various engineering expertise in terms of its readiness, both at present and post the ITER and DEMO stages, is unique and useful. Additional experimental facilities are joining the quest to rapidly mature these technologies, including active devices like the Joint European Torus (JET), Wendelstein 7-X and other international machines, such as an envisioned Divertor Test Tokamak (DTT) and a DEMO-Oriented Neutron Source (DONES).

IT IS NOT ABOUT BETTER CANDLES

Thinking along similar lines as the famous French physicist Édouard Brézin, who said in his autobiographical essay, “electricity was not invented by trying to make better candles”, the roadmap advocates a balance between pragmatism and innovation. It outlines how to systematically promote novel research in physics and engineering in both laboratories and industry, while already apportioning a ten percent allocation of finances to basic research,

“ *Electricity was not invented by trying to make better candles.* ”

Édouard Brézin



Picture: private

Prasoon Raj


Age: 27

Origin: Indian

Currently based at: Karlsruhe Institute for Technology, Germany

 @ak_47raj

 @ak_47raj

 mysteriumcosmographicum.wordpress.com

“ *I am a EUROfusion fellow working in the field of nuclear measurements in fusion reactors, learning, researching and developing the experimental tools. In my childhood and adolescent years, I lived in towns which had only a few hours of electricity per day. It is this first-hand knowledge of the necessity, of full-time access to power for better living, that fascinates and inspires me to work for the quest of fusion electricity.* ”

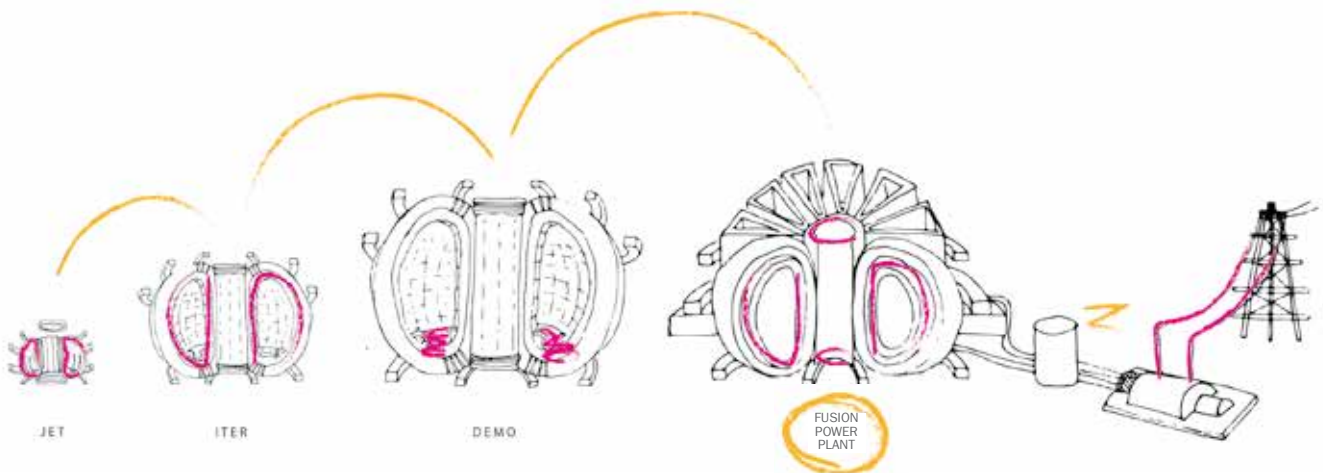
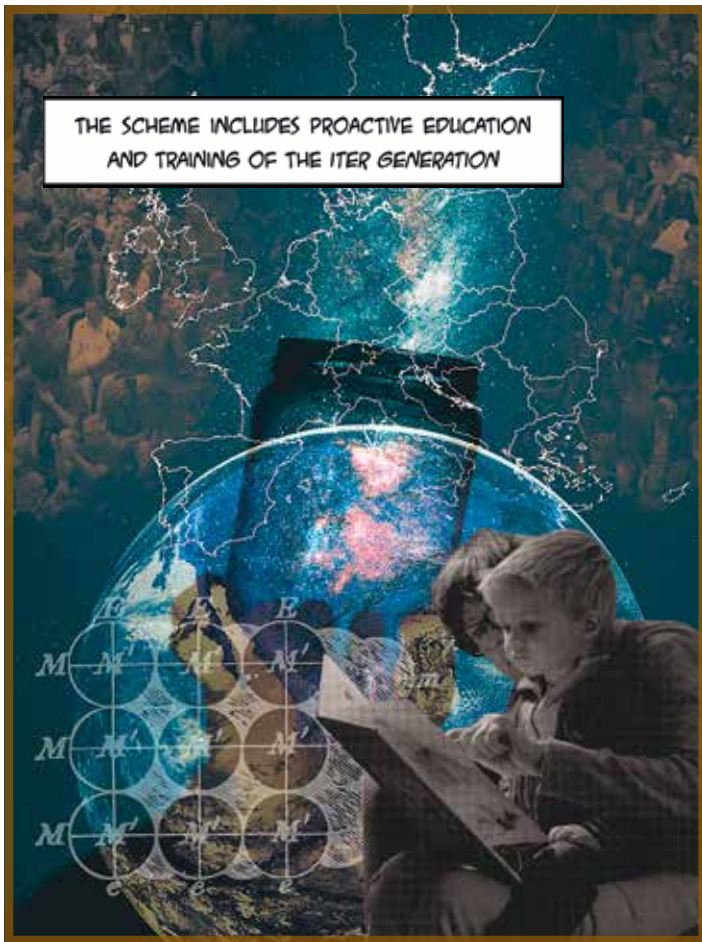
for example, into the physics of confinement or material sciences. The boundaries between the two sciences are the most fertile grounds for innovation, and what is better for it than the multi-disciplinary research demanded in fusion topics.

