FuseNet Project - Final Report

FuseNet
The European Fusion Education Network
PROJECT

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1. Executive Summary

The FP7 coordination action FuseNet, which ran for 5 years starting in October 2008, has successfully developed an active European network on fusion education, and made this sustainable as the FuseNet Association. This new legal entity has already well over 40 fee-paying members – universities, research laboratories and industry involved in the development of fusion energy - and is still growing steadily.

The FuseNet Project has resulted in the development of new learning opportunities in laboratories and industry; the joint development of new educational materials, such as a book on fusion technology, an on-line course, web-based learning tools and hands-on experiments; the coordination and organization of joint educational activities such as summer schools; and the initiation of the annual joint PhD-event. As an important result of the network, joint academic criteria have been established for the award of the European Fusion Master and Doctoral certificates, with the first award ceremony having taken place in September 2013. Several pre-existing fusion doctoral programs have been brought under the FuseNet umbrella. The FuseNet website, which provides transparent access to all FuseNet functions and acts as portal to all fusion education in Europe, is visited by over 4000 unique visitors every month.

Figure 1: The general assembly of the FuseNet Association at its meeting in Sofia, in February 2013

Moreover, weeklong master classes have been organized in which students could work with the hands-on experiments that have been developed with FuseNet support, on the basis of which these plasma labs and courses were evaluated. The annual joint European PhD-event has been organized 3 times, each one benefitting from the experience of the previous edition, further establishing FuseNet as the joint European PhD umbrella. Finally, FuseNet has started a matchmaking service aimed at stimulating internships in industry, in collaboration with the Fusion Industry Innovation Forum.

With that the FuseNet project has delivered its targets, on budget. It has created an active network that runs a set of well-established activities with a large and still increasing membership. The network is ready to take on a central role in the implementation of the Fusion education programme under H2020.

2. A summary description of project context and objectives

2.1 Context: ITER - A new era in the development of fusion energy - the need to educate a new generation fusion scientists and engineers

Nuclear Fusion, the energy source of the stars, holds the promise of clean and safe electricity, for all and forever. However, its realization is an immense scientific and technical challenge, so large in fact that for the past 50 years this development has been carried out in a worldwide collaborative effort. This has led to the ITER project, the first fusion test reactor that will produce about the same amount of power as a gas power station (500 MW), albeit as scientific proof-of-principle and not as production facility.

The reactor will work as power amplifier with a power amplification of 10. ITER is a collaborative project of 7 international parties: China, Japan, India, S-Korea, Russia, the USA and the host party EU. ITER, presently under construction in Cadarache (South of France), counts as one of the largest big science projects, similar in scale, of investment as well as collaboration, with the big accelerators for high-energy physics such as CERN.

Around the signing of the ITER agreement in 2006 and the acceleration of the development of fusion power that this brought along, it was realized that there was a strong need in Europe to educate and train a new generation of fusion scientists and engineers. The need comes forth from the upcoming construction and later exploitation of ITER on the one hand, and the age distribution of the present fusion staff on the other.

Moreover, a shift in the distribution of competences of the fusion professionals is needed: there will be an increased need for various engineering disciplines in view of the extensive design and construction activities, and the fact that in ITER nuclear engineering is much more important than in present day fusion experiments. Another very important factor is that ITER construction will mobilize some 5000 workers in industry, and part of them need to acquire some or extensive fusion-specific training. These developments will be reinforced by the phasing-in of DEMO activities. All these factors called and call for a human resource policy, including adequate education and training, with a long-term view.

At the EU level several actions were launched to meet these demands. In 2008 the fusion development programme, organized under the European Fusion Development Agreement (EFDA) launched a goal-oriented training programme (GOT), with the aim to fill in the gaps in the competence portfolio, and started the EFDA fusion fellowship programme to stimulate excellent young professionals to develop their career in fusion.

In parallel an FP7 coordination action was launched with the aim to strengthen fusion education, concentrating on the Master level. FuseNet, 'the European Fusion Education Network', was launched in response to this call. The FuseNet project has 36 partners, spread over Europe, of which 23 are universities and 13 national laboratories involved in fusion research. The project was awarded a 2 M€ FP7 grant for a 4-year period starting in October 2008, which was later extended with one year to exploit the facilities that had been developed and enable a smooth transition to H2020. As one of the tasks of this project, the FuseNet Association was established. This is a legal entity that can act on behalf of its constituting members: research laboratories, universities and industry that are involved in the development of fusion energy.

In 2012, EFDA published the document 'Fusion Electricity; A roadmap to the realization of fusion energy' which defines the focused research and development effort that is needed in the EU to optimize the (participation of the EU in the) exploitation of ITER and to prepare for the next step: DEMO. This roadmap emphasizes the need for a forward-looking Human Resource strategy and a vigorous education programme that is consistent with the future needs of the programme. In an Annex to the main roadmap document, the education actions needed are specified. The Education chapter of the roadmap is appended at the end of this Section, as it forms an important part of the context of the activities of FuseNet.

2.2 FuseNet project objectives

The FuseNet project was launched with the aim to strengthen fusion education in Europe, improve its quality and attractiveness to students, strengthen the collaboration between the institutions involved, create new learning opportunities such as hands-on experiments and on-line tools, share and jointly develop new teaching material, and organize or support joint educational events. All actions were to be supported by a high-quality website, which would make fusion education easily accessible to students. In short: to create an active, tightly woven education network that maximizes the attractiveness to students of fusion science and technology.

In order to achieve these goals, the FuseNet project defined 10 work packages, plus one for the project coordination, that are grouped in four lines of action:

1. **Establish and run the FuseNet network.**
2. **Learning opportunities**: Strengthen individual learning opportunities in fusion institutes and industry and develop joint educational goals.
3. **Education materials**: Jointly develop fusion education materials and hands-on experiments.
4. **Educational activities**: Coordinate, support and/or organize joint educational activities, such as summer schools.

FuseNet has realized its goals in all four action lines and delivered the deliverables. The FuseNet Association continues the work of the project, with an open membership that is already significantly larger than that of the project consortium and importantly extends to industrial members. The action lines that were developed under the FuseNet project are carried over to the Association, which therefore hits the ground running.

The actions and results of the project are reported below, followed by an analysis of the impact of the project and its extrapolation to the future.

As noted by the Panel on Strategic Orientations of the Fusion Programme, the evolution of the fusion programme requires a shift "from pure research to designing, building and operating future facilities like ITER and DEMO". This transition requires strengthening the available engineering resources, with a marked change from non-nuclear to nuclear technologies, and has to be facilitated during Horizon 2020 by specific measures in support of training and education.

ITER will break new ground in fusion science and the best young scientists should be encouraged to participate in the ITER programme at an early stage of their career.

Fusion laboratories and universities play a key role in providing general training and education in fusion science and technology by selecting and forming "Generation ITER", through theoretical and experimental work on relevant facilities. Their main goal should be that of ensuring adequate access of their scientists and engineers to the leading facilities. These include JET, which represents an intermediate step towards ITER operation because of its large size (and large disruption forces), tritium capability, use of remote handling and of beryllium and is therefore the best place for training scientists and engineers for ITER operation. Similarly, engineering skills for the design and construction of DEMO need to be further consolidated through training of young engineers in the large devices currently under construction (ITER, JT-60SA, W7-X).

The role of fusion laboratories and universities in training and education should be explicitly recognised by specific support at under-graduate and PhD level through Fusenet[19] to be followed by post-doctoral training programmes such as the EFDA Fellowship and Goal Oriented Training EFDA programme. Training in critical qualifications should be reviewed with industry and encouraged. The existing training schemes should be enlarged to involve industry through in-company training of engineers involved in fusion-related tasks and specific training of professionals and technicians, already specialised in fusion, on technologies and standards associated with the transition of fusion to a fully nuclear technology.

A healthy system should aim in the long term at some 300 PhD students and an equivalent number of engineers (either PhD students or trainees) active in fusion, with an appropriate spread over topics in fusion engineering and physics.

[19]Fusenet (the European Fusion Education Network) is the umbrella organization under which all fusion education, from Master (and earlier) to PhD, is coordinated

Figure 2: Excerpt from the 2012 EFDA Fusion Roadmap document 'Fusion Electricity'

3. Description of the main S&T results/foregrounds

3.1 Establishment and Development of the Network

FuseNet has successfully created an active network of fusion education. The executive board (EB), with members from 8 different parties, meet monthly – mostly by videoconference - while the general assembly in which all parties are represented meet once a year. Several work packages have set up their own committees, e.g. committees to assess applications for support to joint educational events or the development of education materials, the editorial board of the FuseNet book on fusion technology, and the committee that has developed the joint criteria for the European fusion master and doctorate certificates. In this way, a large number of experts have been and are involved in the activities of FuseNet, bringing their experience and knowledge to fusion education in Europe and at the same time strengthening the bonds between the research and education communities.

Work Package 11 Overall coordination of the project	**11.1** Overall technical coordination of the project.
	11.2 Overall managerial coordination of the project.

