EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

Socio–Economic Requirements for Competitive Fusion Energy

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INTERNATIONAL SCHOOL OF FUSION REACTOR TECHNOLOGY

9th Course on "Technology of Fusion TOKAMAK Reactors"

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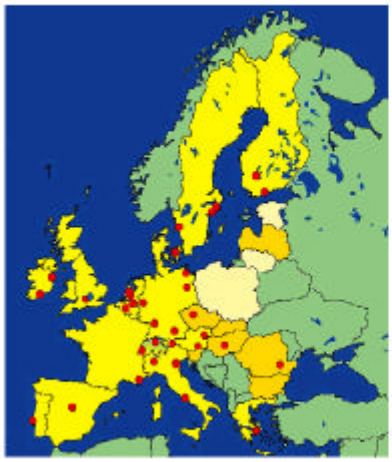
EFDA Associates



EURATOM-Associations:

conduct individually coordinated research (partly on own facilities)

form, together with the Comission, EFDA

Contents

A. Introduction to Socio-Economic Research for Fusion

B. Insight from social sciences

C. Fusion and economics

A. Introduction

1. Scientific vs. market success
2. Degrees of predictability
3. Sociology as a science
4. Aim of Socio-Economic Research in Fusion (SERF)
5. Assumptions underlying SERF
6. Purpose of this presentation

A1 – Scientific vs. market success

The push of R&D community may be sufficient to build an experimental reactor, even a demo. Will the scientific / technical success be enough to bring fusion electricity to the final consumers?

A pull looks necessary in order to make fusion

- More than acceptable, supported by the society,
- More than competitive, attractive for economic producers.

What is necessary to switch from the internal push to the external pull? And to maintain it for 50 years?

A2 – Degrees of predictability? (1/2)

What can we say now about:

- The share of the world Total Primary Energy Supply possibly supplied by fusion in 2100?
- The social support for fusion power plants in 2050?

For comparison, what can we say now about:

- The position of the moon in 2100?
- The weather in Erice Christmas this year?
- the average temperature of the earth be in 2100?

A2 – Degrees of predictability? (2/2)

What is necessary to build reliable forecasts?

- A “simple” system and problem,
- Good measurements,
- A quantitative science, and
- “Simple equations”.

Sometimes our common experience is contradicted:

- general circulation models cannot yet calculate the precise conditions that will eventually reverse the gulf stream,
- sampling surveys can predict the result of some elections.

A3 – Sociology as a Science studies …

The structure of the society and the activities of its members

People leaving together in groups, families, etc. and their habits, customs, activities, etc.

It includes subjects such as:

- Relations inside and among groups different by gender, race, country, religion, age, culture, etc.
- Communication,
- Education, etc.

A3.1 – Is it science?

Physicists and engineers sometimes build equations, which are not reported in their text-books:

- Science = physics, chemistry, etc. ; or
- Science = engineering (mech., elect., infor., etc.)
- Etc.

Sociology = non science

Economics = non science

Psychology = non science

Etc.

Human sciences exist as science, and are useful.

A3.2 – Why so many doubts?

Probably because problems analysed by social sciences are formulated, discussed and solutions proposed making use of the every day language.

The “technical” scientist on the contrary are used to measure the degree of science by the difficulty of the (mathematical) language used to formulate problems and solve them.

Topics, languages and solutions in sociology look so simple that some “technical” scientists propose their own solutions without respect for the methods of sociology.

The effect is wrong decisions (and sarcasm by the sociologist).

A3.3 - EC Research in Social Sciences

Till 2002 social sciences have been a 'support discipline'.

In the 6th FP for the first time they appear in full with the

TITLE: *Citizens and Governance in a Society founded upon Knowledge*

Out of a total budget of 17.5 B€ for R&D in the period 2002-2006, the 6th Framework Program allocates to:

Fusion	750 M€ (4.3%)
Social Sciences	225 M€ (1.3%).

A3.4 - Social Sciences in the 6th FP

"The existence of a priority area dedicated to SE focussed activities within FP6 is a reflection of the perceived importance of this field of research.

So too is the increase in budget for such activities: 225 M€ under the 'citizens and governance' priority of FP6, compared with 147 M€ for 'targeted socio-economic research' under FP5.

When funding for dedicated SE activities in other non-tech. priority areas is taken into account, the total figure under FP6 rises to around 355 M€, and the sum total of all SE activities, including those carried out under technological priority areas, is even higher" *(see: http://dbs.cordis.lu/cordis-cgi/srchidadb?ACTION=D&SESSION=259792003-3-24&DOC=3&TBL=EN_NEWS&RCN=EN_RCN_ID:19793&CALLER=EN_UNIFIEDSRCH)*

A4 – Socio–Economics study …

fusion as an element of energy systems, with:

- *Advantages* – unlimited supply of electricity (?hydrogen) irrespective to location, not contributing to climate changes trans-boundary nor local pollution, low risk, etc.
- *Disadvantages* – shifting time horizon, high R&D and production costs, complex physics and technology, etc.
- *Aspects seen positively / negatively* – centralized large plants, need for other elements, some nuclear wastes, ...

external conditions transforming a technical success into a market success, and

Possible ways to promote social support and maintain the necessary financial support.

A5 - Assumptions underlying Socio Economic studies

To dialogue with external groups with their language

To compare fusion with competing options,

To accept, at least implicitly, to respond or even to adapt fusion programs to external indications.

