Nuclear Fusion Energy for the Netherlands.

A dynamic challenge for the TU/e Bachelor Honor's Academy

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A bit of background

The energy transition and nuclear fusion.

Okay, since you are here, I don't need to tell you about climate change and the need to decarbonize the energy system. So, let's switch gears right away and talk about nuclear fusion: the merging of the atomic nuclei of light elements into heavier ones. It is the process by which the stars generate energy from hydrogen, in the process creating the heavier atoms that make up the world around us. It is the only way of setting free energy of which we know precisely how it works, yet we haven't been able to turn it into a useful energy source yet. *Why is it so interesting?*

The pros and cons of fusion energy

On the credit side of fusion's balance sheet, we find: the fuel is practically inexhaustible, the process is inherently safe and does not emit CO_2, and in principle it could be run in a way that does not produce long-lived radioactive waste. Hence the promise: 'clean energy, for all, forever[1]'. On the debit side: it is super difficult to get the process to run, basically because the cross-section of the fusion reaction (the probability that two nuclei fuse when they meet) is exceedingly small. Only at very high temperatures – tens of millions (!) of degrees – will the reaction take place at a useful rate. Yes, you got that right, that's as hot as the core of a star. Is it at all possible to do that on earth? The invention and construction of machines that create such conditions has been a worldwide quest that started in the 1950s. Worldwide, as in all countries work together on it. This R&D program is not classified, indeed, the collaboration on nuclear fusion by nations between whom there is significant political tension has effectively been a 'peace program'. Now you'll ask: '*if this is such a long-running effort, whence the sudden excitement?*'

Today, billions of dollars flow to fusion startups world-wide.

Fast-forward to 2023. The government-funded R&D programs have generated a huge knowledge and technology base. This has led entrepreneurial researchers to say *'we know enough to start building'*. The past years have seen a rapid increase in the number of start-ups, that aim at bringing commercial fusion power to the market in about a decade. Not only has there been a surge in the number, the private investments have reached staggering levels: some have acquired more than a Billion dollars in funding – that's pretty good going for a startup. The 'Commonwealth Fusion Systems' spinout of MIT has been crowned 'best startup in the USA' by Forbes, which goes to show. So, quite suddenly, dozens of companies are pursuing as many different ways of putting a fusion power plant together. *What does that mean for us at TU/e?*

Eindhoven: the Dutch Fusion hotspot.

As you may be aware: the TU/e offers a unique Master's program on 'Science and Technology of Nuclear Fusion'. It is one of the few fusion specialization programs in the world, probably the largest in the number of students (and certainly the best). The TU/e is one of larger supplier to the international fusion work force, and you will find our students and alumni in all the main fusion labs around the globe.

On the TU/e campus we host the DIFFER institute for fundamental energy research, which is the national center for fusion research. At the university, we have one dedicated fusion research group, and next to that dozens of researchers from other research groups are involved in fusion research. It should be like that, because the topic is truly interdisciplinary, stretching all the way from the theory of hot, turbulent plasmas to materials that can handle intense heat fluxes, the design of superconducting magnets, advanced control systems, the use of artificial intelligence, to the socio-economics of fusion power: *will fusion be economically viable, will it be necessary, will it be wanted by society?*

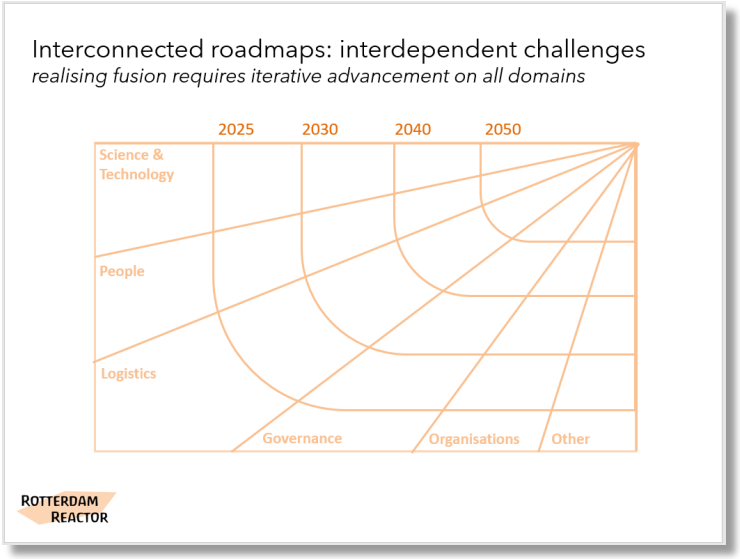
[1] For the critical reader: nothing is 'forever'. But the 'for all' part expresses an ambition which is highly relevant for your project.