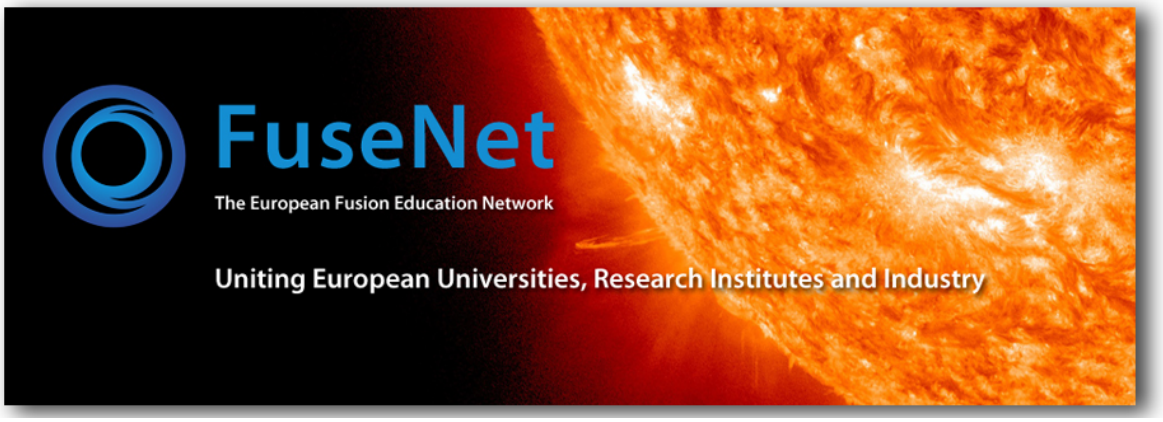
To make FuseNet a sustainable network, the FuseNet Association has been established by notarial deed. This is a legal entity, supported by its members, with objectives similar to those of the FuseNet FP7-project. Next to education and research institutes, companies involved in fusion are explicitly invited to become member and the Fusion Industry Innovation Forum is represented in its Board of Governors. The FuseNet Association awards – as part of its set of baseline activities – European Fusion Doctoral and Master certificates according to the joint criteria that have been developed. A standing committee of experts, the Academic Council, is charged with the responsibility regarding academic matters. The FuseNet Association will apply – on behalf of its members – for financial support for specific actions.

The FuseNet Association is up and running. The statutes were agreed by the parties of the FuseNet project before the association was formally established by notarial deed on 9 Dec 2010; Following the statutes, the Board of Governors has been installed by the General Assembly; the Academic Council has been installed by the Board of Governors; rules of procedure have been drawn up and agreed in the General Assembly, as has the fee structure.

Also in compliance with the statutes, a small executive office has been set up which ensures that a minimum set of functions is carried out professionally: financial administration, web hosting, support to the Board of Governors and the Academic Council. This Executive office has been supported by the FuseNet project (in agreement with the task description) and is run from the fees henceforth.

The Association seeks external funding for its work on fusion education. Presently (October 2013), there are over 40 formal, fee-paying members and this number is growing steadily with 1 or 2 new members every month. Members include national fusion laboratories, universities and industry that are involved in fusion development.

Work Package 1 Establish and run the FUSENET network	**1.1** Establish the European Fusion Education Network (FUSENET) and consolidate the network by forming a FUSENET Association, with appropriate bodies for coordinating activities, such as an Academic Council and standing committees for different areas of fusion education.
	1.2 Provide support to the network (Secretarial services, information exchange)



3.2 The FuseNet Website

In support of all actions of the network, the professional website www.fusenet.eu has been developed. It is primarily directed at the target student groups, aiming at providing an attractive and transparent interface to fusion education.

Work Package 2 Development of a portal FUSENET website	**2.1** Develop attractive FUSENET website, with a transparent overview of learning opportunities for students, information on industry, educational material, ideas for university research projects and PhD subjects, and Wiki-type community tools.
	2.2 Maintain the FUSENET website, keeping the information up-to-date during the period of the project.

The website provides general fusion news, 'eye-witness reports' from the various joint FuseNet activities, overviews of learning opportunities including internships at laboratories as well as industry, and fusion courses taught at universities, a fusion wiki, a webcam on the ITER-site and many other things. It features web forms which can be used to subscribe to the various activities, access to the virtual reality educational environments that have been developed by FuseNet, matchmaking services for industry that is seeking to find undergraduate students for internships or candidates for other positions, an agenda of all fusion related events, general news on fusion topics, blogs of PhD-students in fusion, eye-witness reports of participants to FuseNet activities, …

A few screenshots of the site are provided below, but the best way to explore the site is of course to visit www.fusenet.eu. More than 130 visitors do that already every day, as is demonstrated by the visitor statistics (see figure). The site also has a protected part for members, which is used for the document distribution and archiving (e.g. for meetings of the various FuseNet bodies). Next to the website, FuseNet is also on Twitter and Facebook.

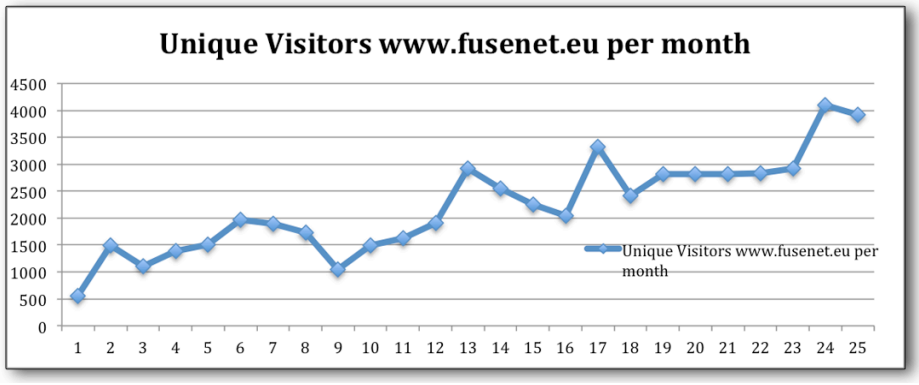


Figure 3: The number of visitors to the FuseNet website per month over the past 2 years (until Sept 30, 2013). The number of visitors is steadily rising, and has reached 4000 unique visitors per month in the fall of 2013.

Figure 4: Screenshot of the FuseNet Website

Figure 5: Students maintain a BLOG on the site and write about their work and lifes as a PhD student in fusion.

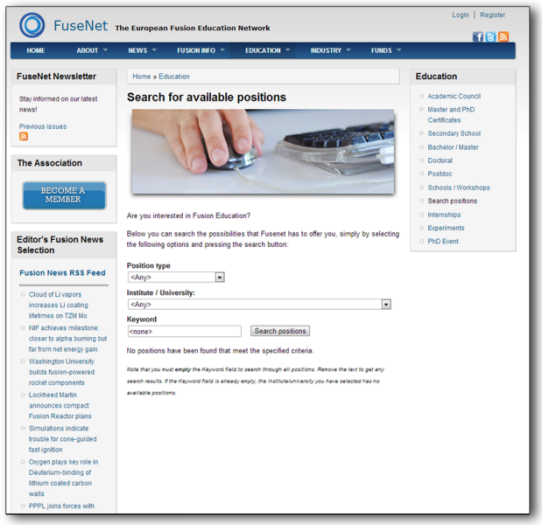


Figure 6: Searching for available positions (e.g. internships, PhD positions, jobs, etc.) at any of the FuseNet partners .

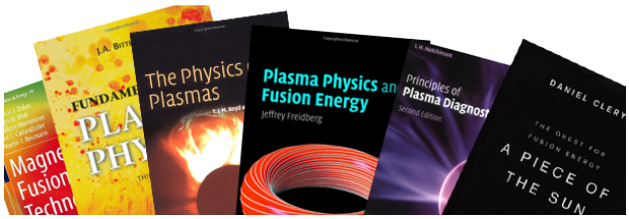


Figure 7: Relevant overviews of fusion books, links, videos, and all major European Fusion devices can be found on the FuseNet website

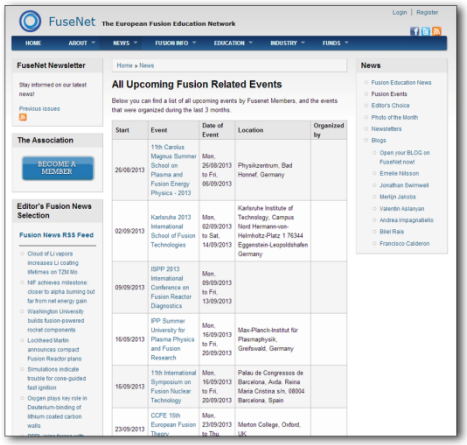


Figure 8: Fusion related Events can be announced on and found through FuseNet's event calendar.

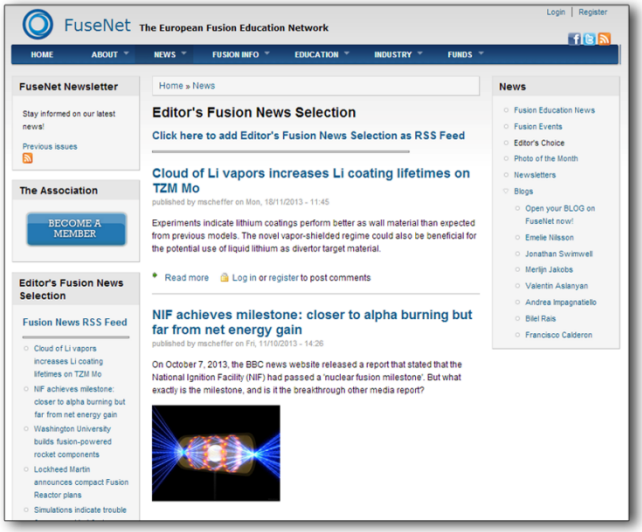


Figure 9: Fusion and fusion Education relevant News is covered on the FuseNet site in separate news categories to which users can subscribe.

3.3 Initial activities: scans of the field

Among the first activities in the project, inventories were made of existing fusion education activities (these are now all associated with FuseNet), and education networks in other fields. In particular the European Nuclear Education Network ENEN is quite similar in set-up and goals and in several ways has served as example when the FuseNet project was first formulated. There have been several contacts between ENEN and FuseNet, and two members of the Board of Governors of FuseNet are also involved in ENEN. After an exchange of ideas between the chairs of both networks it was decided to set up a small working group that will explore further possibilities for collaboration.

On the basis of a questionnaire a database of the educational activities of all FuseNet members has been set up and published on the FuseNet website. The searchable database is kept up-to-date by the FuseNet Members and so serves as a portal for students who are interested in fusion and are looking for educational opportunities.