Fair comparisons imply the need to:

- assess the competing options
- accept the same criteria
- produce comparable results
- use the same methods *(the best available or better ones to be developed on purpose)*
- rely on independent researchers

A6 - This presentation aims at …

- presenting you “feed for thoughts”,
- providing you with an analysis of fusion topics using a different “reference system”,
- giving you hints for a different approach in the future:
  - Human sciences exist and are as good as more mature sciences, such as physics or engineering;
  - It is an advantage to use them;
  - It is very dangerous to mimic them just because the language appears simpler, pretending to be an expert;
- Showing some different tools for discussion

To ripe their full benefit, it is necessary to rely on independent experts of each science branch.

B. Insight from Social Sciences

1. What is fusion now: the problems of “megascience”.
2. Sampling surveys and public opinion
3. Focus groups: measuring opinions and perceptions, communication
4. Awareness for participative decision making
5. Possible research lines

B1- What is fusion now?

Three main characteristics

- long time horizon,
- broad international co-ordination,
- dependence on large research facilities

make it a MEGASCIENCE project, a large technical system, where 'technical' cannot be separated from 'social'.

Theoretical sociology studies how to reconcile megascience, governance, comprehension-trust, democratic participation.

(Lars Ingelstam, Fusion as a Large Technical System, 1999)

Megascience (OECD) is '.. a project that addresses a set of scientific problems of such a significance, scope and complexity as to require an unusually large-scale collaborative effort, along with the facilities, instruments, human resources, & logistic support needed to carry it out'.

B1.1-Social patterns of megascience projects

- Tendency to be described in superlatives by proponents
- Unclear boundaries between factual and rhetorical arguments

  (E.g. with the intention to achieve public acceptance and legitimate large and long term costs, proponents of fusion have in the past described the development of fusion power as equivalent to the discovery of fire.)
- The effect is to create enormously high expectations, and
- In case of delay, breakdowns or other setbacks, the public is prone to see these problems as total failures.

B1.2-The dilemma of megascience proponents

'For scientist the situation is difficult to handle: it is necessary to gain public and political acceptance, yet creating unrealistic expectations and offering promises that have little chance of being fulfilled under the stipulated budget, can rapidly overthrow this support.

The former public enthusiasm over the scientific project might than fade away, and the common feeling of witnessing an important historic process changes into a feeling witnessing and financing a costly fiasco. As a result the willingness to maintain the financial support is reduced or even relinquished' (W.D. Kay, 1994)

Dependence or autonomy for researchers?

B1.3-The decision making process …

… for a long term, large scale project is a complex arrangement. Its presence in the political decision making process is complicating the situation for the political actors. The decision to support a development of such a project cannot be based on an assumption of instant or close benefits. Rather, the presumed gain will not be observed until many years. The political actors have little incentives to allocate large resources to long term projects.

What may prevent them from investing all money and political prestige in short or medium term projects? A larger budget? Hopes for long term solution? Rely on many options to solve a big and otherwise unsolvable problem? Or what? …

Eventually, since the decision making is complex, it requires to researchers interactions and responsiveness to changes in the scientific, technical and financial situation.

B1.4-In the early years of fusion science …

… the researchers laid it down that a viable fusion reactor would be constructed within the near future (20-50 years). Slowly it became apparent that this promise would not be fulfilled; the researchers had run into serious difficulties on several fields, and the fusion power problem appeared to be more complicated than first assumed. The consequence was a delay which hurt the cause of fusion research.

Promising to much is a danger, responsibility is important when selling the research to other actors of the society, because: *'The externalised cost of overselling science is no different from the cost of pollution: we leave it to the next generation of scientists to clean up the mess when we create expectations that may not be realized'* (K.Patel,1994).

Today fusion researchers have to work hard to restore the public trust in their field.

B1.5 – The shifting time horizon

In the early years of fusion science, researchers laid down that a viable fusion reactor would be constructed within the near future (20-50 years).

That this promise would not be fulfilled became apparent only slowly. Why did the prevailing forecasts of the time necessary to develop fusion turned out to be so wrong?

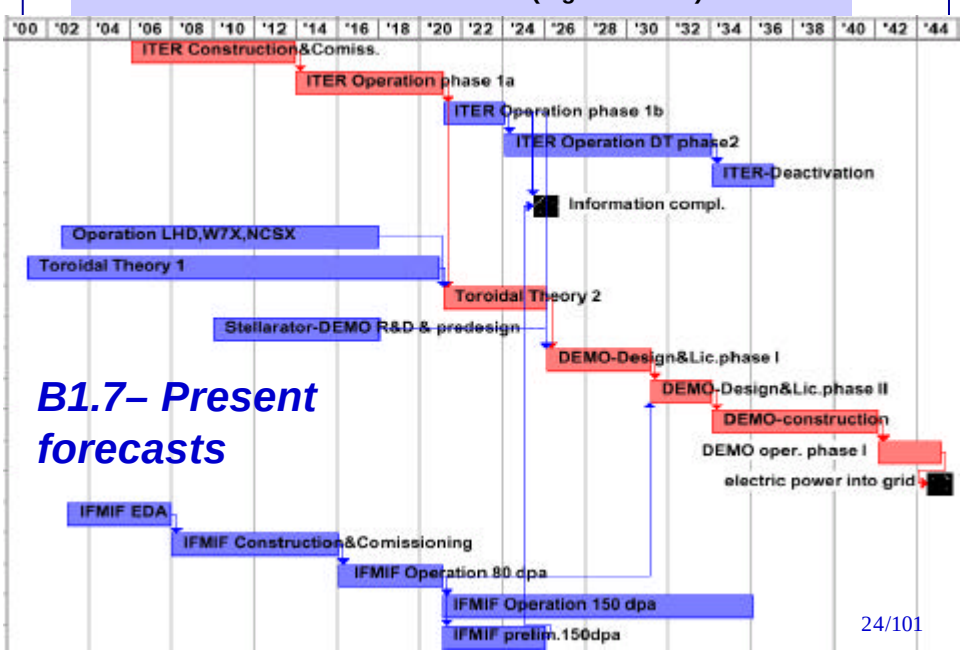
Why the prevailing forecasts were so wrong?