The challenge: bring fusion power to the Netherlands

If we assume for the minute that one or more of the startups are going to be successful, what does it take to bring fusion power to the Netherlands? To answer that question, you will develop roadmaps. Plural, because there are several different, interconnected, roadmaps that need to be developed in parallel. The technology roadmap is well known and taken care of by the startups.

But building a demonstrator is by far not enough to make fusion power land in society. What else needs to happen, and when? To give you an idea: we need to develop an industry and supply chain (logistic roadmap), we need to create political support at all levels, which includes legislation (Governance roadmap); we need to find ways to finance the project – will it be a private company, or a state-owned enterprise that builds and runs the first fusion power plant in the Netherlands? (Economics roadmap); we need to map out all social aspects, from social acceptance (crucial) to the impact on jobs and quality of life (social roadmap); we need to train people who can build and run the power plant and populate the highly specialized supply industry (training roadmap); we need to map out the way in which a fusion power plant will be integrated in the energy system – will it produce electricity or heat, who will be the end users – industry, district heating? What are the synergies with other components of the energy system?

In the graph below, due to Rotterdam Reactor (see below), the interconnected roadmaps are schematically depicted. All those line must come together, literally, to reach the goal. But the content of those roadmaps, the milestones and timelines, the interconnections, and finally the time at which that is goal is reached – all of that is still open.



Interconnected roadmaps – the end point may be blurry, but concrete action is required now.

All those roadmaps need to be drawn. Because, strangely, they don't exist yet! The technology roadmap has been detailed, already for long. But all the other roadmaps: nothing. Yet, these are going to determine the success of failure of fusion energy. Or at the very least, the pace at which it can be introduced.

What will you do?

You'll work with Rotterdam Reactor on the development of the roadmaps. This will involve speaking to different parties to gather information. Defining tangible milestones. Develop a view on how the popular perception, the financial scheme, and the political support influence each other. Figure out other interconnections – and place them on a timeline. Analyze the plans of the Rotterdam Reactor and where they can do better, where they should spend most effort. Write an action plan: throughout the program, you, with your team, will work on concrete smaller challenges to put the analysis in action.

Your partner in this adventure: Foundation the Rotterdam Reactor

You won't need to start from scratch. A few alumni of the TU/e fusion department have set up a foundation called 'the Rotterdam Reactor', led by Guido Lange. Guido gave a presentation during the kick-off meeting, of which the slides are available on the Track website.

They are our partner in this Honors Track. They have the necessary expertise and network which they are keen on sharing with you. Because they expect the world of your creative power.

> *Why Rotterdam – why not Eindhoven!*
> You may wonder, since we are TU/e, why aren't we advocating fusion power for the Brainport. Well, there is something to be said for that, too. But there is a very good reason why Rotterdam reactor focuses on the Rotterdam seaport area. Because this seaport, today, is strongly oriented on the shipping of fossil fuel. And so is the heavy petrochemical industry, refineries etc., in the area. Hence, the energy transition is going to massively impact Rotterdam, its industry, its population, its economy, its jobs. Fusion energy might just be the technology that can help Rotterdam to transition to a new, cleaner, yet economically and socially viable future. And at the same time: fusion power plants need big parts, that can easily be shipped to the Rotterdam Seaport. And vice versa, should the Netherlands develop a key technology for the deployment of fusion power worldwide, then the proximity of the seaport is a great advantage. So, let's not be too chauvinistic and think about the future of Rotterdam. The Rotterdam Reactor – invented in Eindhoven.

We won't let you swim: training, network, visits…

As many of the aspects of this challenge will likely be new to you, we plan on giving you concise introductions on topics like:

- Nuclear fusion (how does it work, why is it difficult) – without becoming very technical
- Roadmapping and scenario development
- Economics of the deployment of a new power source
- The energy system
- Socio-economics of fusion
- The Rotterdam case.

And we help you set up visits with relevant parties – which could include a visit to a cluster of fusion startups in the Oxford area (UK).

Training will be given by experts from the Rotterdam Reactor as well as the TU/e Fusion group.

An interdisciplinary team of about 10 students

As you can see, this project is going to ask for a lot of different angles. So we are looking at putting together a truly interdisciplinary team.

We expect that the team will organize itself into smaller groups that look at the different roadmaps, while always working together as the full team, sharing information and insights. Because the holistic view is essential.