Further, an inventory of related fields was made with an analysis of possible synergies. This included a.o. Data analysis/mining; Robotics/remote handling; Manufacturing and material science; High performance computing; Advanced Detection sysems and optics; and nuclear fission. Of each topic, academic institutions and industries are listed and possible synergies are indicated.

The reports of all inventories are published on the FuseNet website.

Work Package 3 Inventory of existing fusion education activities, best practices of other fields, and possibly synergies with related fields	**3.1** Make inventory of existing fusion education initiatives such as PhD courses, master courses, summer schools, etc. Make the material available on the FUSENET website. Update the material during the period of the project.
	3.2 Make inventory of best practices other fields (ENEN, CERN, NASA, WNU, BNEN, etc.)
	3.3 Make inventory existing links to related fields, such as high-speed computing, materials science, fission, IT, etc. Explore possible links that should be developed. Make the links explicit on the FUSENET website.

3.4 Individual learning opportunities and educational goals

Doctoral networks, the annual PhD event and the FuseNet certificates

An important result of the work in FuseNet is the establishment of joint academic criteria for the award of the European Fusion Doctorate and the European Fusion MSc certificates. In the development of these criteria many experts active in fusion education were involved. In particular, pre-existing fusion doctorate networks1 as well as the universities offering specialized fusion education took part in the discussion and after extensive deliberation agreed on common educational standards for the fusion doctorate. In the establishment of the joint criteria for the fusion master, the French fusion master network, the Erasmus Mundus Fusion Master and Doctoral college network, the Padova-Munich-Lisbon doctoral network and again universities offering a master specialization in fusion such as Prague, York, and Eindhoven took part.

It is important to note that the programmes of pre-existing doctoral networks are compatible with the FuseNet criteria, while the curriculum of the new UK Fusion Centre for Doctoral Training (coordinated by York university) was specifically designed to comply with these criteria. This shows the harmonization as well as quality push that is achieved by having the community agree on joint criteria.

[1] There are two – pre-existing – fusion doctoral networks in Europe that now operate under the umbrella of FuseNet: 1. The Padova-Munich-Lisbon European Fusion doctoral network, and 2. The Erasmus Mundus Fusion doctoral network, which brought together the PLM and French network, and used some of the criteria developed by FuseNet to set up its doctoral college

For the Fusion Master as well as the Fusion Doctorate, the added value of the FuseNet network was to agree on Europe-wide accepted criteria and doing so by putting the bar high: the requirements are challenging and will push the level of fusion education. The criteria specify a study load for the fusion core (breadth) as well as for specialization (depth), and cover physics, technology as well as generic skills. These criteria introduce a uniform high quality standard that will make 'fusion' a quality brand apart from a specialization.

The accreditation of master and doctorate training programs and the award of certificates is now in the hands of the FuseNet Association, which for this purpose has installed an Academic Council of independent experts. The certificate award ceremony was organized at the Joint European Torus JET, where the awarded students were treated to a scientific programme, followed by a nocturnal tour of the JET facilities (which due to machine operations cannot be visited until 22:00 hr).

We note here, judging from the response when the possibility to apply for the certificate was opened, that there is a great interest among the students to earn the distinguishing 'Fusion doctorate' or 'Fusion MSc' certificate. Clearly the field attract highly motivated students who are keen to get the official recognition of the effort they made by specializing in fusion science and technology.

Figure 10: The first twenty students received their European Fusion Master's and Doctorate Certificates

Figure 11: FuseNet Certificate holders showing their obtained certificates - together with representatives from EFDA, FuseNet and CCFE, where the students also received a tour of the JET facilities.

Another very important joint activity is the annual PhD-event, which brings together all PhD students in the European Fusion programme, including the students of three doctoral networks, each of which has hosted the event once. The annual PhD-event is reported in more detail under the heading 'joint educational activities'.

Through the establishment the joint criteria, also the homogenization of the two pre-existing doctoral networks was effectuated. The effective merging was further achieved by the joint organization of the above mentioned annual event, to which all PhD-students active in fusion are invited. Also, the networks have opened their courses to each other's students. Finally, the boards of both networks have close contact and are represented in each other's meetings, and are both represented in the FuseNet board where they meet almost monthly. Thus, a homogenization of fusion doctoral research and training was achieved under the umbrella of Fusenet.

With the establishment of the joint educational goals for the Fusion MSc and Doctoral Certificates, and thereby the establishment of an umbrella that unifies the academic criteria used by various doctoral networks, work package 6 of the project has been fully implemented.

Work Package 6 Development educational goals PhD and Master level	**6.1** Identify required knowledge for PhD students, and establish the criteria for a European Fusion Doctorate certificate. Prepare the establishment of a single European Fusion Doctoral Network.
	6.2 Identify required knowledge for master students and guidelines for curricula. Establish the criteria for the award of a "European Master in Magnetic Fusion Science and Engineering" certificate.

Figure 12: Participants of the third FuseNet Phd Event organised at the Physics department of the University of York in June 2013.

Internships, traineeships, and matchmaking with industry

Another important function of the network is to promote the participation of Master students in fusion research through internships. With the involvement of industry in ITER, internships in industry have gained in importance. They also constitute a very effective way of establishing collaborative contacts between industry and academia involved in fusion. Moreover, they introduce students to potential future employers. This is an activity that has been initiated under the FuseNet project and is being taken further by the Association.

The website serves as the platform where projects are advertised – or, as is the more common practice, where institutions can list their fields of research and contact persons, inviting students to contact them and discuss possibilities on an individual basis. This action initially targeted internships at universities and research institutes, and has now been expanded to industry. Students could apply for limited financial support under the FuseNet project, which has shown to be a very (cost) effective way of stimulating student mobility and participation in research (see under 3.4).

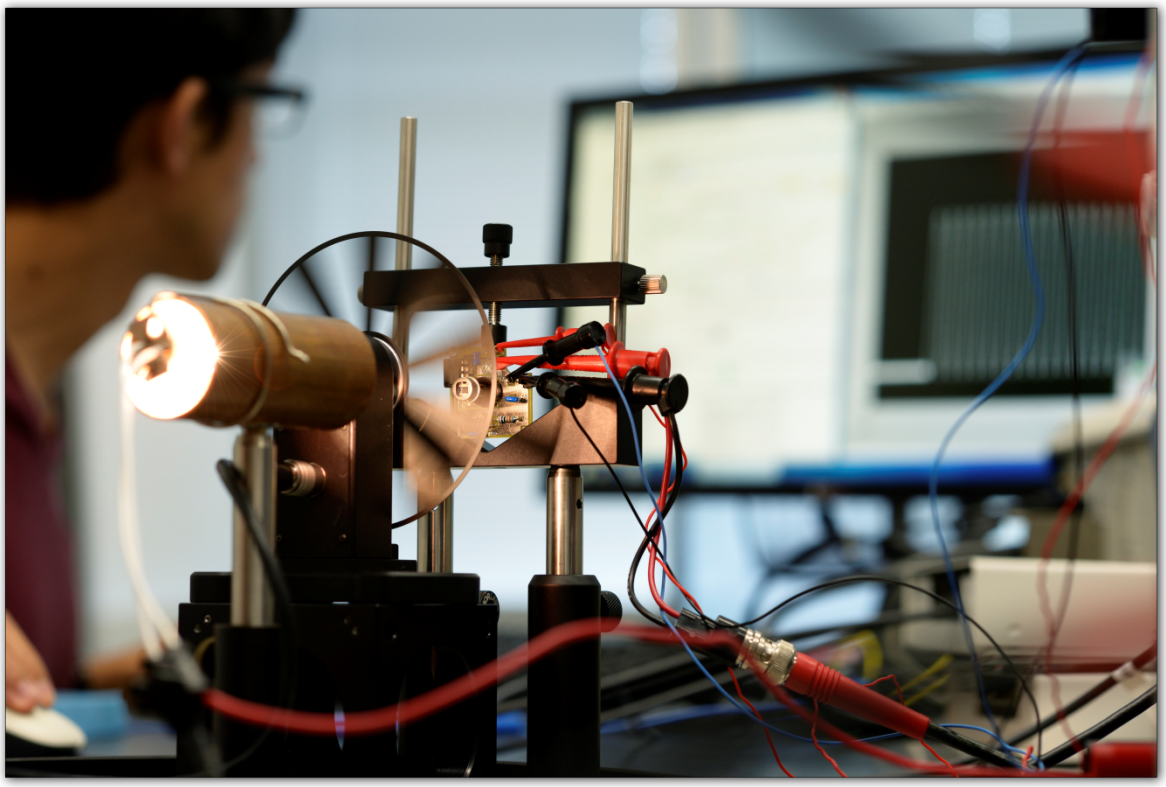


Figure 13: Student using microwave components to study stray microwave components to study stray radiation during his internship; Student mobility has been a very successful and cost effective method to enhance education and establish new connections within the FuseNet project.

The FuseNet project further foresaw the organization of a summer student program on fusion technology. This has mostly been shaped by the organization of the Karlsruhe summer school on fusion technology. An effort was made to organize internships in industry directly related to this summer school, but this turned out to be logistically too complicated. Instead the generic matchmaking service for industrial internships was launched using the FuseNet website. This has indeed led to such internships, as is illustrated by the student blog below.

Figure 14: Group photo of the 2011 edition of the KIT summer school

Work Package 4 Development of individual learning opportunities in the fusion programme ((summer) internships, traineeships, visits, research subjects) for different target groups	**4.1** Make inventory of existing short-time traineeships and (summer) internships for Bachelor / Master (science and engineering) students at fusion facilities and industry, and make this information available on the FUSENET website.
	4.2 Organise a summer programme for technical/master students.
	4.3 Development of an effective match-making service for internships in industry, in collaboration with Fusion Industry Innovation Forum (FIIF)

3.5 Joint development of educational materials

Development of hands-on experiments

FuseNet aims at improving the educational environment for fusion students by making available more hands-on experiments. An action was launched to develop prototype experiments (including detailed building instructions), lab courses and pilot workshops for master and PhD students. The first call for proposals was so successful that the action was enlarged and a second call was organized.