A HERCULEAN YET INVITING ENTERPRISE

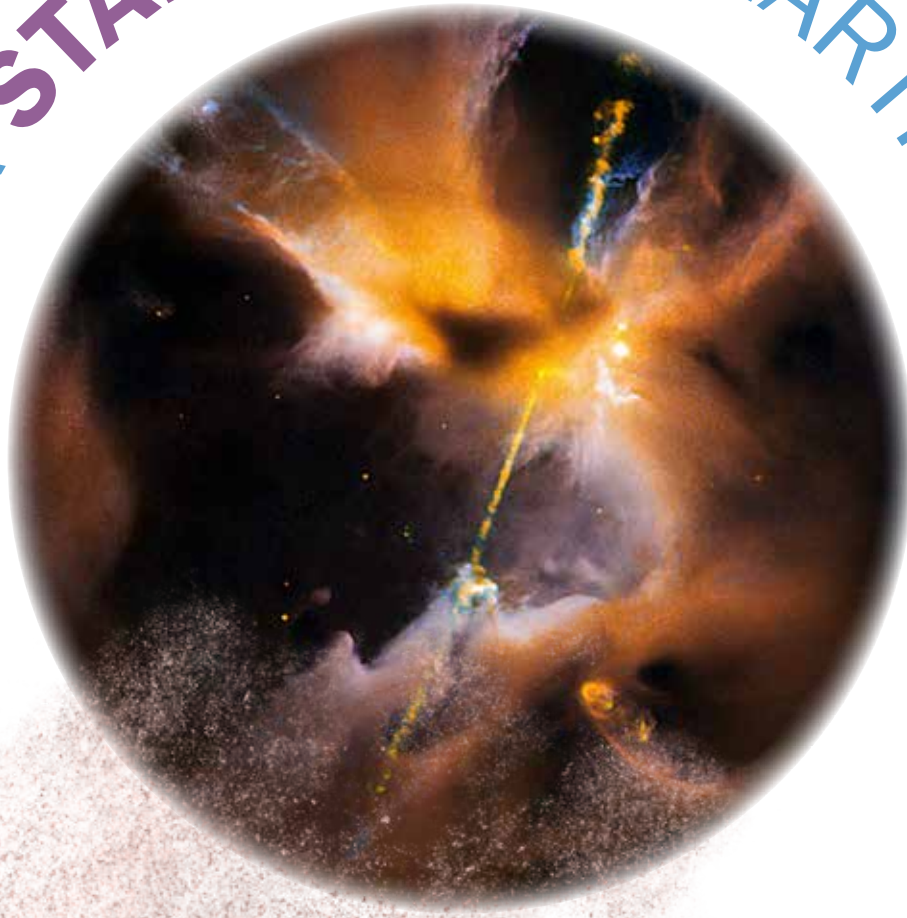
The European Union is the epitome of international partnership and industrial collaborations. Both of which have been repeatedly and exclusively highlighted in its fusion masterplan. For the purpose of experiments, ideas and experiences, numerous labs from the U.S., Japan, China, South Korea, and beyond have found a place in the programme. At the same time, the existing market-players have been incorporated from the early stages of the work. The goal here is to convert nuclear fusion into a prolific commercial entity soon. Extending its entrepreneurial spirit, Europe also welcomes and supports spin-offs of fusion research. Practical businesses based on diverse and potent ideas from fusion sciences, like the transfer of superconducting technology to the MRI, had and will continue to have great impact on the society.

This humongous project demands a large and specialised work-force, which is progressively going to grow up to four times the current number during its course. Thus, the scheme includes proactive education and training of the ITER generation. Feeding hundreds of new graduates into research and industry, Europe is already attracting youngsters to fusion, including non-Europeans, like me.

Without a doubt, fusion is a complex process and its machinery is unimaginably sophisticated. The European endeavour is based on game-changing scientific evidence. The risks are well-calculated and their achievements so far are highly promising, giving us all the reasons to believe in the picture painted in the roadmap.



A STAR WAR ON EARTH

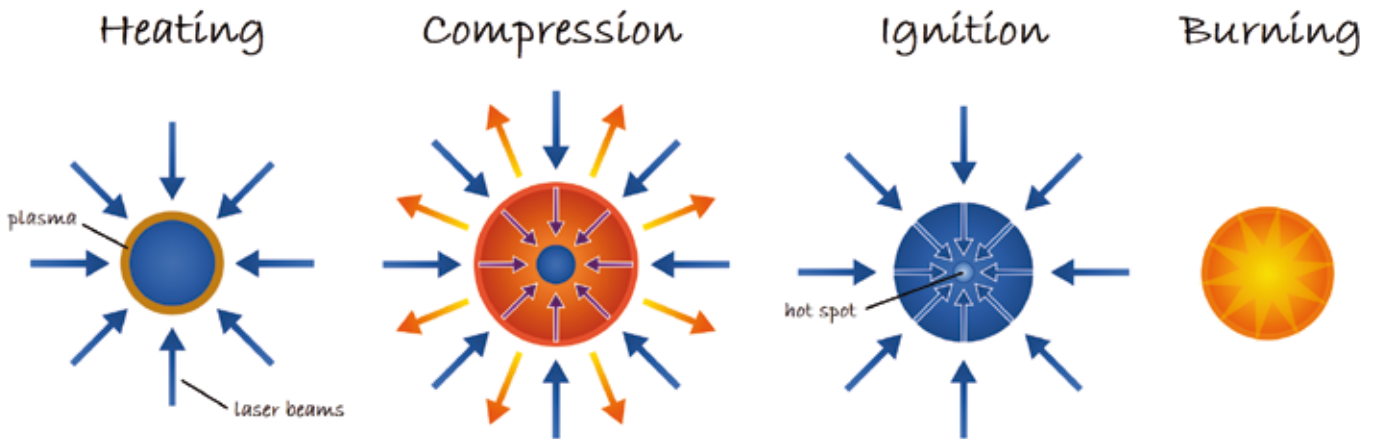


The two lightsabre-like streams are jets of energised gas, ejected from the poles of a young star.

Source: Creative Commons/ESA

Turning the power of the universe into an energy source here on Earth is quite challenging. Most of Europe's fusion devices focus on magnetic fusion, but this is not the only competitor in the race. I would like to speak out in favour of another approach: laser-driven fusion which may prove a competitor for the almighty magnetic confinement.

Since the dawn of civilisation, mankind has always looked to the Sun as Earth's primary source of energy: the Sun warms the planet, drives the hydrologic cycle, and makes life on Earth possible. Now a "star war" has begun: fusion research is about to imitate this powerful star. We want to bring it down to Earth and control it.



Inertial confinement fusion implosion process Picture: Creative Commons/bdesham

CLASH OF THE TITANS

Since the late 1940s, researchers have been using magnetic fields to confine plasmas. Plasma, or the fourth state of matter, is confined by an intense magnetic field. But there are different ways of creating such a plasma. Fusion research in Europe primarily focuses on magnetic confinement fusion (MCF). The fusion experiment, which can be either a tokamak or a stellarator, produces low-density plasma over an extended period with the help of a strong magnetic field.

There is however another approach, the one my research work is looking at. It is called inertial confinement fusion (ICF). In the 1970s, researchers began experimenting with powerful lasers in order to further develop the inertial confinement approach for fusion plasmas. A huge amount of energy is applied to a tiny spherical pellet of deuterium and tritium to generate a very dense plasma of a very short duration. Instead of a magnetic field, the plasma is confined by the inertia of its own mass. In the race for nuclear fusion energy, ICF is worth a mention.