B1.6-Why the prevailing forecasts were so wrong?

Technically, the researchers had run into serious difficulties on several fields, and the fusion power problem appeared to be more complicated than first assumed.

Organizationally, long time horizon, broad international coordination and dependence on large facilities make it very difficult the "governance" of such *megascience* projects and globalised research.

ITER´s role for alternatives (e.g.stellarator)



B1.7– Present forecasts

B1.8 – Forty more years …

For researchers and developers:

more time, (more resources, better research, more contributions from other branches, better experiments, more reliable research, less risks) more "utility"

For entrepreneurs and businesses:

more time, (more expenses, more interests paid on investments, delayed returns) less profits, even chances to lose all.

In economics, the unit of measure of cost and benefits contracts with the years, because of discounting. At 7% real, to pay back 3€ invested today, 50 years from now I have to collect 100€constant, 200y 2.3M€

B2. – Sampling survey: Eurobarometer

In spring 2002 the carried out a sampling survey on "Energy: Issues Options and Technologies – Science and Society" (EUR 20628, Dec 2002)

Fusion was mentioned explicitly in three questions

B2.1 – Energy sources in 2050

Europeans were asked to say which energy sources

1. Solid fuels (coal, peat, etc.)
2. Oil
3. Natural gas
4. Nuclear fission
5. Nuclear fusion
6. Hydroelectric power (dams, etc.)
7. Other renewable sources of energy (solar, wind, biomass , etc.)

would be the best in 2050 on the basis of 3 different criteria:

1. price,
2. efficiency, and
3. protection of the environment.

B2.1a – Energy sources in 2050: price (1/2)

European clearly have faith in renewable energy sources, as 40% of them consider that solar power, wind power and biomass will in the long run be the cheapest forms of energy, and 24% of them choose hydroelectric power. Another 21% choose natural gas, and nuclear fusion is the choice of 14% of those interviewed.

Perceptions vary fairly markedly from country to country: Denmark, the Netherlands and Sweden place most faith in recently developed renewable energy sources (solar etc.). Some countries which are themselves producers of hydroelectric power, have more faith in those technologies (Sweden, 37%, Austria 35%), and in Greece, Italy and Portugal the top choice is natural gas.

B2.1a – Energy sources in 2050: price (2/2)

Nuclear fusion is a more frequent choice in countries where the average level of education is high, e.g. Finland (29%) Sweden (28%), the Netherlands (25%) and Denmark (23%).

Cultural factors also tend to influence the percentages in favour of renewable energy sources (48% amongst those who have continued their education beyond the age of 20, compared with an average of 37%) and nuclear fusion (20%, compared with an average of 10%).

There is scarcely any difference between the answers given by men and women, apart from the fact that 20% of women are don't knows, compared with 12% of men.

B2.1b – Energy sources in 2050: amount

When asked to say which energy resources will provide the greatest amount of useful energy, Europeans are less certain (don't knows accounting for 19% of answers) but they again, albeit a smaller proportion of them (27%), opt for renewable energy sources. This time, nuclear fusion comes second (22%), followed by natural gas (20%), hydroelectric energy (17%) and nuclear fission (17%).

The factors we have described as affecting choices with regard to the price criterion play a more or less similar role here.

B2.1c – Energy sources in 2050: environment

The vast majority of Europeans choose new (solar etc.) (67%) or conventional (hydroelectric) (38%) renewable energy sources; natural gas comes third, with 10%.

More than two-thirds of Europeans (68%) are positively inclined towards renewable energy sources on the basis of at least one criterion (the most frequently cited obviously being their environmental qualities). A breakdown of this overall figure shows the most frequent response profile (26%) to be positive on the basis of all three criteria, i.e. price, efficiency and environmental protection. The next most frequent response profile is one of reservations as regards efficiency (21%) but positive views as regards the other criteria and, lastly, one which is positive only as regards the environmental criterion (21%).

B2.2a – Fusion power: safe?

Europeans have serious doubts on fusion safety against major nuclear accidents, 45% of the answers being don't know and just over a third (35%) of respondents saying 'no'.

It should be mentioned that the proportion of negative answers and don't knows was as high in some countries where the average level of education is as high, e.g. in Denmark, where don't knows accounted for 57% of the total, as in countries in southern Europe where the average level of education is not as high (57% don't knows in Spain, for instance).

The only Member State where there is a significantly more positive answer is Finland (33%), a country known for having a 'technology optimism' level which is often above that of the rest of the European Union.

B2.2b – Fusion power: wastes?

The second question concerned the amount of nuclear waste power stations using nuclear fusion would produce.