Work Package 7 Increasing the access to existing fusion-related experiments and infrastructure for teaching purposes, and the development of new teaching hardware	**7.1** Make an inventory of existing hands-on experiments for educational purposes and best practices of plasma/fusion related experiments. Identify the current usage and ways to optimise the usage.
	7.2 Develop new, or strengthen existing hands-on experiments (such as a set of practica for basic plasma physics and diagnostics) and make it available to master students.

As a result of this action 16 new plasma/fusion experiments were developed that can be used in hands-on laboratory classes. Developing such classes was deemed particularly necessary for fusion education, as the experiments generally requires plasma experiments involving vacuum equipment, high voltage supplies and often some materials issues, that are typically are not very cheap or simple to build. The new experiments range from elementary set-ups to teach the fundamentals to quite advanced plasma and diagnostic experiments to go into more depth. Even for the simple experiments, and certainly for the more complex ones, a significant effort went into the design of the devices to make them appropriate for use by students in a practicum environment. And, so that every interested institution can copy the set ups without having to reinvent them, detailed descriptions have been made available, as part of the task, to the level of technical drawings and item lists.

A brochure, with a brief description of all projects and links to the relevant material and key persons, provides the perfect introduction to interested parties, be it teachers looking for laboratories they could built or students interested in participating in some existing ones.

Figure 15: Front page of booklet on hands-on experiments on plasma physics and nuclear fusion, as an easy reference guide to teachers and students.

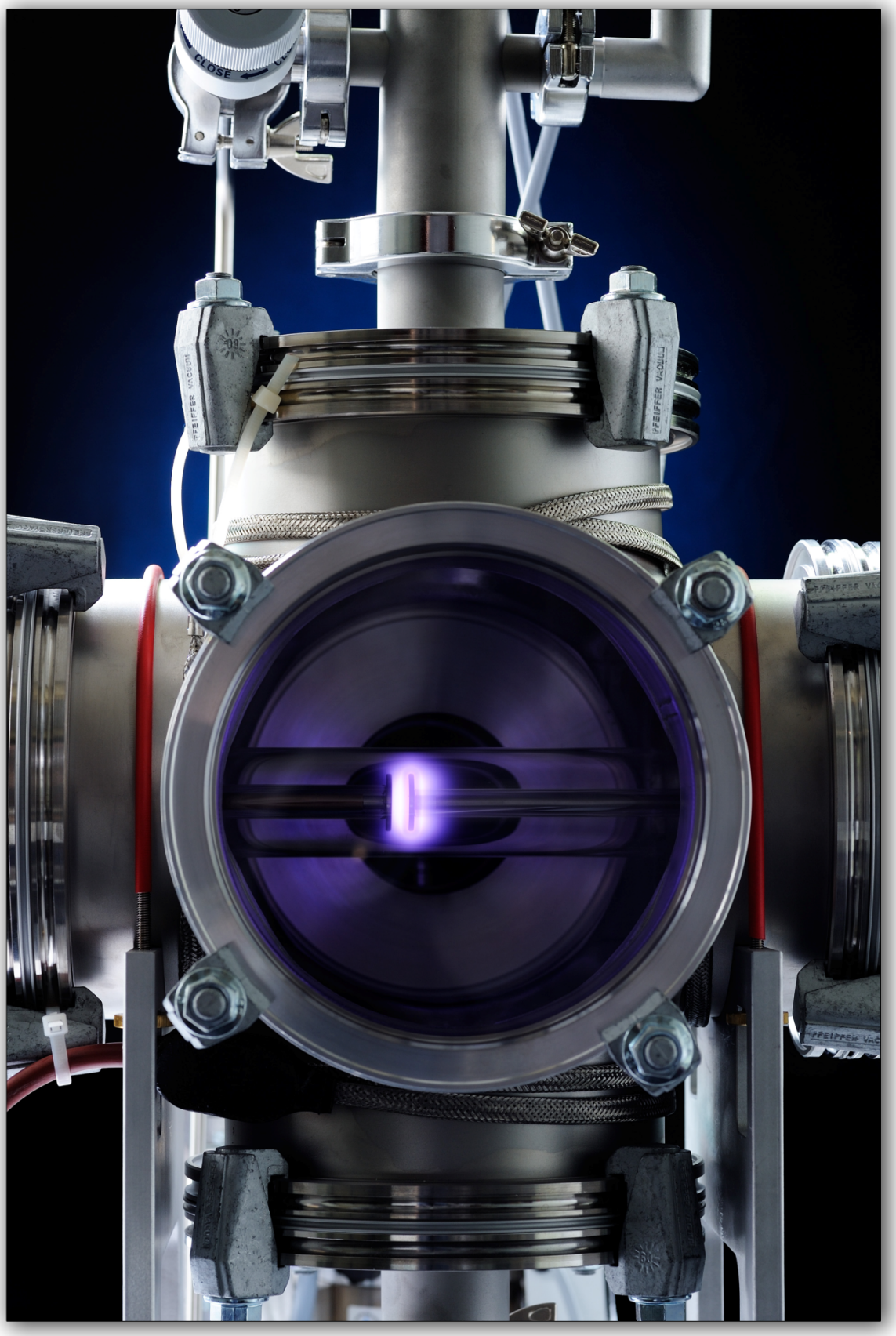
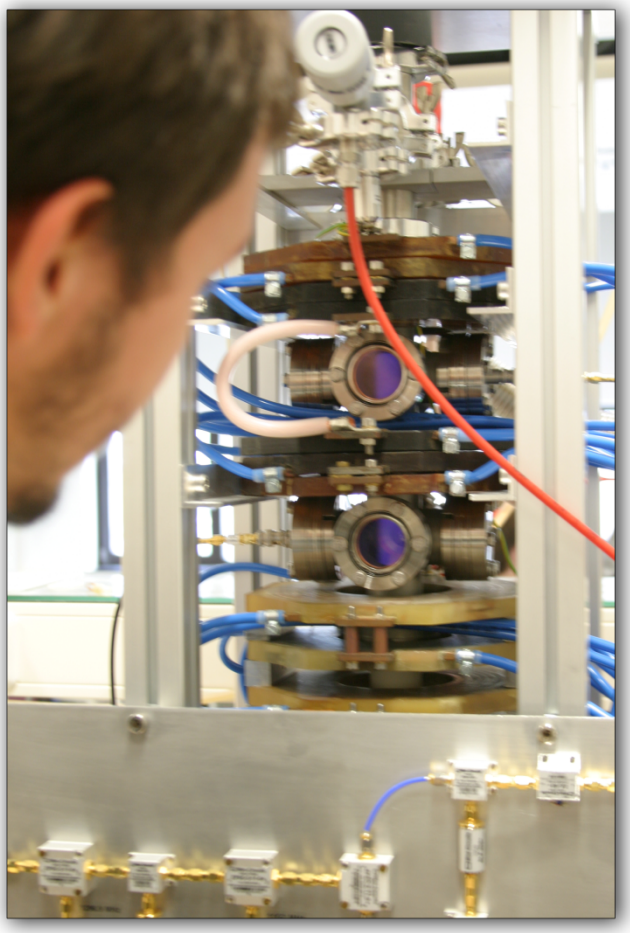
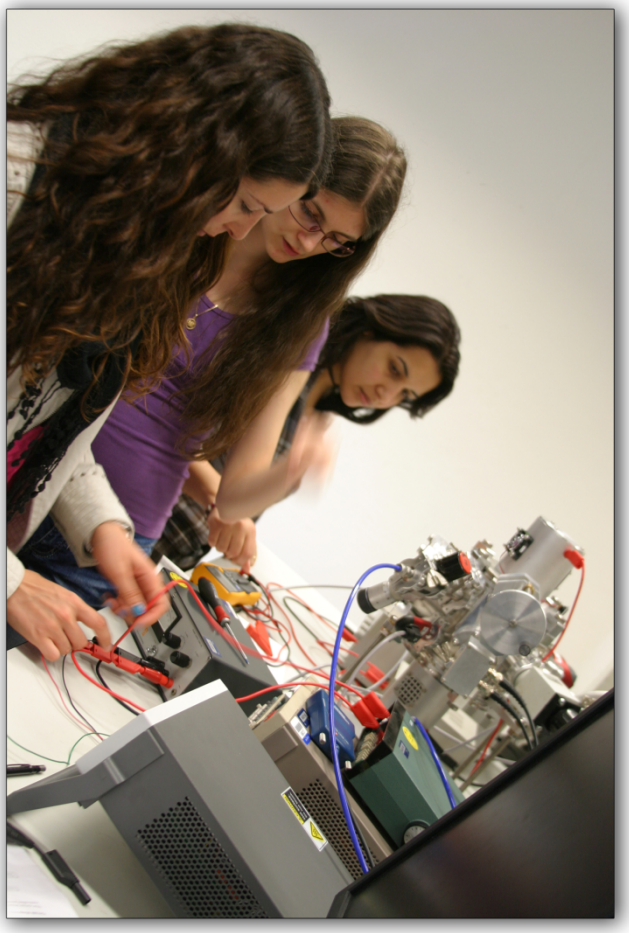


Figure 16: Hardware experiment built with support of FuseNet, to study the effects that determine the electrical breakdown in a gas.

The existing hardware, built with Fusenet support, can and has indeed been shared. Three highly successful pilot courses were organized in each of which about a dozen students from various European countries came together for an intensive 1-week course in hands-on plasma labs at Eindhoven and Lausanne (see the photos below for photos of students at work during these 1-week courses). These pilot courses have been evaluated on the basis of the student feedback as well as the experience of the teachers, resulting in some fine-tuning of the organization and teaching material.