THE MAGIC OF THE “MISSING MASS”

In fusion, deuterium and tritium must collide with high kinetic energy to overcome the repulsive electrostatic force that keeps them apart. They are thus “fused” into a new, heavier helium nucleus and a neutron. Only a very high temperature, hotter than in the Sun’s core is able to facilitate these extremely-high energy collisions. The helium nucleus together with

the neutron have a slightly smaller mass than the sum of the masses of the original deuterium and hydrogen nuclei, and when the latter finally do combine an amazing thing happens. The “missing mass” is given off as energy according to Albert Einstein’s famous formula $E=mc^2$.

INERTIAL CONFINEMENT FUSION: A TINY CONCENTRATION OF ENERGY

Inertial confinement fusion is implemented by heating and compressing a microsphere which is filled with a deuterium and tritium mixture. It can reach a temperature of 100 million degrees Celsius and is one-hundred times the density of lead.

Powerful laser beams supply sufficient energy to heat and compress the fuel target. The heat of the laser vaporises the outer layer of the target, exploding it towards the outside (“rocket effect”). According to Isaac Newton’s Third Law, reaction forces create an inward travelling shockwave which propagates from the surface to the innermost layer. It compresses the fuel and triggers fusion reactions in the central part with the highest temperature and density, known as the “hot-spot”.

If the energy released by fusion reactions is high enough, and sufficient hot-spot temperature and density are achieved, a self-sustaining wave of plasma burning is propagated in the surrounding fuel which also begins to undergo fusion. When these conditions are achieved, the plasma is said to have been ignited.

REACHING IGNITION

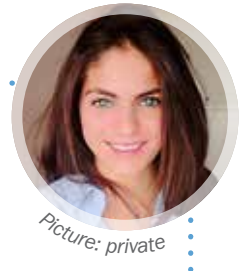
The essential step for both magnetic confinement as well as laser-induced fusion is to achieve ignition. In other words, it is necessary that the amount of energy yield exceeds the amount of energy spent in order to heat and maintain the fuel at high temperature compared to the energy lost. When we attain fusion reactions that sustain without the contribution of external sources of energy, ignition is achieved. It is very difficult to compare the magnetic and the laser-driven fusion heating methods. Both approaches have pros and cons. If we take a deeper look at the ICF process, four key issues are highlighted: efficient coupling of driver energy to the target, efficient use of the coupled energy to compress the fuel, maintenance of almost spherical symmetry and limitation of the dangerous effects of Rayleigh Taylor instabilities. Large-scale experiments prove that ICF must be further investigated in order to figure out those remaining questions.

ON THE PATH TO LIMITLESS POWER

The largest operational ICF experiments are carried out at the Laser Mega Joule facility in France and the National Ignition facility in California and are designed to accommodate 176 and 192 laser beamlines, respectively. Although ignition of fusion fuel has not yet been achieved, there has been substantial scientific and technological progress over the past decade. Imagine, ICF relies on a process in which a huge amount of energy originates from a fuel microsphere only the size of a pinhead. Just one kilogram of deuterium and tritium fuel mixture produces as much energy as is produced by ten tons of coal.

The following step on the path towards the further development of ICF will be the achievement of the gain required for net energy production. Also, we will focus on the technology for a future ICF nuclear fusion reactor.

I am looking forward to the realisation of inertial fusion energy which would be, just like a successful magnetic fusion reactor, an achievement which satisfies the world's hunger for energy. It would keep our planet clean without major environmental consequences. ■



Arianna Serpi

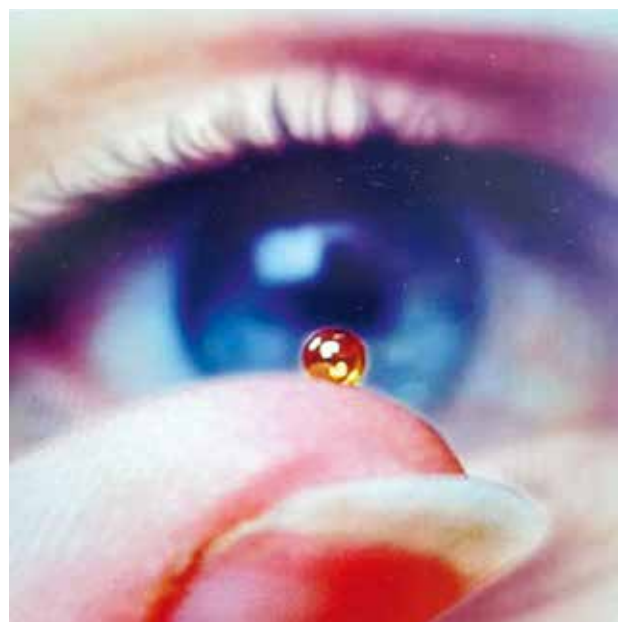
Age: 26

Origin: Italian

Currently based at: Rome, Italy

Picture: private

“ I am a nuclear engineer who is fascinated by fusion. I really believe that this will be the future of energy so I am honored to share my passion, in an understandable way, along with other young advocates. EUROfusion inspires me because, I think that collaboration is the key to solving the challenges in many fields, especially since it plays such a vital role in everyone's future. ”



Fuel target for ICF: microsphere filled with deuterium and tritium mix
Picture: Lawrence Livermore National Laboratory

To me, it is very clear that the primary source of energy for the Earth is, and will be, nuclear energy. So, I am really proud to be participating in the process of commercialising fusion power for human civilization. ITER and, subsequently, DEMO are intended to bring the first commercial nuclear fusion energy reactor online early in the second half of the century.



Picture: private

Nithya Muthusonai

Age: 33+

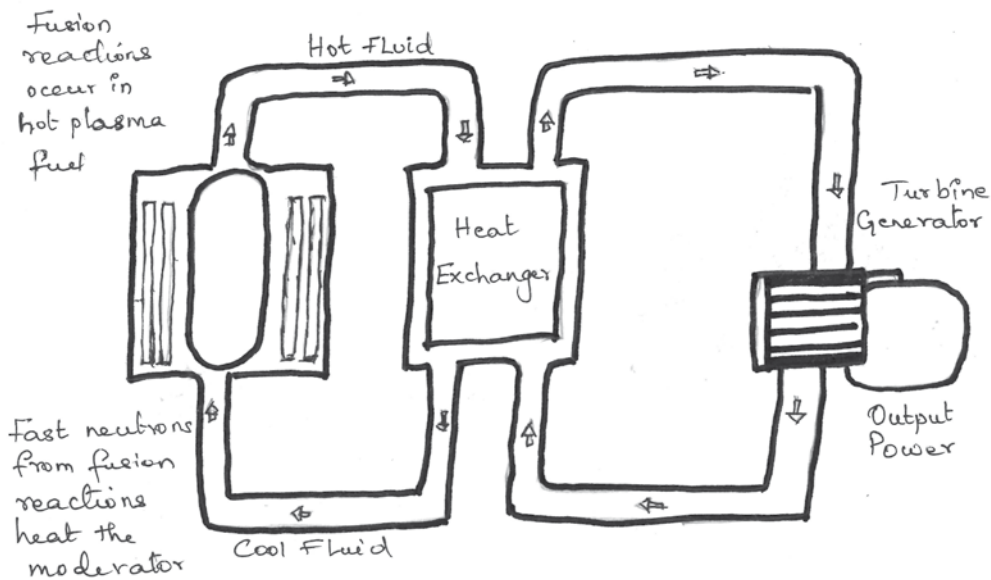
Origin: Indian

Currently based at:

Culham Centre for Fusion Energy,
United Kingdom

“ I am an experienced Technical Author/ Plant Engineer working at the Culham Science Centre for Fusion Energy. I like to put all of my energies into a project that fascinates me or really kindles my interest. I will always try to incorporate my own creative skills or workmanship. Therefore, I am part of this cutting-edge technology creation – Fusion Energy. It feels right to write about fusion energy at this time and I am excited to highlight some of the benefits of fusion for our ecosystem. ”

FUSION AS A BENEFIT



Illustrations: Nithya Muthusonai

How do we create energy from fusion? A fusion reaction can be used to produce power through steam turbines, neutron blankets or direct conversion.

BREEDING THE FUEL

When I started working as Technical Author/Plant Engineer at the Culham Centre for Fusion Energy (run by the United Kingdom Atomic Energy Authority), I was not aware that fusion energy would provide more energy for a given weight of fuel than any other fuel-consuming energy source currently in use. The fuel itself is abundant in the Earth's ocean. About 1 in 6,500 hydrogen atoms in seawater is deuterium.

50-50 deuterium-tritium reaction is most efficient at a relatively low temperature (still 100-150million degrees). Its energy yield is greater than other fusion reactions. Unlike deuterium (which can be extracted from seawater) though, tritium is not naturally abundant and will need to be produced. Our fusion research has taken care of that. Our colleagues are currently designing breeding blankets for reactors. They will produce sufficient tritium to power the reactor themselves.

Currently, the process of designing breeding blankets is extremely time-consuming. But, EUROfusion and the United Kingdom Atomic Energy Authority are working together to develop innovative software to optimise the lengthy and costly process of designing such blankets.

BENEFITS OF FUSION

Despite being technically non-renewable, fusion power has many of the benefits of renewable energy sources, such as being a long-term energy supply and not emitting greenhouse gases since they do not use resource-limited energy sources like fossil fuels.

Like the current nuclear fission, fusion will provide a very high power-generation density and uninterrupted power delivery because it is independent from the weather, unlike wind and solar power. Fusion production costs do not suffer from diseconomies of

scale. The cost of water and wind energy can be estimated by way of the perfect planning and development of optimal locations first. In future, the initial fusion power plants could be sited in less ideal locations. It uses only very little fuel, for example a 2GW plant will use about 500kg of fuel per year. Also, it produces radiotoxic waste which is easier to handle than the remains which come from a fission power plant.

Since the raw resource, seawater, is abundant and widespread, the production cost for building fusion reactors will not increase much, even if large numbers of plants are built. Desalination plants can be considered to purify the seawater by way of distillation or reverse osmosis.

Another big bonus is that the radioactive elements at play in a fusion reaction. The tritium will decay only within 12,5 years. The radioactive structure that surrounds the reactor will take in the order of a hundred years. This makes nuclear fusion still more attractive than fission which has to take into account rather millennia. The quantities of tritium in a reactor a very small and therefore the radioactive risks are limited.

Under proper monitoring, the risk of waste products being used for nuclear weapons is low. Moreover, the fuel for energy would no longer be a geopolitical issue. Also, fusion is triggering research into low activation materials. EUROfusion and the United Kingdom Atomic Energy Authority have recently embarked on a broad programme to design next-generation RAFM (Reduced Activation Ferritic Martensitic) steels. As a result, for example, silicon carbide (SiC/SiC) composites are now qualified for use in jet turbines. These are able to operate with higher temperatures and offer a lower weight. As a result, up to 15% fuel of airplanes.



POWER FOR EVERYONE

ITER and DEMO, at a later date, will pave the way for the realisation of fusion. Using this as a starting point, and taking the history of the uptake of nuclear fission as a guide, the scenario suggests a rapid adoption of nuclear fusion energy.

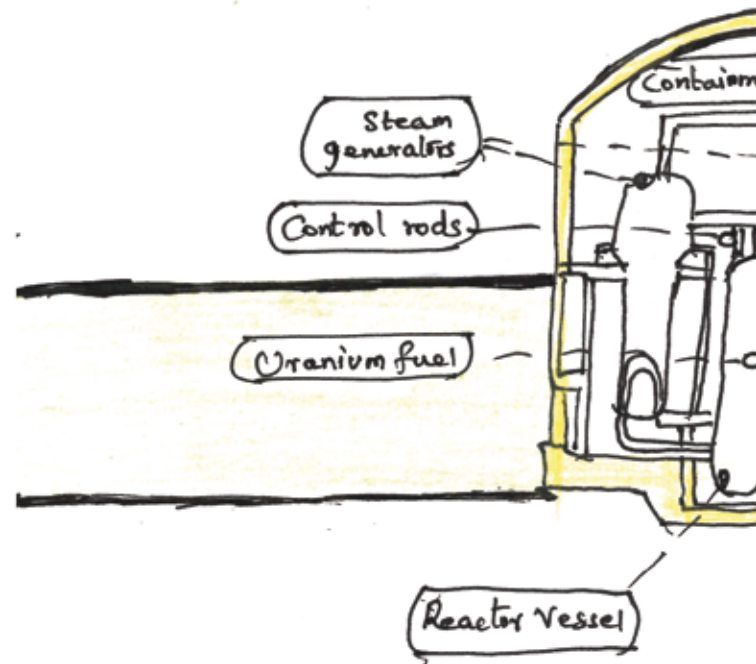
Right now, many people across Europe, and even beyond, are focusing on making fusion both environmentally and economically attractive. We are seeking new materials and continuing the quest for qualified, high performing fusion plasma, which will, in the end realise a fusion reactor that generates power for everyone.

WAY TO CREATE NEW ENERGY

Fundamentally speaking, there are two major motives for research. On the one hand, there is intellectual ambition. On the other hand, it is a simple matter of survival. The use of fossil fuels causes global warming and extreme weather conditions. Above that, the sea level rises.

It is hoped that alternative sources of energy will provide electricity worldwide. In this field, scientists are being proactive in building a world-class fusion reactor while employing cutting-edge technology. Hence, there are sufficient reasons for the whole of Europe to be talking and working together in order to find a solution to the ever increasing energy demands.