Almost half of Europeans (49%) say they do not know, about a third (33%) think that such power stations will produce as much waste as today's nuclear power stations do, and 18% think they will not. This pessimism is very evenly spread throughout Europe, as affirmative answers (i.e. there would as much waste produced) outnumbered negative answers in all Member States.

In two countries, however, the percentages of those answering 'no' were higher, i.e. in Finland (29%) and the Netherlands (28%). Amongst Europeans who have studied beyond the age of 20, the proportion of positive answers is slightly higher (25%).

B2.2c – Fusion power: GHG ?

The third question concerned the possible contribution of this new type of energy to global warming.

Don't knows account for about the same proportion (47%) and again pessimistic answers outnumber optimistic answers, about a third of respondents (32%) agreeing that this future form of energy will contribute significantly to global warming, compared with 21% who think it will not.

In the Netherlands, Denmark, Sweden and Finland, a higher proportion of respondents (37%, 38%, 47% and 48% respectively) consider that this form of energy will not contribute to global warming.

B2.3 – Fusion R&D commitments

Europeans would firstly like to see the EU do more in two areas: renewable energy sources (69%) and cleaner means of transport (51%). Nuclear fusion comes next (21%). Conventional energy sources trail far behind, with natural gas scoring 13%, nuclear fission 10%, oil 6%, and coal 5%.

These preferences are linked in part to respondents' political views. For instance, renewable energy sources and cleaner means of transport are the most frequent choices of those on the centre-left of the political spectrum, with 75% (average 69%) and 57% (average 51%) respectively. By contrast, those who lean more to the right more frequently choose research into nuclear fusion (29%, compared with an average of 21%).

B2.4 – Confidence levels

The suggested uncertainty level of the results is lower than 3%, because the sample includes more than 16000 interviews (about 1000 per member state).

However this uncertainty for fusion is much higher because only 3% of the respondents knows about EC fusion R&D (15% on EC energy R&D). According to a survey carried out in Germany in 1999, only 4% of the population knows what is fusion.

Experimental social studies for fusion need different methods.

B2.5 – Experimental Social Science methods for fusion

- Instead of asking an opinion on a general / distant concept such as fusion, it is better to ask about something more concrete and nearer, such as the construction of a large experimental fusion facility in the neighbourhood: ITER as a proxy for fusion.
- Instead of using static techniques (questionnaires), through dynamic methods it is possible to explore more in depth perceptions and emotions, which are very important in energy – environment topics, where sometimes decisions are not based upon rational criteria.

Focus groups measure also the effects of communication

Awareness workshops start changing the attitudes.

B3.1a – The Focus Group methodology

- Semi – structured group discussions, where group dynamics prevails and emotions emerge.
- Main steps:
  - Definition of themes
  - Elaboration of a ‘Protocol’
  - Identification of ‘target’ population
  - Recruitment of participants
  - A ‘test’ group
  - The focus group discussions (recorded)
  - The analysis
  - Feedback to the participants

B3.1b – FG: Advantages / disadvantages

Advantages	Disadvantages
Fast collection of information	Weak capability of generalisation
Interactions within group	Weak representative power
Rich and diverse information	Difficulty in getting individual independent answers
Flexible tool – large field of applications	Difficult synthesis
Accessible data	Bias by the animator
Safety of data	

B3.1c –The POFFICAD project

Public opinion via Focus group on energy scenarios including Fusion and on ITER siting in Cadarache (2002)

- SCK•CEN, Mol, Belgium
- IRSN, Paris, France
- CEPE, Zurich, Switzerland

B3.1d – Themes

- Perception of risk (safety, health, quality of life, financially,…)
- Place: Impact on the region (economic, social, employment, stigmatisation of the region,…)
- An innovative facility in a site with a long tradition (fusion-fission, research,…)
- International dimension of the project (shared responsibility, collaboration,…)
- Trust (credibility, openness, trust in science and expertise,…)
- Information and communication (what information, format, actors and credibility,…)

B3.1e – Actors

- General Population
  - Locally (4 neighbouring villages)
  - Regionally (up to few tens of km)
- Emergency workers
- ‘Associations’ (environmental, Comité Local d’Information, pro and anti nuclear,…)
- Local and regional authorities (level of department and communities)

B3.2a – Main results: perception of risks

- Population
  - Quality of life, waste, seismic risk, safety, future generations
- Local authorities
  - Public support; no major concerns except socio-economic dimension
- Associations
  - Waste, environment, health; 1 participant: latent opposition
- Emergency workers
  - Risk doesn't exist yet, not well informed, no viewpoints

B3.2b – Trust: general population

- Confusion
  - Experts of site considered as responsible persons
- Local authorities not considered as communicators
- Perceived lack of information
- Influence of past experiences
- Transparency – competence – independent control
- Role of trade unions and associations (no real relay)
- Distrust in political actors
- Scientists: trusted, but bad communicators

B3.2c – Trust : other actors

- Authorities, emergency workers: no relevant comments
- Associations
  - Transparency
  - Independent control: condition for acceptability
  - Credibility: local control, multi-level control

B3.3a – Advantages and disadvantages according to general population

	Positive perception	Negative perception
Flow of population	A ‘welcome’ to…	An ‘invasion’
Economic impact	Employment Infrastructure	Employment for locals???
Image of the region	Avoid a ‘desert’ region	Loss of local identity; the ‘waste bin’

B3.3b – Advantages and disadvantages (other groups)

- Authorities:
  - economic benefit
  - Possible discussions: harmony of spread of costs/benefits; impact on prices for houses etc. Need for intercommunity structure
- Emergency workers:
  - Increase of population: safety, hospitals,…
  - But: not unique: cf. tourism
- Associations:
  - Need for an 'intelligent vision on use of the territory' -> Role of Public authorities!!