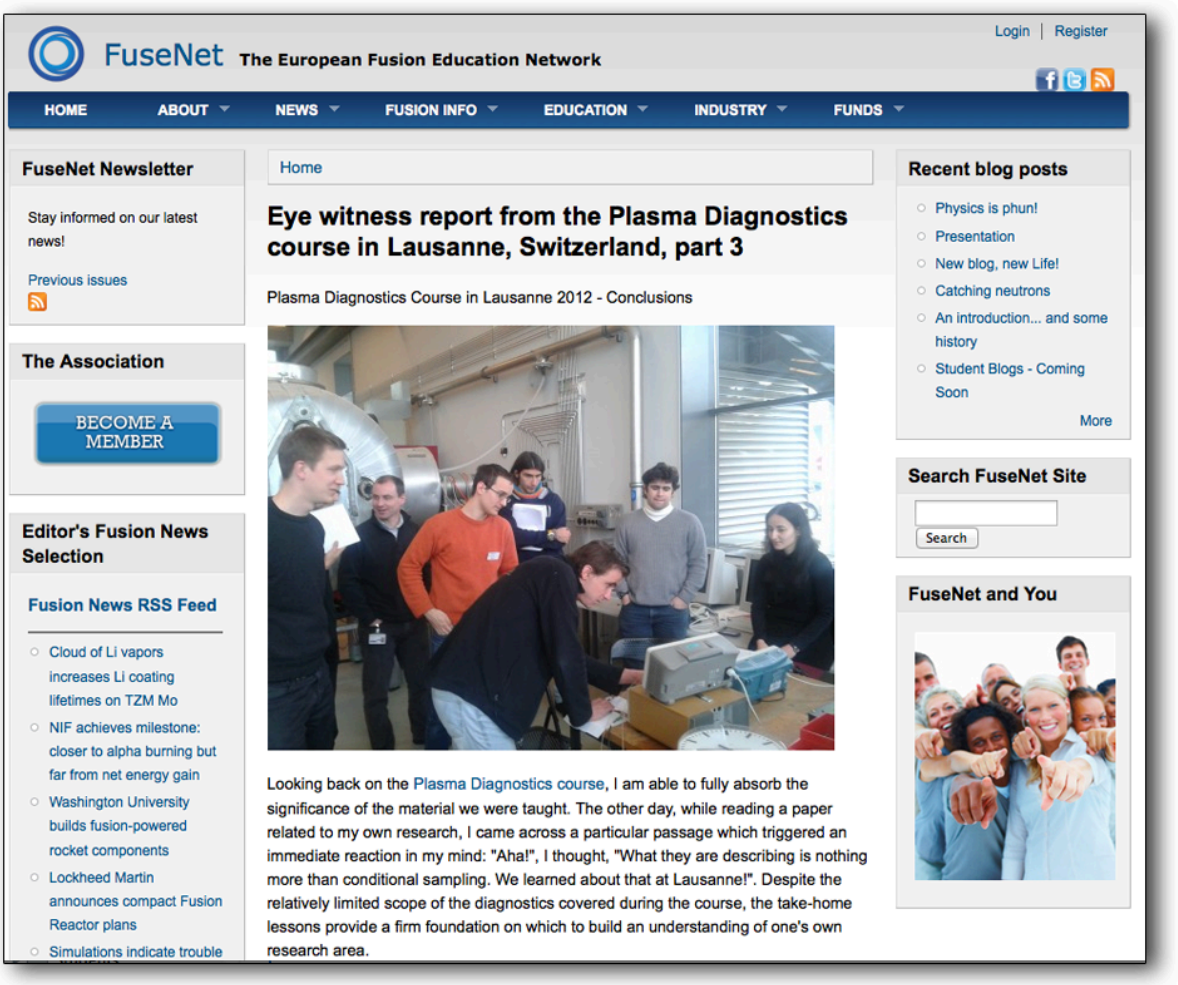


Figure 17: One of the eye-witness reports on the FuseNet site from the Plasma Diagnostics course in Lausanne, 2012

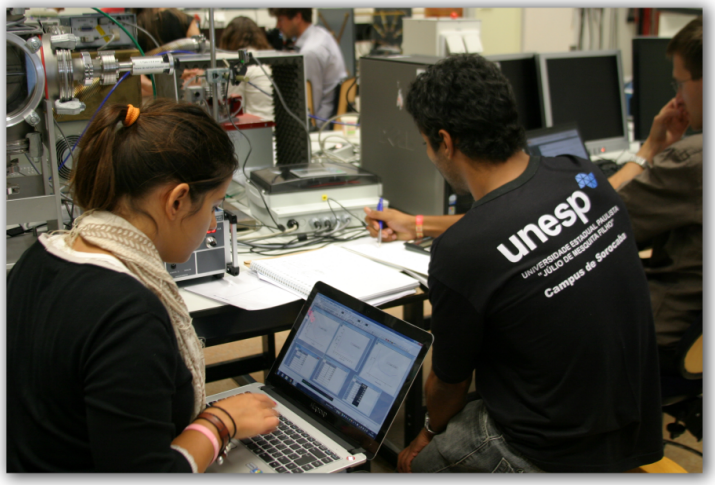


Figure 18: Third edition of the Hands-On PlasmaLab course at Eindhoven University of Technology, 2013

'Remote hands-on experiments'

As part of this action also pilots with 'remote hands-on experiments' were developed: real experiments that can be done by students via an internet link from a remote location. These vary from small experiments, among others at Lisbon and Eindhoven, to the tokamak Golem at Prague University, where students can run a real tokamak remotely and which serves as an excellent introductory experience to fusion research. These on-line experiments are embedded in tutorial programs, which challenge the student with research assignments. The associated student discussion forum turns out to be an effective means to enable interaction between students, with great educational added value.

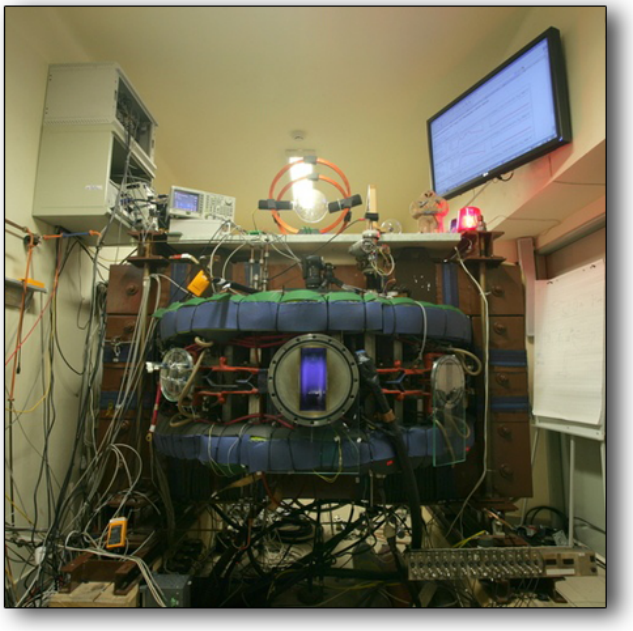


Figure 20: GOLEM tokamak being operated remotely

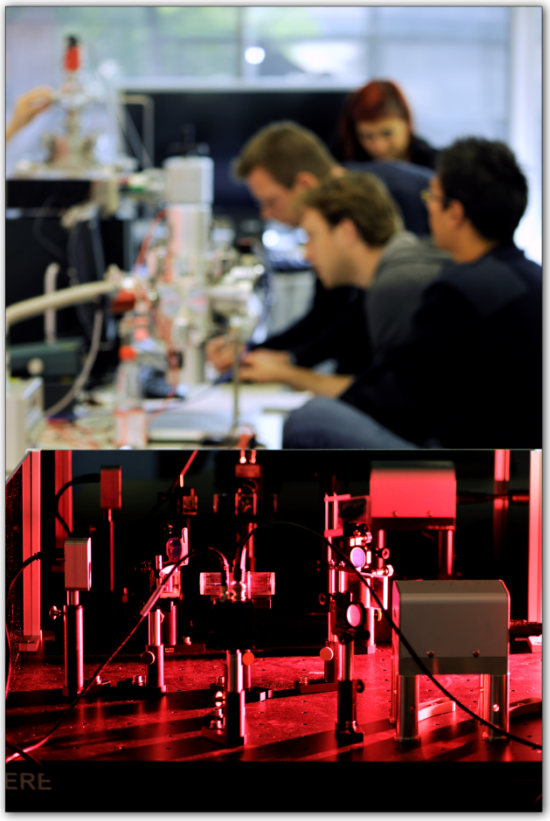


Figure 19: Students working on combination of live and remote experiments

Figure 21: GOLEM tokamak being operated remotely

Web-based tools

FuseNet also developed web-based virtual reality environments to be used in fusion education. These vary from an interactive plasma calculation tool to virtual reality realizations of JET and ITER. Each tool was tested and reviewed by professionals from FuseNet members other than the author of the tool, to get good feedback and improve the tools further for use in education.