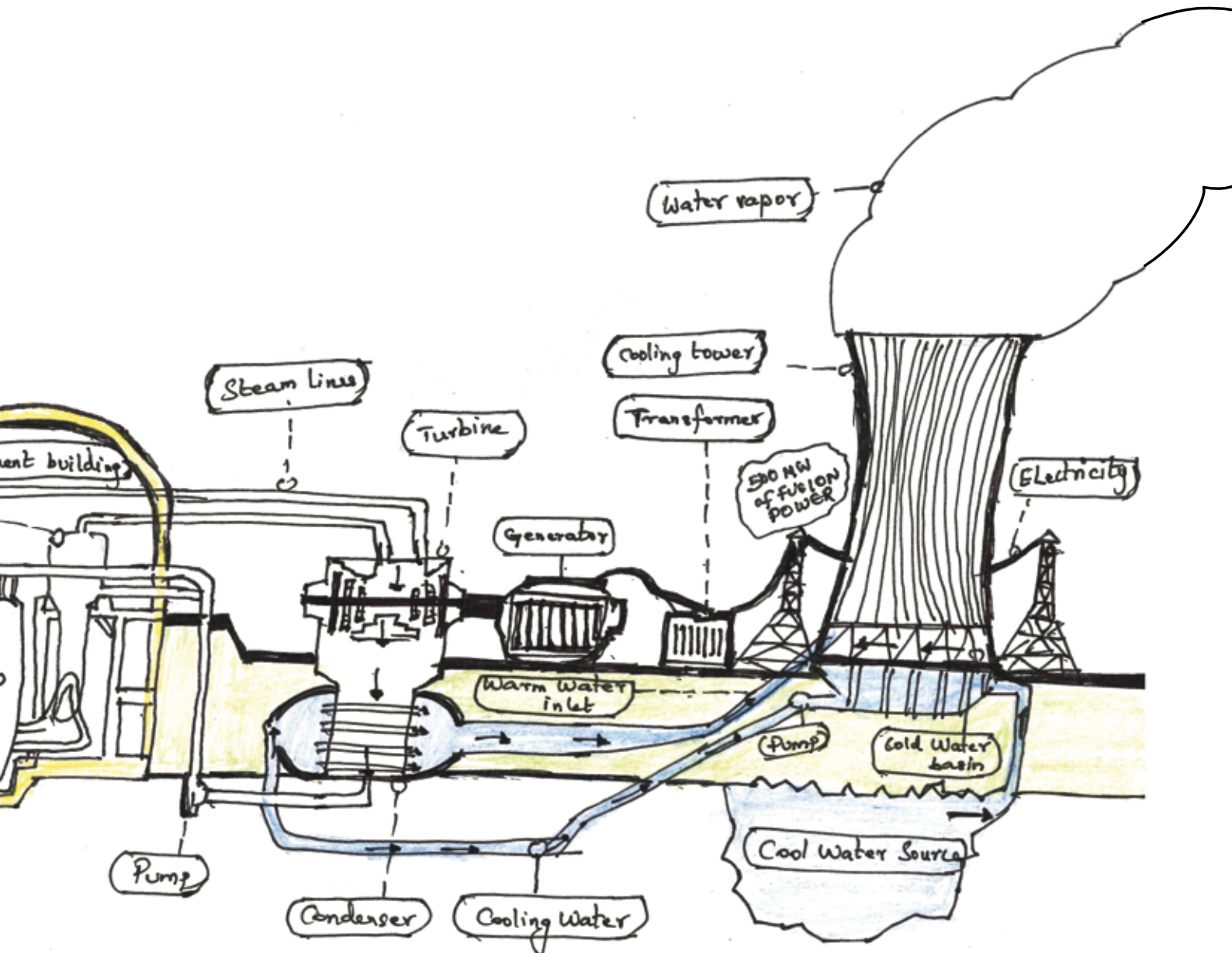
I would once again like to highlight the safety and environmental aspects here because when we think of nuclear energy, the first question that comes to our mind is "Is this safe for our environment and future generations? The answer is "Yes, it is", after considering the following features; effluents and effective waste management.



JOINING THE QUEST AT CULHAM

Above all, the energy source for the power production is available naturally and easily accessible. I am more than excited to join the team at Culham in its quest!

Our most famous experiment, the Joint European Torus (JET), has produced 16 megawatts of fusion power and proved the technical plausibility of fusion using deuterium and tritium, which are currently considered the most efficient fuels. JET will see another experimental



→
 Future Time
 Great Grand Children Old Growth Forest Green-Tech Stability

campaign during the next two years and I am eagerly looking forward to participating. With ITER, the challenge is now to prove that fusion reactions can work under power plant conditions. DEMO will be the first device to produce electricity from fusion shortly after 2050.