B3.4a – Experimental nature of ITER: the general population

- Fusion – Fission:
  - Differences in Waste, accidents,…(larger distance)
- Energy policy
  - Political choices; allocation of financing; energy needs perceived
- Innovative project
  - Experimental character well perceived
  - Progress is difficult vs. progress is task of scientists (trust in science)

B3.4b – Experimental character of ITER

- Authorities
  - Distinction fission-fusion: waste, environment
  - Experimental character -> acceptability!!!
- Emergency workers
  - Treat as rigorously as other risks
  - Local competences exist
- Associations
  - Characteristics of ITER justify investments

B3.5a – International dimension

About the international dimension of the project

- Local population: no special attention
- Population at larger distance: spontaneous discussion:
  - Prestige, credibility !
  - Loss of control?
  - French experience guarantee of safety

B3.5b – International dimension

- Local authorities:
  - Aware of international character of management
  - Local support needed for international negotiations
- Emergency workers: no opinions formulated
- Associations:
  - Financial concerns: Research as financial adventure
  - Results belong to global patrimony; benefits for entire world
  - Compensations for local hosts

B3.6a – Information

- General population
  - Not informed
  - More information needed about
    - Risks and safety
    - Future energy
    - Other activities at Cadarache
  - Independent information
  - Wish for participation

B3.6b – Information

- Local authorities
  - Consider themselves to be informed
  - Info: by experts and communication specialists
  - Own role: info about economic impact
- Emergency workers
  - Consider themselves to be not informed
- Associations
  - Relay of information
  - Public debate based on prior information
    - Consultation and participation
  - Elected people play role in information

B3.7a – Conclusions: population/authorities

- Questioning attitude
- Political authorities not credible
- Concerns related to waste and future generations
- Need for information – wish for participation

- Welcome to project
- Role as relay of information
- Concerns about distribution of costs and benefits; land-use; …
- Information – no participation

B3.7b – Conclusions: Associations

- No relay role for population or authorities
  - But: Role for associations
- Some actors: wish for participations
- Concerns: close to population

B3.7c – Conclusions: Emergency workers

- No openness – little relevant information about their attitudes

B3.7d – Conclusions: information

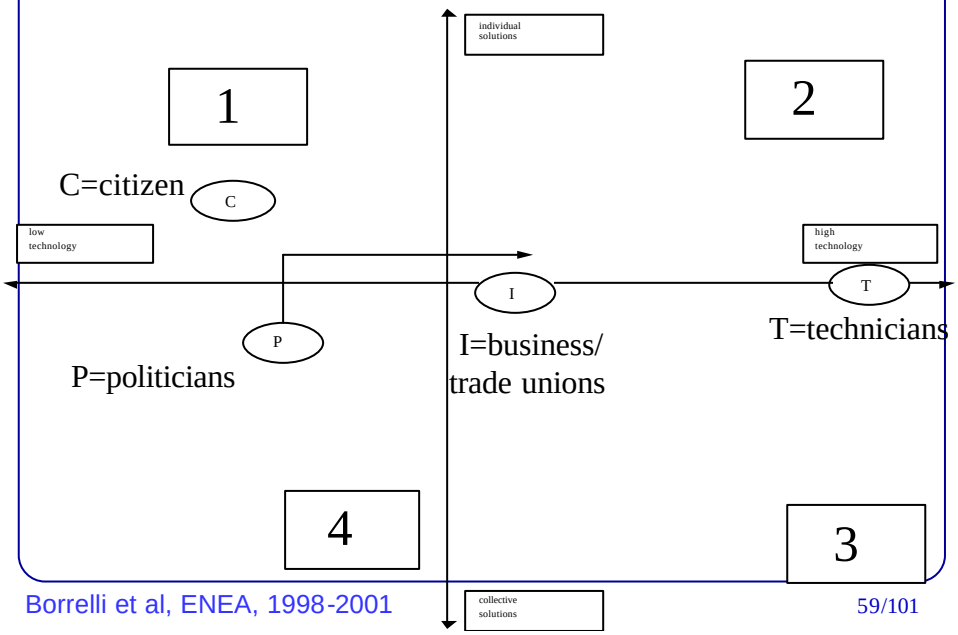
- Population
  - Need for information
  - Wish for participation
  - Many topics and wishes
  - Difficulty in identifying credible actors
- Information and communication : contribution to acceptability!!!

B3.8 – Public Opinion & Social Acceptance

Focus group in France found out that the public attitude towards the construction of ITER around Cadarache is generally positive, but there is a strong request for information in order to have a better idea of advantages and disadvantages of building ITER.

The report of this activity is a good starting point to prepare the public debate, which is part of the French procedure to approve the construction of ITER.