Members of FuseNet can access these tools through the website:

- The virtual fusion exhibition and JET remote handling tool
- Online plasma calculator (WPC)
- Tokamak particle simulator
- METIS plasma model
- GOLEM tokamak virtual model and control room simulator
- The virtual ITER tool

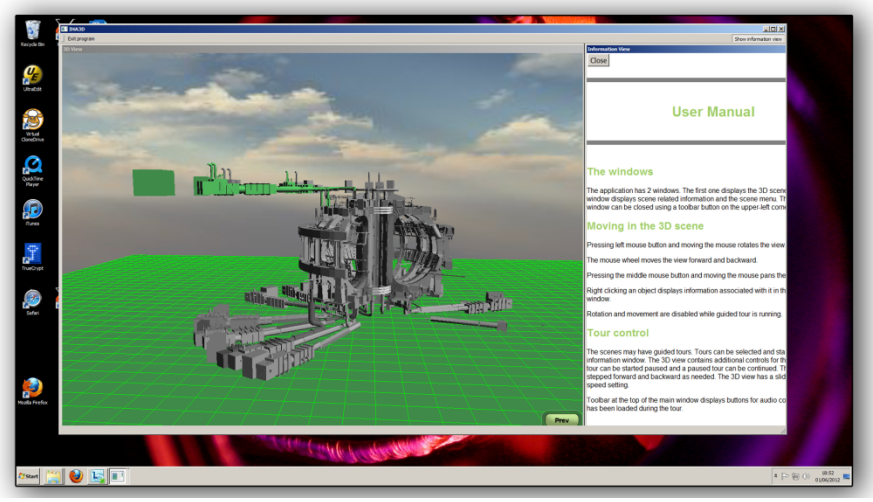


Figure 23: Exploring different components in the virtual ITER tool.

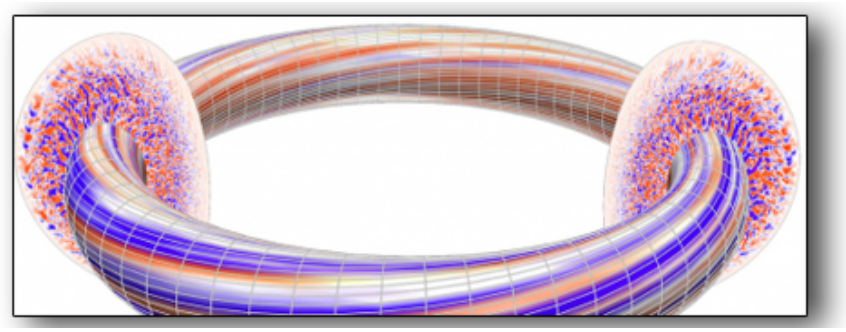


Figure 22: Fusion codes and software tools can be found through the "Fusion info" menu on the FuseNet website.

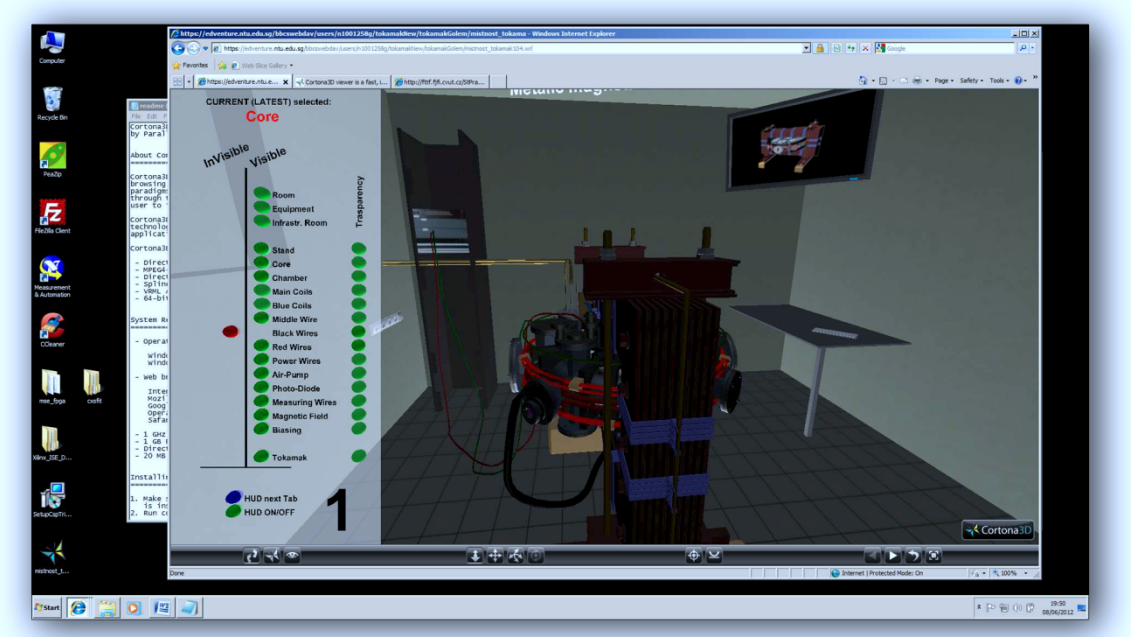


Figure 24: Golem virtual tool.

Figure 25: METIS is a tokamak plasma simulation tool

A paper-based book and a web-based course

Two actions concerned the joint development of course material.

First, a complete interactive, on-line introduction to plasma physics and fusion was developed with FuseNet support, evaluated and made available to the FuseNet members and, at full cost, to external users). The course material is backed up with interactive sessions by teaching staff at Queens University (Belfast), the developer and host of the course. This educational approach is particularly suited – among others – for workers in fusion-related industry who cannot take courses live at a university, but in this way can bring their academic knowledge of plasma physics and fusion science up to an adequate level.

Work Package 9 Development of multimedia teaching materials	**9.1** Develop pilot online course on plasma physics, tokamak physics or a related subject. Aim at 1st and 2nd year master year subjects.
	9.2 Develop virtual tokamak / virtual plasma physics lab for online experimentation (plasma behaviour, remote handling).

Second, the fusion field lacks a good, modern book on fusion technology, and FuseNet took action to fill this gap. After an initial inventory of available material, an editorial board was formed which developed a detailed plan for the contents and production of such a book. The book will be produced by the IAEA, in first instance as a paper book. The publication of an interactive web-based version will be considered later. The FuseNet project/budget did not include the actual production of the book, only the design of its contents.

Figure 26: A new textbook on Fusion Technology is in preparation.
For more information and a provisional table of contents, see http://www.fusenet.eu/books

The editorial board agreed on an expanded table of contents that gives a good coverage of the field of fusion technology and fits within the format of the IAEA book. Specialist authors were found for all chapters, and they agreed to contribute their chapters under guidance of the editorial board, who would also see to the integration and consistency of all contributions. Moreover, Dr. Tom Dolan, main author of the book "Magnetic Fusion Technology", was found to be willing to act as an external reviewer of the manuscript.

Whereas the actual production of the book was not part of the FUSENET charge, parties were found willing to sponsor the production of the book and the writing process is already well in progress. Eight chapters have been written and are being or have been reviewed by dr. Dolan. The book is expected to have about 500 pages.

Work Package 8 Identify existing master level educational material and develop plan for top-quality master-level text on fusion technology	**8.1** Identify existing materials that can be either integrated into a master-level textbook or made available to the fusion education community in other ways.
	8.2 Develop a plan for producing a top quality master-level textbook on fusion technology, including a list of interested authors and possible funding sources.
	8.3 Support by the editorial board of the Fusenet book on Fusion Technology to the writing and production process.

3.6 Joint educational activities

FuseNet has a coordinating role for pre-existing educational events such as summer schools for which it provides some financial support, it initiates and organizes events that were found to be lacking, and has a special budget to support individual students – either to take part in joint activities or internships outside their home country.

Summer schools

FuseNet has made an inventory of the different fusion summer schools that are available in Europe. A meeting with all summer school organizers has been organized. It was found that there is a good spread of topics and levels, providing for all target groups. In particular, the recently started fusion technology summer school (Karlsruhe) fills an important gap. The organizers of the schools agreed to further harmonize the programs of the schools where necessary.

All schools are advertised through the FuseNet website, which also publishes 'eye-witness reports' from participants. The schools can apply for financial support from FuseNet for part of the organization budget, subject to rules e.g. with respect to the multinational European participation.

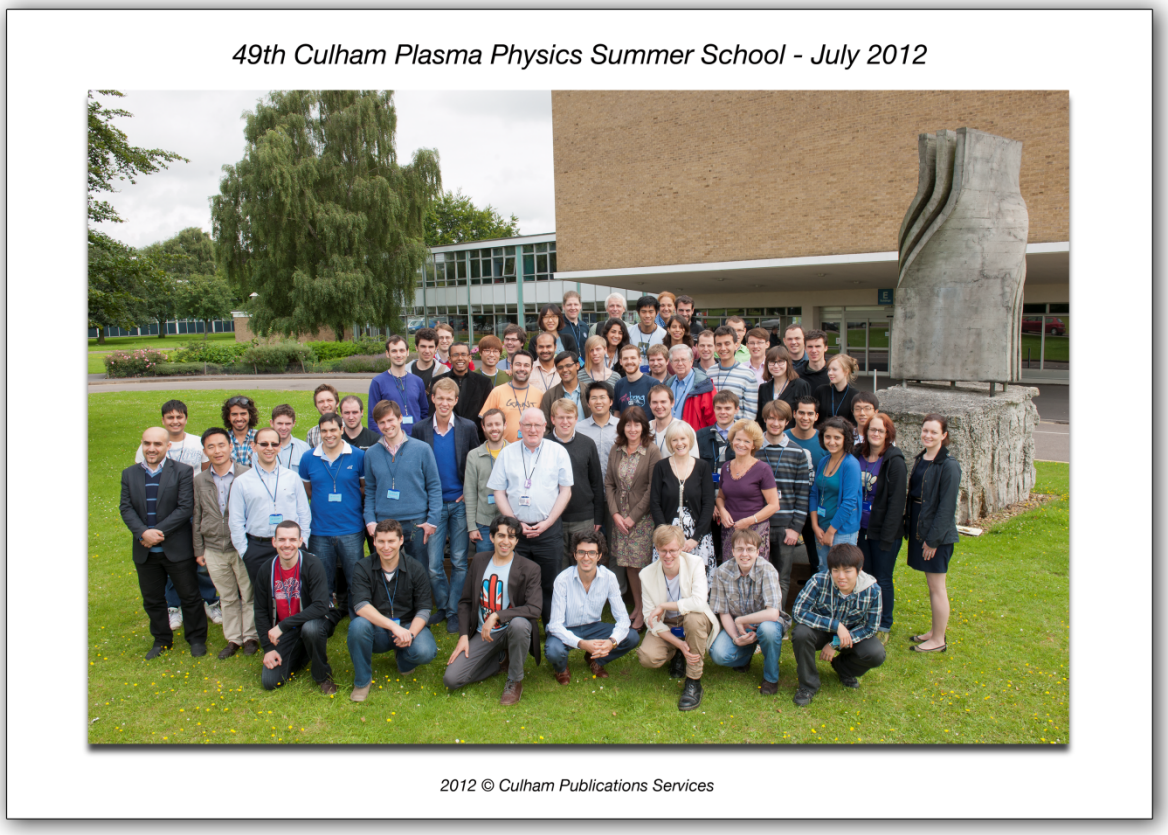


Figure 27: The 2012 Culham Plasma Physics Summer School was organised with FuseNet support.