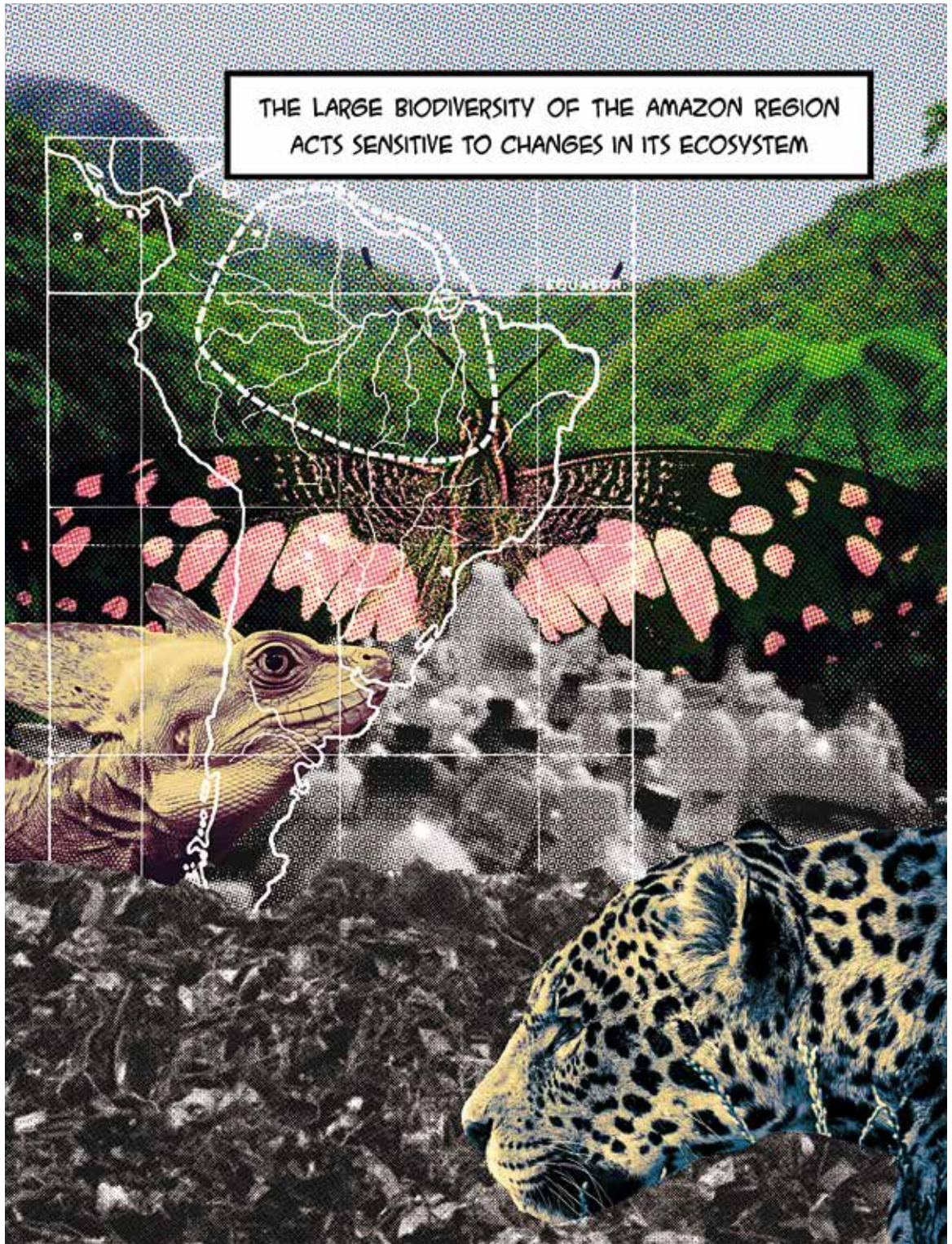
POWER FOR A DIGITALLY DRIVEN WORLD

I hope that my article has shown the many ways in which mankind benefits from fusion research. Fusion could also be used in inter-

stellar space, where solar energy is not available. Therefore, we are not going to see just our techno-fantasy in computer graphic format, but it will also be live at some point in the not too distant future. Fusion is a potentially fascinating technology. I'd love to believe that this could someday become our standard method of power generation. My colleagues and I are honoured to be working towards this power source to offer coming generations a sustainable energy source for a digitally driven world. ■

FUSION IN PERU:

BATTLING INEQUALITY AND CLIMATE CHANGE



Picture: Paula Calleja



Picture: private

Balbin Arias Julio

Age: 27

Origin: Peru

Currently based at:

Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France

 @balbin_ar

“ I am currently doing my doctoral research at *Institute de Recherche sur la Fusion par Confinement Magnétique – CEA*. From my beginnings in the academic world, I was attracted to fusion. If it is successful it could provide an incredible source of energy, with almost negligible levels of contamination. Fusion energy opens up a path towards protecting the planet. And I seek to contribute to the search for a better world for future generations. ”

My hope is that one day nuclear fusion will be a new and much better energy option for the people of Peru. And that the country would abandon traditional methods of resource extraction, which, through the decades, have only brought pollution and destruction to our ecosystem. Moreover, the availability of fusion energy will reduce the effects of climate change. We also have to consider alternatives to renewable sources since experts have already calculated that solar and wind will not be able to produce sufficient energy to replace fossil fuels and nuclear fission plants.

GENERAL VISION OF ENERGY RESOURCES IN PERU

In Peru, the national energy network relies heavily on fossil fuels. In 2014 and 2015, the energy consumption from natural gas, diesel, gasoline, industrial petroleum and carbon represented 64 % of the total expenditure. Hydroelectric production represented just 25 % of total production; nevertheless Peru only has 3 Gigawatt of installed power from a total of 75 Gigawatt.

Also, we must consider that almost all energy sources located close to big cities are part of the national hydroelectric network. An installation of new plants in far places would increment electrical tariffs. In addition, the ecological impact would be greater than in locations near to hydroelectric plants due to the large biodiversity of the Amazon region which is sensitive to changes in its ecosystem.

RENEWABLE ENERGY SOURCES – A REAL SOLUTION?

In 2014, renewable energy sources only represented around five percent of the Peruvian energy production. Wind, solar and geothermal power delivered a total of 142 MW, 80 MW and zero MW which is low for sustainable pretensions. These energy sources face the additional problem that no suitable storage solutions are available yet. Moreover, they are also sensitive to climate change factors which can influence the amount of energy produced over a long period of time.

FUSION IN PERU: FUTURE VISION AND IMPLICATIONS

Peru is a developing country and greatly affected by resource extraction which has only resulted in pollution and damages to its ecosystem. Of course, it does not have a real adaption or targeted development structure towards one of the most prominent and hopeful sources of energy in the future: nuclear fusion. An alleged immersion of Peru in research and collaboration for nuclear fusion, would offer an energy source capable of homogenising energy distribution to all Peruvian communities. The distribution of energy would be a powerful way to harmonise this country which today is marked by vast inequality.

FUTURE PLANS TO ACHIEVE FUSION: MORE THAN A DREAM

If we literally look at the situation on the ground now, we can clearly see that there are no fusion energy experts in abundance available in Peru as yet. But a critical mass, although small, is forming in various developed countries.

Anyway, IPEN (Instituto Peruano de Energía Nuclear), the Peruvian Institute of Nuclear Energy, could develop an infrastructure for a research and development programme. Just as Europe has done, and it is possible to obtain fusion facilities „second hand“ from countries that are modernising their devices in order to develop a Peruvian fusion energy infrastructure from this point onwards.

DREAMS, HOPE AND DEVELOPMENTAL PURSUIT

When I left Peru I wanted to become a critical mind. I wanted to be able to develop a future vision for my country, to contribute my experience, however small, to pursuing that reality. I dream of being able to show my country that the options for development and equality can start with wondering about the universe, and continue by using the knowledge that nature provides us with. ■

“ I dream of being able to show my country that the options for development and equality can start with wondering about the universe, and continue by using the knowledge that nature provides us with. ”