B4 – Eu. Awareness Scenario Workshops



Borrelli et al, ENEA, 1998-2001

B4.1 – Gaining the trust of local population

- Conduct in depth socio – economic surveys of the local area
- Gain the support of the local authorities
- Gain the trust of the local opinion leaders, interviews
- Prepare an info package: why we speak of fusion, how it works, what is the state of the research, how it is done, safety environmental social and economic aspects
- Conduct public hearing to inform the local organizations: schools, political parties and labour unions, sectoral and cultural , associations, voluntary service associations, sport, etc. (low attendance from the 120 invited in separate sessions)

B4.2 – EASW: aim and methodology

EASW aims at increase the conscious participation of local communities to their choices on science and technology?

How?

- 1-2 days, 5-6 moderators, 30-50 participants: resident citizens, politicians, entrepreneurs, technology experts
- The community is asked to develop guidelines and scenarios for a general development strategy: what balance between low and high tech? between collective and individual solutions?
- Each group reports the proposals in a general sessions; 4 separate groups, reshuffled from the original 4, discuss and rank the proposals; final votes are in a new general session. Abstention is not permitted.

B4.3 – EASW: experimental evidence (1/2)

(Porto Torres, Sardinia, Italy, 1998-9)

- The population expressed a strong need for participation in local decision making.
- Development strategies have to be based upon composite visions.
- Once gained the support of local actors, it is possible to establish a local network and develop the trust necessary to start an awareness process.
- The participants perceived the importance of their participation, worked hard and at the end were ready to become ‘partners’ in the public awareness process.

B4.3 – EASW: experimental evidence (2/2)

- The environmental compatibility seems to be the most important element to accept the project
- Second important factor is information and communication, which must be large, complete and continuous
- Economic factors rank third: the implementation of the project must improve the local economic development.

What has changed? The attitude towards new technologies, the willingness to learn more about fusion and its advantages, the willingness to discuss optimal safety and environmental aspects.

B5 - What new social sciences research for fusion?

- Has the public opinion a clear enough perception of the clouds over the long term global energy perspectives? That the present energy system is non sustainable? Is it clear that for 2050 we count on energy sources and technologies that are not yet proved, very expensive or polluting?
- How can a global project like fusion take advantage from globalisation process, international environment protection conventions and protocols, etc.? Is it possible / useful to build alliances with other ‘energy related groups’: renewables? Oil & gas? Utilities? Research institutions?
- Is there something the fusion community can do to avoid the risk of ‘technology lock in’ (with fission)? Fusion as the natural evolution of fission? Co-operation or rivalry? Can fusion be accepted by the same public that does not accept fission?

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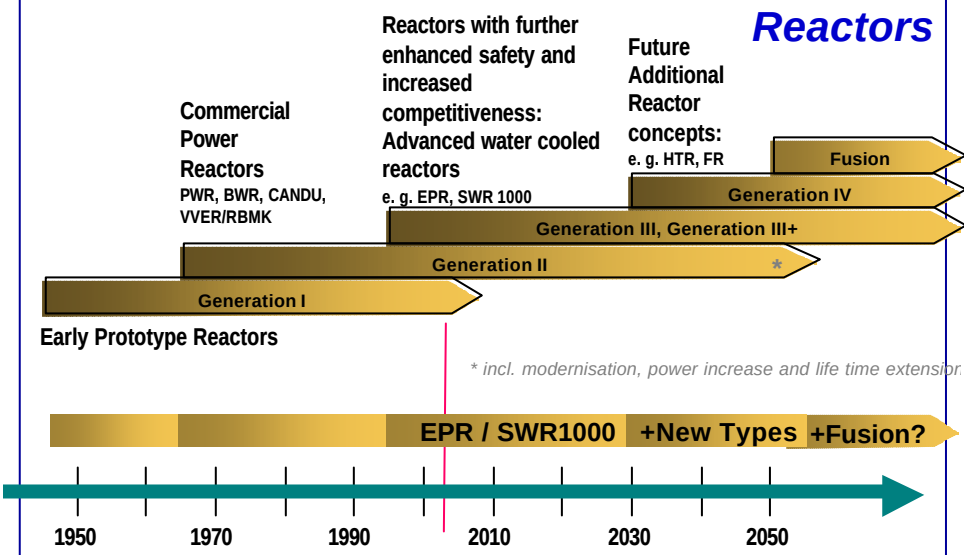
B5 – Future Reactors



Taken from: Dr. Ralf Güldner, Managing Director, Framatome, WNA Symposium 3-5 Sept. 2003

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C. Fusion and Economics

1. Present situation vs. future expectations
2. Methods for scenario analyses
3. Direct cost assessment
4. Environmental externalities
5. Technology learning
6. Long term scenarios

C1 - What is fusion now? R&D

A consumer of public R&D funds, which has produced some spin-offs, knowledge, and may become a producer in 2050.