Annual PhD-event

As a special, new, joint event, aimed at stimulating the bonding in the present generation of fusion students, FuseNet initiated and funds the organization of an annual PhD-event. This event is meant for all European PhD-students in fusion (indeed, participation in these events is a requirement for the fusion doctorate certificate) and is set up in such a way that it allows for ample discussion between students, as well as bringing the students in contact with top scientists. The topics are not restricted to fusion per se, because stimulating the students to develop a sound sense of context is an important goal of this event. Three editions of this event have been organized, in Garching, Pont-à-Mouson, and York, respectively. Each event benefitted from the experience of the previous editions and the student response, which was already good in the first edition has become even better. In particular, the increasingly strong involvement of students in the organization of the event proved to work out very well.

Figure 28: Group photo of the 2nd FuseNet PhD event, 2012, at the University of Lorraine in Pont-à-Mousson, France.

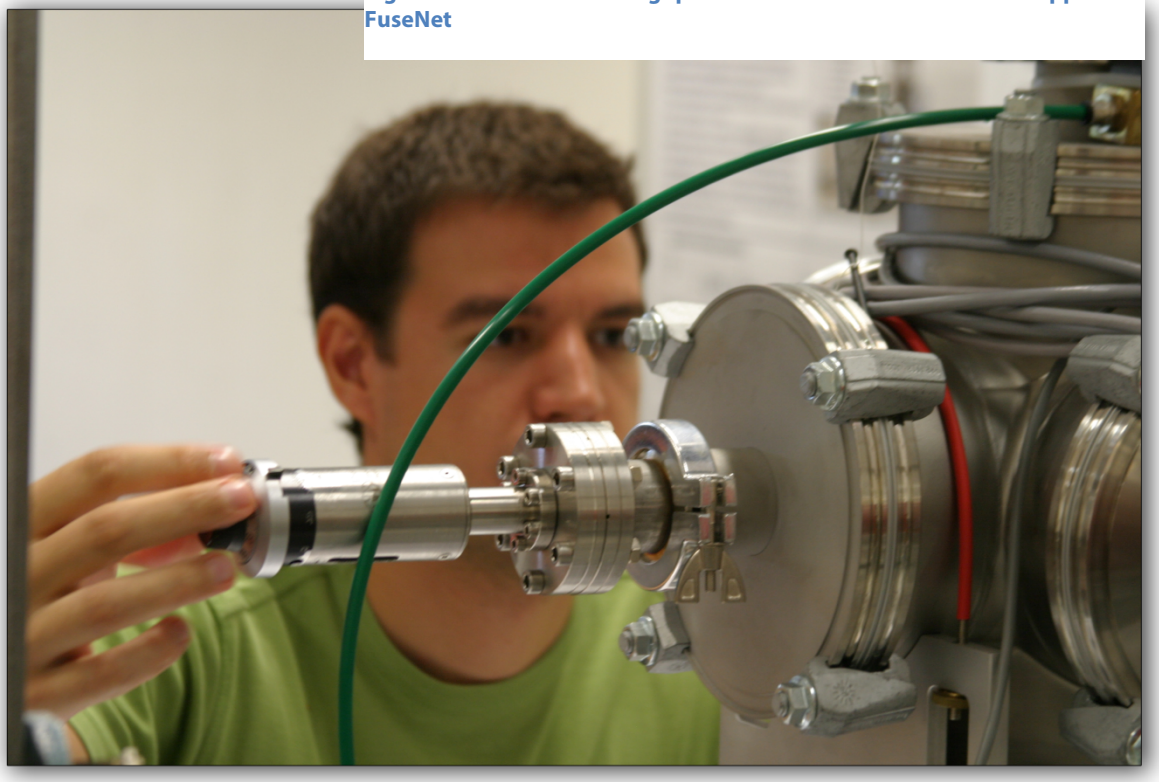
Work Package 5 Development and coordination of international fusion courses such as summer courses and specialised courses	**5.1** Develop a detailed plan, including a list of interested organising partners and possibilities for funding, for a yearly EU doctoral event aimed at getting together all the PhD students in the same phase (50 a year), where they follow lectures (for example, "Project management of international projects", and "basic tokamak operation") and present their own research.
	5.2 Review and coordination of existing summer schools
	5.3 Evaluation and optimization of the annual joint European PhD-event, including the organization of the 3rd edition in 2013

Support to individual students

FuseNet had a budget - 100 kEuro, in agreement with FP7 regulations – for financial support to individual students. This was used to stimulate students to take part in the joint educational activities, or to support internships outside their home country. This fund, accessible through the website, has proven to be a cost-effective and efficient way of stimulating student participation in the European fusion programme. Moreover, the possibility to participate in summer schools or to do an internship at a foreign university greatly adds to the attractiveness of fusion as field of specialization. Since the required levels of financial support for students at the master level are relatively modest, more than a hundred individual requests could be granted. This particular support scheme is simple and very effective, and could have had even more traction if the budget had not been capped at 100 kEuro.

It was also interesting to observe how quickly this source for support became known and appreciated by the student community.

Figure 29: Student taking part in education event with support of FuseNet

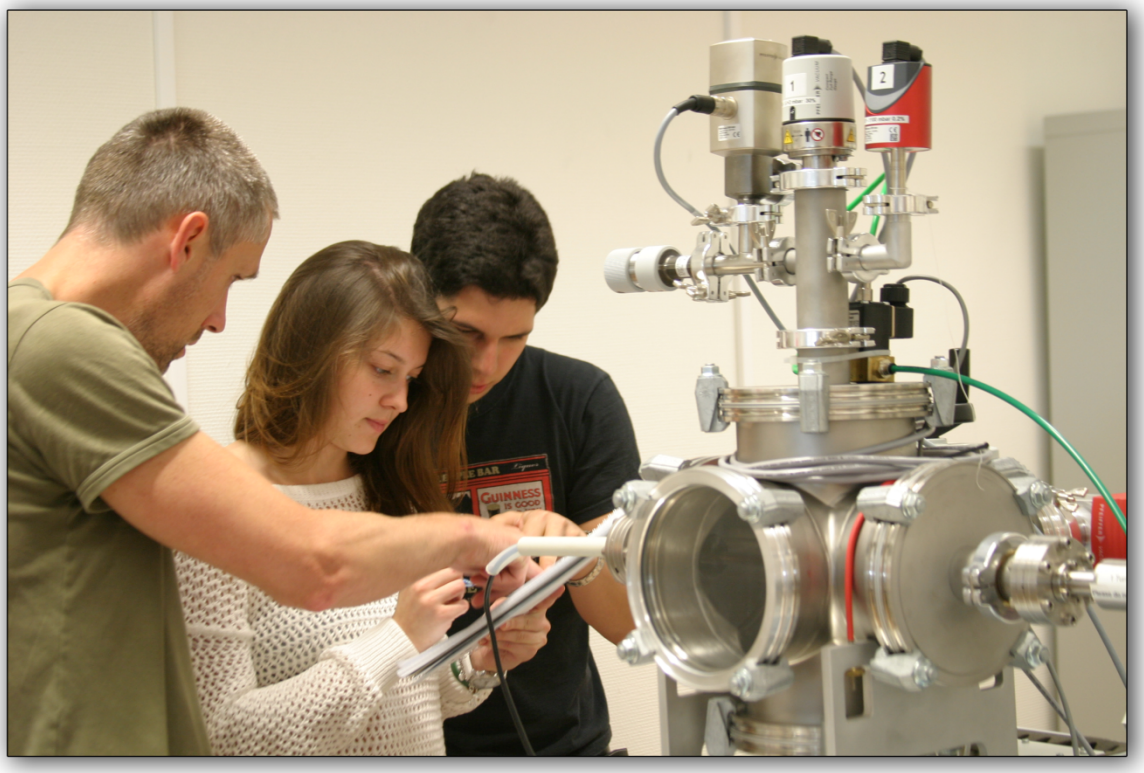


Support to educational activities at MSc and PhD level

Already mentioned throughout the report: FuseNet has supported a variety of educational activities, including summer schools, master classes, and the annual FuseNet PhD-event.

Needless to say, all these great many financial support actions needed to follow a rigorous application and selection procedure. For the application, web based forms were used to streamline the process, and a board was set up to assess the requests, everything backed up by the financial administration office of the University Lorraine (lead party in this workpackage).

Work Package 10 Funding of organization and coordination of joint educational activities in support of European Doctorate and Master level education	**10.1** Organize joint educational activities on PhD level.
	10.2 Organize joint educational activities on Master level.
	10.3 Develop scheme for awarding scholarships to facilitate special individual educational activities.
	10.4 Set up and run an administration system to process the requests for funding of joint educational activities.