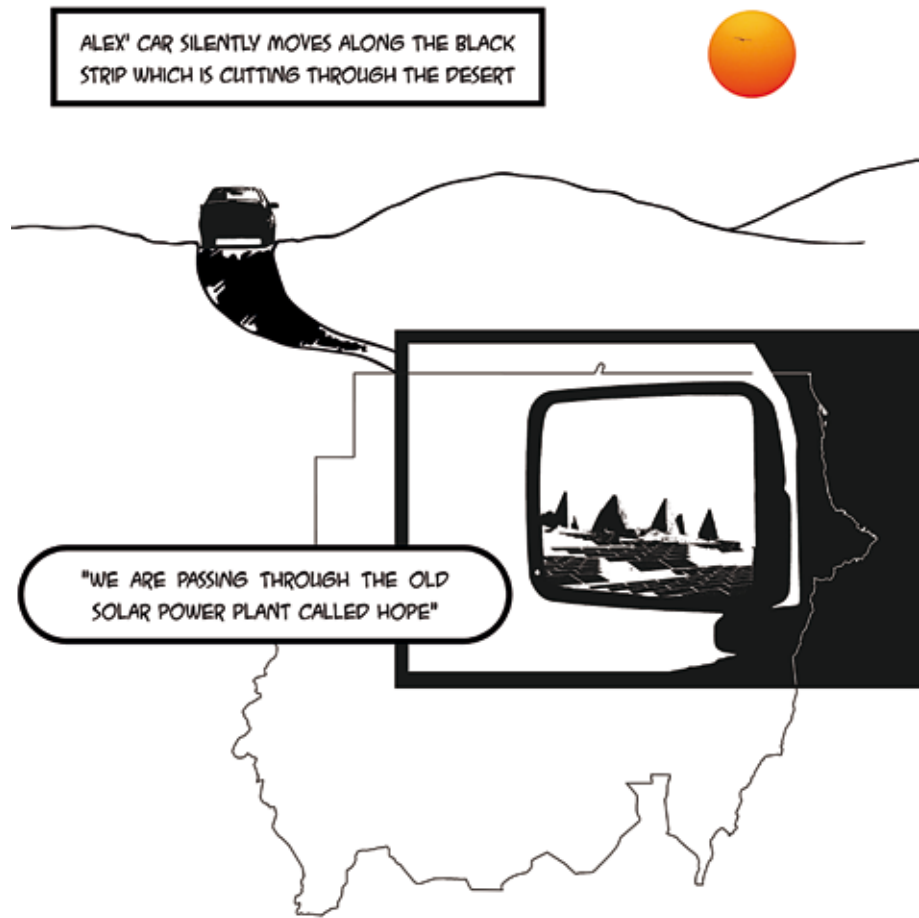
Balbin Arias Julio

A DESERT RIDE

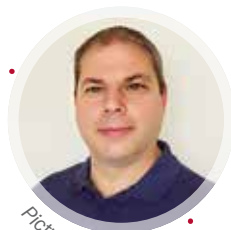
Alex's car silently moves along the black strip that cuts through the desert. Its air conditioning creates a perfect temperature contrasting with the 45° degrees outside. Alex, one of the continent's leading metrologists, is looking forward to meeting up with some old friends at Porto Sudan. Today, one of the world's most prestigious energy projects will be reaching an important milestone, so he brought his daughters, Jessica and Simona, along with him on the trip to the coast.

Suddenly, Simona taps on the car window: "What's this?" and points towards a shady area in the desert. "That is the old solar power plant called HOPE. The solar panels were used to capture the Sun's energy and convert it into electricity. Didn't you hear about it in school?"

"No, sorry. Apparently our history lessons didn't include solar this year. We have just started looking at oil and coal and we'll probably finish with uranium. Maybe Jessica knows..?" Simona gives a little sigh and turns towards her older sister.



Illustrations: Paula Calleja



Picture: private

Alessandro Lo Bue

Age: 50

Origin: Italian

Currently based at:

Fusion For Energy, Spain

“ I am an industrial engineer with 20 years of experience in measurements of large volume components for nuclear fusion. Since I moved from a private company to EUROfusion's Italian Research Unit, I was keen to be part of the fusion family, to build a better future for everyone. Nowadays, with Fusion for Energy and EUROfusion, the start of fusion energy is a fact to me now. The story I wrote unfolds in a better future of which I have always dreamt. ”

After a few moments, Jessica finally answers the question: "Yes, I know about HOPE, and I know that nowadays most of the solar plants are only used for local energy stations, to recharge cars and trucks."

"Exactly Jessica!" says Alex. "Let's check the next fuel station. Our car needs recharging." Actually the car's energy meter was still close to half full, with no need to recharge until the destination. But Alex wanted to show them the special fuel station that had just appeared right in front of them. It had been Sudan's first solar power plant for vehicles. And had been the first facility of its kind to employ the, at the time, new superconducting cables, other than fusion power plants.

After plugging the recharging cable into the car, the three of them enter the station shop. Simona

and Jessica rush towards the screens looking to see whether they can purchase something 'on the go'. Suddenly Jessica stops. "Dad, what is this?"

In front of her, an exhibition box held three samples of electric power cables. The first was a traditional copper cable used to distribute 100,000 V, enough energy for a small town with 50,000 inhabitants. The second cable was made using an alloy of niobium and tin with a cross-section five times smaller than the copper one. This one was also primarily used a long time ago in the ground-breaking ITER project. The third cable was the current version. This one is capable of delivering the same amount of Volts but has a wire diameter 20 times smaller than first copper cable.

"These cables show the evolution of superconducting technologies over the years. You know that superconductivity is the phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain materials, when cooled below a characteristic critical temperature. Such cables are extremely efficient for high power loads but it took us a while to figure out how to build them. Over the years, the critical temperature has risen from the original -260 degrees Celsius up to +45 degrees Celsius."

To Alex, it still seemed incredible to see how technology had advanced so rapidly between 2000 and 2070. In actual fact, it was not such a challenge to make a superconductive strain work at 20 degrees. The real struggle was to have a resistant casing in place to protect the internal superconductive material, and resist at the high-energy flow.

During this explanation, Simona joins in with the conversation. Right next to the box with the cables was a picture of the inauguration day of the Nubian station. "Dad, who are they? Do you know any of them?"

"Yes of course. They are Maurizio Gasparo, Alfred Bigdoor, Peter Barabaschi, and Giampy Federici, Alexander Goodolive, all of them are involved in creating the technology used in our fusion reactors today."

"But Dad, this picture is so old. Are those people still contributing to technical developments?"

"Of course, my darling, fusion research did not only realise fusion energy. It has generated many important applications in other fields. For example, the new superconducting materials were used for in modern Magnetic Resonance Imaging, or MRI in short, and in our precise electronic microscopes. Genetic treatments were improved enabling cures for many diseases. As a result, the average lifetime expectation was extended ten years compared to 2030. It is also thanks to this fact that these people are all still alive and in good shape."

"Wow, says a stunned Simona. "Therefore, you could say that fusion research had made us live longer." "Yes, longer and better."

Alex cannot help but think that this is not only due to technical breakthroughs in medicine. 50 years ago, Sudan was a war-torn country. At that time, no man in possession of all his marbles would have entered the Nubian Desert with his family. Even if the drought and the lack of water on this side of the Earth would not have killed him, military groups surely would.