How many economic resources? About 1 B$'00

For comparison:

World Gross Domestic Product:	35000 B$'00
World R&D investments:	600 B$'00 (1.7% of GDP)
	(the EU political goal is 3%)
World Energy R&D investments	10 B$'00 (1.7% of R&D tot)

C1.1 – World Energy Balance, 2001, Mtoe

SUPPLY AND CONSUMPTION	Coal	Crude Oil	Petroleum Products	Gas	Nuclear	Hydro	Combustible Renewables & Waste	Other*	Total
Indigenous Prod.	2360.82	3651.33	-	2139.12	691.90	221.50	1093.62	50.86	10209.14
Imports	435.81	2089.71	715.22	549.84	-	-	0.76	42.58	3833.91
Exports	-445.34	-1999.25	-793.98	-547.69	-	-	-1.12	-41.92	-3829.30
Stock Changes	-9.65	-9.40	-10.67	-19.25	-	-	0.25	-	-48.72
TPES	**2341.64**	**3732.38**	**-89.43**	**2122.02**	**691.90**	**221.50**	**1093.50**	**51.53**	**10165.03**
Transformations									
TFC	**514.85**	**10.55**	**2997.57**	**1137.07**	**-**	**-**	**993.45**	**1341.12**	**6994.61**
Industry Sector	386.37	9.59	579.96	509.87	-	-	160.33	554.75	2200.87
Transport Sector	5.44	0.01	1715.71	54.16	-	-	7.78	19.34	1802.45
Other Sectors	112.43	0.96	514.04	573.05	-	-	825.34	767.02	2792.83
Non-Energy Use	10.61	-	187.85	-	-	-	-	-	198.46

C1.2 – Comparison with global yearly values of Energy Systems *(in B$'00)*

Economic Resources:		about 70,000
Gross Domestic Product:		35,000
Energy Systems:	end use	about 10,000 (30% GDP)
	final (sales)	3000-3500 (10% GDP)
	primary	1400-1800 (4-5% GDP)
Energy R&D		10 (0.3% of energy sales)
Fusion R&D		1

International industries in software & IT, health, pharmaceuticals spend in R&D more than 10% of their sales, oil & gas industries less than 1%, as beverages and tobacco industries.

Only 1.5% of the venture capital investments in 1998 – nearly US$B 40 – has been used by energy industries

C1.3 – Some economic benefits: spin-off

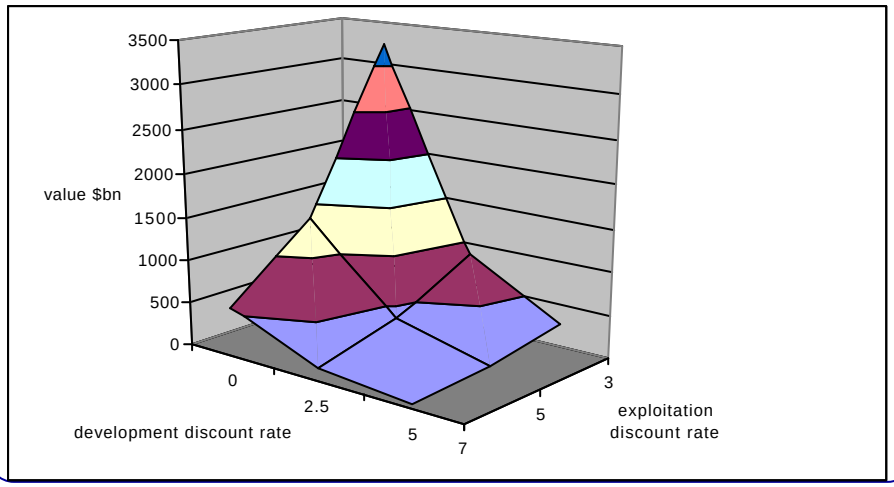
- the production of steels with very high specifications, which practically do not have any imperfections;
- the production of novel carbon-fibre-reinforced carbons of high homogeneity and thermal conductivity, but at economical prices;
- the near-net-shape processing of high-purity beryllium components to achieve savings in material and in costs;
- the development of the most powerful cryopump ever built with a pumping capacity twice as high as that of earlier pumps and the highest trapping coefficient ever achieved (47% of the theoretical value of a black hole);
- the development of flexible cryopipes for the transport of liquid helium with lower losses than hitherto achievable;
- for radio frequency heating systems new high-performance tetrodes and new coaxial transmission lines for high operating voltages were produced in cooperation with industry.

C1.4 – Net Present Value of fusion R&D?

The net present value of future economic benefits from all fusion R&D over the decades depends on:

- Probability of success of each step
- Discount rates for public funds
- Discount rates of future fusion power plants
- Electricity price
- Market shares
- Etc.

C1.5 – Risk-adjusted net present value of the fusion R&D programme



C1.6 – What may fusion become?

An element of global energy systems, i.e.

- An economic producer of energy commodities,
- In form of electricity, possibly of clean fuels (H2)
- With very high investments and fixed costs
- Where the demand continues to grow,
- the revenues fluctuate parallel to market prices
- With non negligible positive and negative externalities
- Etc.

Present studies try to quantify that future possible market, in terms of quantities and prices.