4. The potential impact and main dissemination activities and exploitation of results

In a way, in much of the work of FuseNet the dissemination of the work is the essence. All actions that were aimed at the development and support of individual learning opportunities, the organisation and support of joint educational activities, the development of educational tools, all these actions are for use by the community and were successfully launched as such. Also the inventory of educational opportunities, the searchable database on the website, the matchmaking service are clear examples of actions that are fully aimed at dissemination. The on-line availability of the FuseNet web-based tools is another obvious example.

In a somewhat different way, the joint academic criteria for the European Fusion Master and Doctoral certificates have a widespread impact on the community, as we see that they have a positive impact on the design of educational curricula in many universities. In terms of dissemination, this is a very direct and targeted action.

Apart from those actions, which are fundamentally about dissemination, we can distinguish the following actions aimed at increasing the awareness of the work of FuseNet:

a) First and foremost: the FuseNet website.
b) The organisation of Sessions on Education at international conferences.
c) The presence with a booth at international conferences.
d) Acting as the single voice of Fusion Education, on behalf of the members, in various gremia and fora in which Fusion Education is discussed.

The website, with over 130 unique visitors each day, each visiting several pages, is probably the most effective way in which the results of FuseNet have been made public.

FuseNet has initiated and organized special sessions on Fusion education at several EPS conferences on Fusion. These were typically attended by about 50-100 participants and led to good discussion on education, which then fed into the development of fusion education as supported by FuseNet. FuseNet also participated – representing the fusion education community – in round table discussions at conferences, and organized a discussion session with representatives from industry to address the question what they see as the most pressing needs concerning fusion education. Papers on fusion education and training were presented at several conferences.

To increase the visibility of its work, FuseNet was present with a booth at several conferences such as SOFT (2012), the ITER Business forum (2012), and the International Symposium on Fusion Nuclear Technology (2013).

Finally, FuseNet was invited on several occasions to speak on behalf of its members on fusion education, or to take part in round table discussions.

'If you are bright and ambitious, and thrilled by the prospect of doing research on one of the world's most exciting big science projects in a stimulating, multidisciplinary, international environment, and moreover keen on contributing to a clean energy supply for all, for ever, then Fusion is probably just the thing for you.'

This appetizer, addressed to prospective students of nuclear fusion, expresses the spirit of the European Fusion Education Network FuseNet, which started about 2 years ago as a FP7 coordination action.

FUSENET

The information portal on fusion education www.fusenet.eu

FUSENET coordinates joint educational activities, such as the annual summer school on Fusion Technology in Karlsruhe.

The motivation for the establishment of this network is the advent of ITER, the large international fusion reactor presently under construction in Cadarache (France). ITER is one of the exceptionally large Big Science projects, and the international collaboration on which it is founded – comprising China, India, Japan, S-Korea, the USA and Russia, with the EU as leading and host party – is the broadest ever. With ITER, there is a broad international political commitment to the development of fusion power for the coming decades. ITER calls for a new generation of fusion engineers and researchers – and conversely, ITER and the associated research offer an exciting career perspective.

But fusion is much more than a career perspective. The development of fusion power is characterized by extreme challenges: heating the fuel to temperatures ten times hotter than the sun; confining this hot plasma in a cage of superconducting magnets that are kept at a few degrees above the absolute zero temperature; inventing materials that can handle neutron fluxes a hundred times more intense than in present devices. And more. ITER is often touted to be the most complex device mankind has endeavored to construct. A challenge to the high-tech industries involved in the construction, that need to develop new technologies – which in turn will boost their competitiveness. A challenge, indeed, calling for a new generation of bright young minds, trained in an interdisciplinary mix of science and technology.

With that in mind, the FuseNet network was launched. With 36 members – universities, research labs – from across Europe, its mission is to improve the quality and appeal of fusion education all over Europe, by sharing educational material and best practices, making hands-on labs available as well as virtual educational tools, preparing a text book on fusion engineering, and supporting the organization of joint educational events such as summer schools. Fusenet also supports students who want to do an internship outside their home university. Importantly, Fusenet has established common criteria for the awarding of European Fusion Master and Doctoral certificates, the quality of which is guaranteed by an academic council.

The FuseNet website provides transparent information to students on where courses on fusion science and technology are taught, where they can do internships, how they can participate in the hands-on plasma lab courses and, of course, how they can apply for individual support for participating in joint educational activities.

Why don't you sample it at www.fusenet.eu?

FUSENET stimulates the development of joint educational tools, such as the hands-on Plasmalab at the Eindhoven University of Technology. (Photo by: Bart van Overbeeke)

Figure 30: Publication of FuseNet in issue 326 of 'The Parliament' magazine, an established magazine that provides EU political news and information.

Figure 31: Successful dissemination activities for FuseNet with a booth and panel discussion on fusion education at the 27th Symposium on Fusion Technology in Liege, Belgium.

5. The address of the project's public website, as well as relevant contact details

Official website of the FuseNet Association: http://www.fusenet.eu/

Information on the FP7 project: http://fusenet.eu/node/171

FuseNet Executive Office Address:

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Secretary of the FuseNet Association	secretary@fusenet.eu
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Phone numbers:

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6. Project logo

FuseNet

The European Fusion Education Network

7. List of beneficiaries with corresponding contact names

Name of beneficiary	Contact person
1. Technische Universiteit Eindhoven	Roger Jaspers
2. Stichting Fundamenteel Onderzoek der Materie (FOM)	Hugo de Blank
3. University of Innsbruck	Codrina Ionita-Schrittwieser
4. Université Libre de Bruxelles	Prof. dr. Daniele Carati
5. Ghent University	Anne-Lore Verplanken
6. Institute of Plasma Physics	Jan Mlynar
7. Czech Technical University in Prague	Svoboda Vojtech
8. Charles University in Prague	Milan Tichy
9. Danmarks Tekniske Universitet	Volker Naulin
10. Tampere University of technology	Jouni Mattila
11. Université de Lorraine[1]	Marie-Sophie Melinette
12. Commissariat à l'Energie Atomique	Clement Laviron
13. Ecole Polytechnique	Jean-Marcel Rax
14. Karlsruhe Institute of Technology[2]	Dirk Radloff
15. Max-Planck-Institute für PlasmaPhysik	Jean-Marie Noterdaeme
16. Forschungszentrum Jülich GmbH	B. Unterberg
17. Budepest University of Technology and Economics	Gergo Pokol
18. MTA Wigner Research Centre for Physics[3]	Lilla Farkas Király
19. Széchenyi István University Györ	Berta Miklos
20. Università degli Studi di Padova	Fiorella Colautti
21. Consiglio Nazionale delle Ricerche	Marco Tardocchi
22. Università degli Studi di Milano-Bicocca	Giuseppe Gorini
23. Institute of Plasma Physics and Laser Microfusion	Helena Howaniec
24. Technical University of Lisbon	Horacio Fernandes
25. St. Kliment Ohridski University of Sofia	Evgenia Benova
26. Alexandru Ioan Cuza University	Lucel Sirghi
27. Centro de Investigaciones, Energéticas Medioambientales y Tecnológicas	Kieran McCarthy
28. Ecole Polytechnique Fédérale de Lausanne	Ivo Furno
29. Cranfield University	Dr Evgeniy Shapiro
30. Culham Science Centre for Fusion Energy[4]	Martin O'Brien
31. University of Warwick	Erwin Verwichte
32. University of York	Kieran Gibson
33. Queen's University of Belfast	Bill Graham
34. National Technical University of Athens	Kyriakos Hizanidis
35. Aristotle University of Thessaloniki	Loukas Vlahos

[1] Formerly: Université Henri Poincaré, Nancy I

[2] Formerly: Forschungszentrum Karlsruhe GmbH

[3] Formerly: KFKI Research Institute for Particle and Nuclear Physics

[4] Formerly: United Kingdom Atomic Energy Authority

8. Fusion Master Programmes in Europe

FuseNet concentrates on the coordination of fusion education in Europe and aims at increasing the opportunities for young bright students to have access to a high level education in this field. Several FuseNet members offer a dedicated fusion master programme, whereas others provide the opportunity of a special master track in fusion (i.e. specialization with the physics or engineering curriculum). Nearly all other academic FuseNet members offer one or more fusion related courses.

In the table below, an overview is presented on the educational fusion programmes for master students in Europe. More information on the fusion specific courses can be found at the FuseNet website under: http://www.fusenet.eu/coursesearch (this list is maintained by the individual members, so the completeness and up-to-dateness is not the responsibility of FuseNet).

Organisation	Programme	Number of students (2013)	Programme duration	Internship Project (ECTS)
Fusion-EP (Universities of Ghent, Madrid, Stuttgart, Lorraine)	Dedicated European master of science in Nuclear Fusion and Engineering Physics	26	2 year	30
Eindhoven University of Technology	Dedicated Master of Science and Technology of Nuclear Fusion	15	2 year	15 + 50
University of Rome "Tor Vergata"	2 level dedicated Master course in Fusion Energy Science and Engineering	7	1 year	10
University of York	Dedicated Master of Science in Fusion Energy	12-14	1 year	30
French Fusion Master: Universities of Lorraine, Paris, Marseilles, Bordeaux	Master track with specialization magnetic confinement, inertial confinement, Nuclear Technology	41	2 year	
Charles University Prague – CVUT	Physics and Technology of Thermonuclear Fusion	11	2 year	14+30
BME- Budapest	Fusion Track within physics	7	2 year	
Sofia University	Dedicate master programme Fusion and Plasma Technology	6	2 year	30
Ecole Polytechnique Lausanne - EPFL	Part of Physics, Engineering Physics or Nuclear Engineering	10	2 years	30
University of Lisbon - IST	Plasma/Fusion track in Engineering Physics	6	2 years	6+30
Karlsruhe Institute of Technology	Track in Master of Science in Physics	20	2 years	30