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Environmental externalities of a future fusion plant

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Introduction

In the framework of the Socio-Economic Research on Fusion (SERF), which was jointly conducted by the European Commission and the Fusion Associations, several economic and social questions concerning the future of fusion as a power source were addressed. Beside the direct costs, environmental and safety aspects will play a major role in the future. All the damages that are not reflected in the market price are called external costs. Externalities or external costs related to energy production are in general defined as costs imposed to society that are not accounted for by the producers or consumers of energy, e.g. public health, agriculture, ecosystems etc are affected by environmental effects of energy production. The external cost is a common measure that allows for the comparison of very different technologies. The whole concept of external costs is not without problems. It is for example by no means simple to give a money value for a human life. A second difficulty is the valuing of risk. Is risk simply the occurrence probability times expected damage or do damages exceeding a certain size, what we usually call catastrophe, need a special treatment?

Methodology

The methodology used for the assessment of the environmental external impacts of the fusion fuel cycle is the one developed within the ExternE [EC (1995), EC (1998)] project. The method used is a bottom up, site specific and marginal approach, i.e. it considers extra effects due to a new activity at a studied site. Quantification of impacts is achieved through damage functions or impact pathway analysis. The whole fuel and life cycle of the plant is considered.

Site Characterisation and Plant Model

The plant in the investigation was assumed to be sited at Lauffen in Germany at the river Neckar. Two fusion plant models are considered [Hamacher]. Most characteristics of models are copied from the European safety study SEAFP [Raeder]. The two models differ considerably in the technology used. The first model uses advanced technology like vanadium alloys as structural material and helium as coolant while the second model utilises more state of the art technology like low activation martensitic steels as structural materials and water as coolant. The parts of the plant not included in the above-mentioned study are taken form the ITER design [ITER] and from data of a fission plant [Schwaiger].

Table 1. Fusion plant parameters

	Model 1	Model 2
Thermal Power [MW]	3520	3810
Fusion Power [MW]	3000	3000
Electrical Power [MW]	1000	1000
Heating Power and Current Drive [MW]	75	75
Coolant T (p) [^{o}C (bar)]	Helium	Water
in	260 (90)	265 (130)
out	560 (90)	310 (130)
Availability [%]	75	75
Breeder	Li_2O	$Li_{17}Pb_{83}$
Structural Material	V5Ti	LA12TaLC
Major Radius [m]	9,4	10,3
Minor Radius [m]	2,09	3,43
Neutron Wall Load [MW/m^2]	2,1	1,2
Magnetic Field at Coil [T]	12,8	11,9

Assessment of externalities

The whole fuel and life cycle of the fusion economy was investigated. But it was realised that only the energy conversion step is relevant. The life cycle of the fusion plant was assessed in all stages:

* manufacturing of materials [Schleisner (1998a)], construction of the plant [Saez (1998)]: externalities arise due to the energy need for the manufacturing process, the emissions and accidents due to transports, the occupational accidents during the construction phase
* plant operation [Saez (1998)]
  during the plant operation gaseous and liquid radioactive releases lead to externalities, only gaseous emissions were considered in this analysis,
* decommissioning and site restoration [Hallberg]
  externalities arise due to transport necessities and due to occupational accidents
* waste storage [Korhonen]
  radioactive releases to the biosphere are the major external effects for the radioactive waste storage

Results

The results indicate that external costs of fusion are of the same order of magnitude as the ones from renewable energy sources [Saez (1999)]. One of the relatively more significant contributions to plant model 2 was the C-14 isotope, released during normal operation, which entered the world wide carbon cycle. For both models a considerable fraction of the external costs is due to the materials manufacturing, occupational accidents during construction, occupational impacts during decommissioning and the waste disposal.

Table 2. Summary of external cost of the fusion fuel cycle

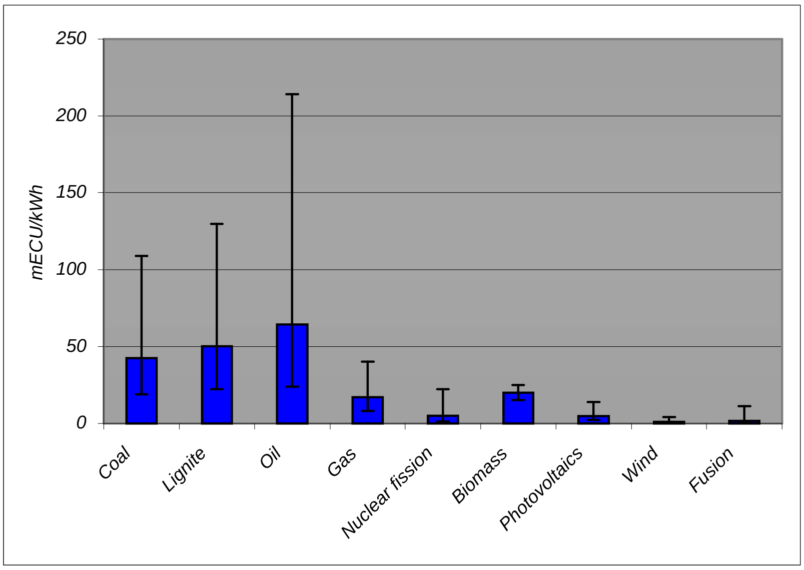
	Burdens			Model 1 (mECU/ kWh)	Model 2 (mECU/ kWh)	σ_g class
Fuel supply				Ng	Ng	
Fuel transport				Ng	Ng	
Material manufacturing				3.2E-01	3.2E-01	B
Construction	Emissions of the transport			2.9E-02	3.0E-02	B
	Road accidents			4.4E-03	4.6E-03	A
	Occupational accidents			2.3E-01	2.3E-01	A
Power plant operation	Stage	Local	Inhalation	6.0E-07	3.0E-05	B
			Cloud	1.1E-07	9.8E-07	B
			Ground	6.0E-05	8.9E-03	B
			Ingestion	Nq	Nq	B
		Regional		Nq	Nq	B
		Global		9.04E-02	1.59E+00	B
	Occupational exposure			4.4E-03	2.4E-02 – 9.7E-02	A
	Other occupational accidents			8.0E-02	8.0E-02	A
	Radiological accidents		BDBA(1)	1.4E-08	2.0E-07	B
Decom-missioning	Transports			1.2E-03	1.7E-03	B
	Occupational impacts			2.6E-01	2.6E-01	A
	Recycling plant	Radiological impacts		9.5E-05	9.5E-05	B
		Non radiological impacts		6.9E-02	6.9E-02	B
Waste disposal				2.0E-01	9.0E-02	
Site restoration	Transports			3.2E.03	3.2E-03	B
Sub-Total				1.29 (0.37-5.42)	2.71 (0.66-12.2)	

Ng: Negligible Nq: Not quantified

σ_g classification has been done according to [Rabl, 1997] where :
A = high confidence, corresponding to •g = 2.5 to 4, and B = medium confidence, corresponding to •g = 4 to 6.

Comparison with other conversion technologies

In the picture below a comparison of fusion with other technologies is shown [Schleissner (1998b)]. Fusion belongs to the technologies with low external costs, it is comparable with wind and solar technologies. The additional advantage of fusion is that it is not an intermittent source of electricity. On the other hand it needs to be mentioned that fusion will not come into operation before 50 years form now. In the mean time other technologies might make considerable progress in their environmental performance. External costs of fossil fuels is dominated by climate change issues.



Discussion and Outlook

The method of external costs does allow a first comparison between different technologies on behalf of their overall environmental performance. The method can not replace a public debate on technologies but it can give numerous inputs to such a debate.

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