"As soon as the first commercial fusion reactor had generated power, plenty of reactors were built around the world. There was no longer any need for coal, oil, or fossil fuels; as we used to call them back then, as well as uranium."

"The first consequence was that there was no more war over the control of the oil reserves in the world." Alex started to enjoy this little lecture because his memories were still vivid. "We had realised by that time anyhow, that oil was sparse although most of our engines ran on it. This was one reason to push for fusion energy. Secondly, we were able better distribute energy, even to remote parts in the world which had suffered for many years. In doing so, we also decreased the greenhouse gas."

"Nowadays solar energy is only used in places like this energy station. Most of the desert today is a green garden, thanks to electric pumps which distribute water from the sea across the entire African continent. The abundance of



water and electricity has empowered the local economy dramatically. Since people no longer needed to spend the day looking for food or water, an infrastructure could be built rapidly. It was a virtuous circle towards a better world, powered by fusion energy.”

A ringing sound briskly interrupts Alex. It is Luigi Rareseed.

“Hi Alex, I am gliding above Port Sudan harbour right now, I can see the boat approaching the pier.”

“Great. Listen, I am on my way to Port Sudan, I will be arriving in three hours.”

“OK, very good, we will meet at the pier then!”

Simona, who had overheard parts of the conversation, immediately asks: “Did he say that he is on a glider, Dad?”

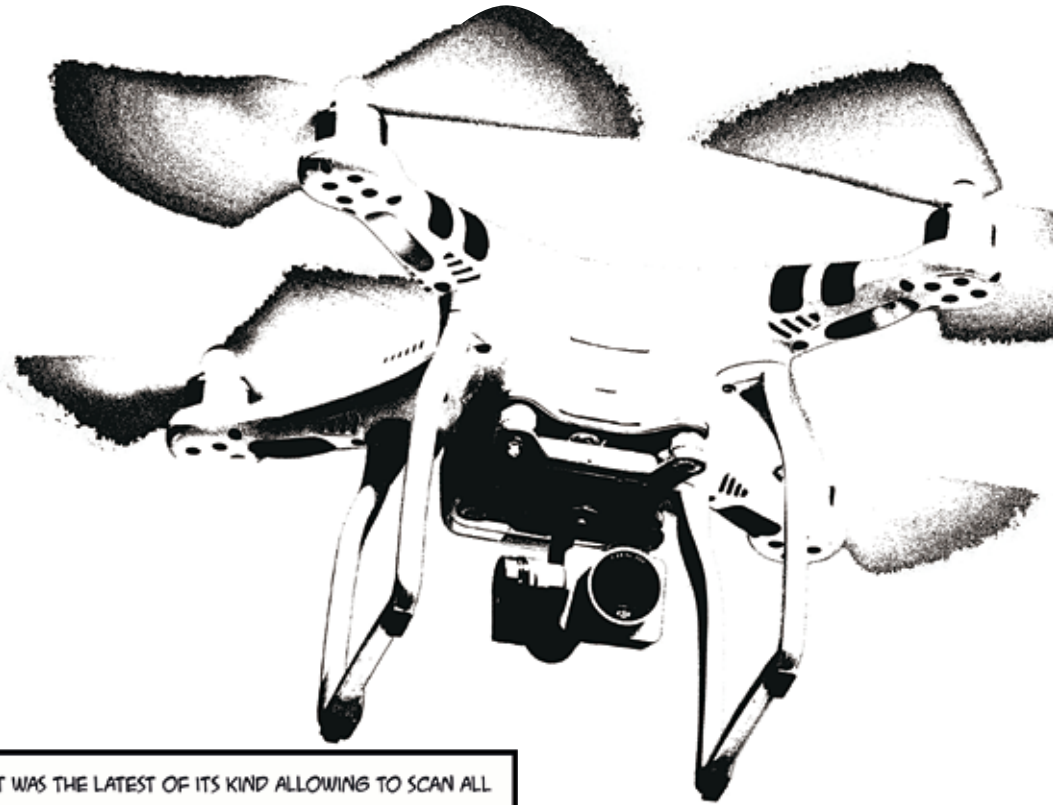
“Yes, but not a normal glider. This thing is brand new. An electric motor supports it, thanks to the new battery technology, also developed as a result of fusion-driven research in nanotube technologies.”

Finally, their car had been fully recharged and the family could continue the trip to Port Sudan.

“Ah, by the way”, it was a curious Simona asking again. “Why are you meeting with Luigi anyway?”

“I told you, there is something big happening today. The main piece of a fourth generation fusion reactor is going to see the light of day. And it is happening here, in Port Sudan.” Alex could not hide his own excitement.

“As you know, in a tokamak reactor the vacuum vessel is the main component. The vessel holds the hot plasma and magnetic coils confine it.



IT WAS THE LATEST OF ITS KIND ALLOWING TO SCAN ALL SURFACES WHILE FLYING AROUND THE COMPONENT.

Today I am going to measure the first sector for acceptance”. He was really proud to be in charge of this important task along with his colleagues Alex and Luigi. The team of metrologists had to ensure that the components met the requirements for building a nuclear fusion reactor.

”Nicolas will also be there”, Alex adds. Nicolas was employed by the industrial organisation that ensures the proper manufacturing process of fusion power plants. He also was godfather to Alex’s daughters and enjoyed some fame among them.

”Really? How cool!”, Jessica said.

”Yes. As you know, he is in charge of the components which come from the American continent. This one was made in Canada.”

”Wow, this is big”, says Luigi who had joined Alex and his daughters immediately after they had left the car at Port Sudan. All of them looked up at the large container that was seated on an incredibly huge tanker.

”Is it a stellarator?“, asks Simona?

”Yes, and it is a huge one, I hope it does not scare you,” Nicolas answers.

The stellarator is another type of fusion device, in addition to the well-known tokamak, which applies D-shaped magnets. A stellarator features a much more complex structure of magnets which appear to look like fighting squids. Although the measuring technology was up to the challenge, the sheer size of the stellarator device was still something stunning, even for the team of experts. The Sudan project should, in the end, prove that a stellarator was able to meet the requirements of a full-scale reactor just as well as the tokamak.

Alex was still fiddling with the drone which allowed them to scan all surfaces while flying around the component. ”Nice”, acknowledges Nicolas. ”Yes, it is the latest technology. I remember when I saw it for the first time. It was back then in England. Do you remember JET?” he asks. They did, of course, remember the Joint European Tokamak. The father of all tokamaks and predecessor of ITER was something unique back in the 1990s. Not for the first time today, Alex looked back at the long road of fusion history and felt the strong sense of satisfaction. ■

Any resemblance to real events and/or to real persons, living or dead is purely coincidental.

EUROPEAN CONSORTIUM FOR THE DEVELOPMENT OF FUSION ENERGY REALISING FUSION ELECTRICITY





EUROfusion



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