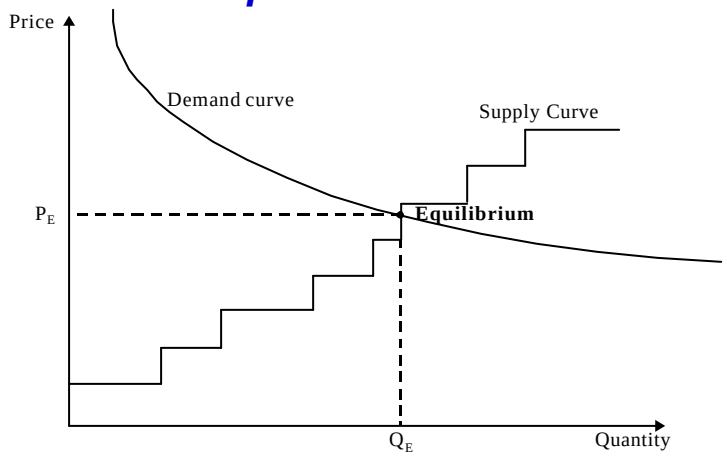
C2 – Methodologies

Present economic laws are projected into the future,

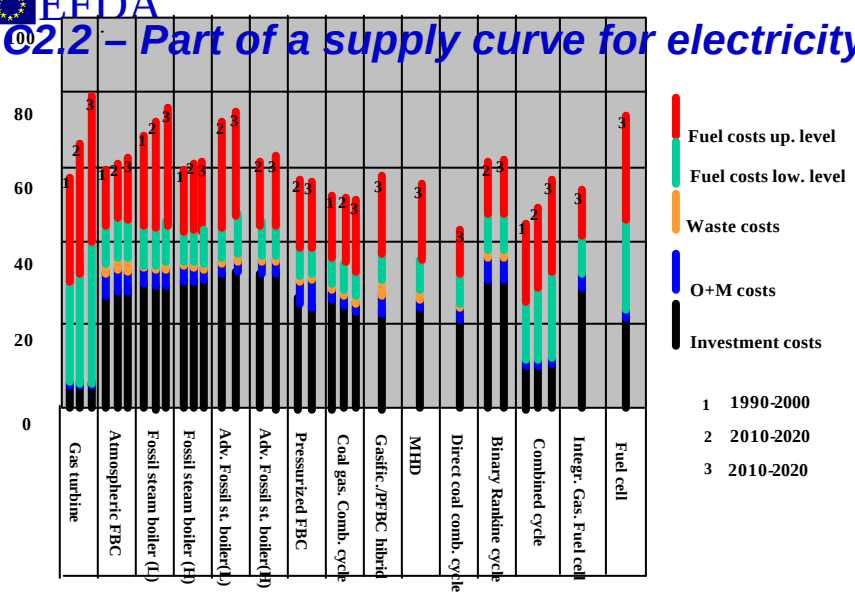
- by means of mathematical models
- as an interacting set of economic markets (electricity, gasoline, passenger.km, heating, etc), and
- a competing set of energy producing and consuming technologies,
- sensitive to the rules of economic competitions, sensitive to external drivers (policy, environment, resources, etc.)
- Sometimes extended to represent all the economy.

Since forecasting capabilities are poor in such a complex system, the scenario approach is used.

C2.1 – Base representation of each market



C2.2 – Part of a supply curve for electricity



Production cost of different fossil fuel power plants (mill/kWh)

G. Simbolotti, ENEA, 1998

C2.3 – How will each market evolve?

What quantities at what prices will be consumed each year?

- How will the demand curve change?
- How will the supply curve change?

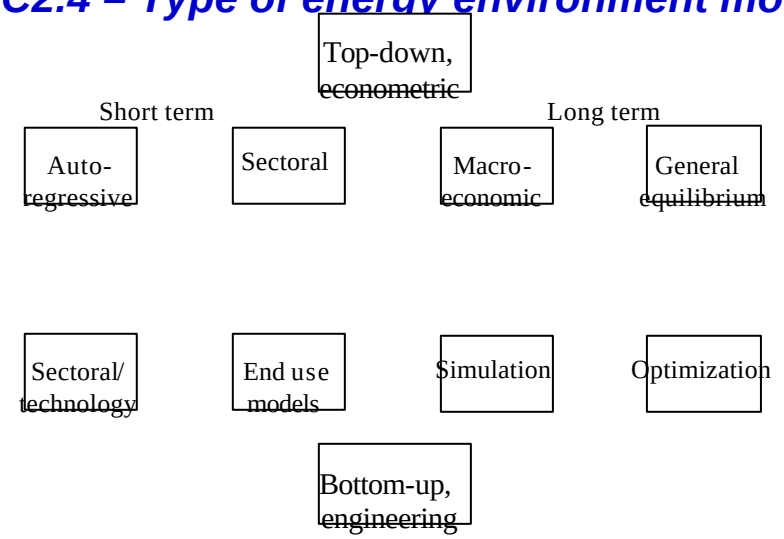
According to the main long term policy goals:

- Energy security,
- Global climate change mitigation and environment protection,
- Economic sustainability,

And other external drivers:

- Technology improvements,
- Ultimate energy resource constraints,
- Even the market boundaries can change
- Etc.

C2.4 – Type of energy environment models



C2.5 – SERF studies on supply curve evolution

How will present production (direct) costs evolve? How might fusion production cost compare with others?

How climate change mitigation policies will impact supply curves? (How climate damages and adaptation will impact demand curves?)

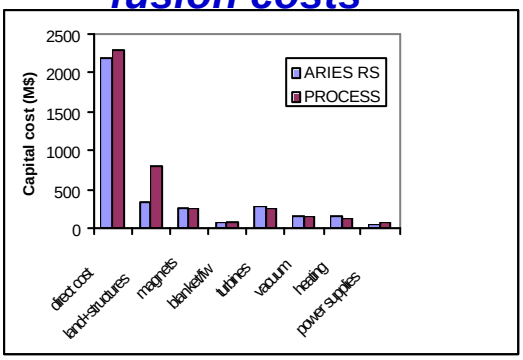
What additional external costs be internalised (as it happened in the '80 with acid deposition precursors)? How Life Cycle Assessment / ExternE values change with time / scenario?

To what extent technology learning will change the competitiveness of different sources?

Are there synergies with other energy supply sources?

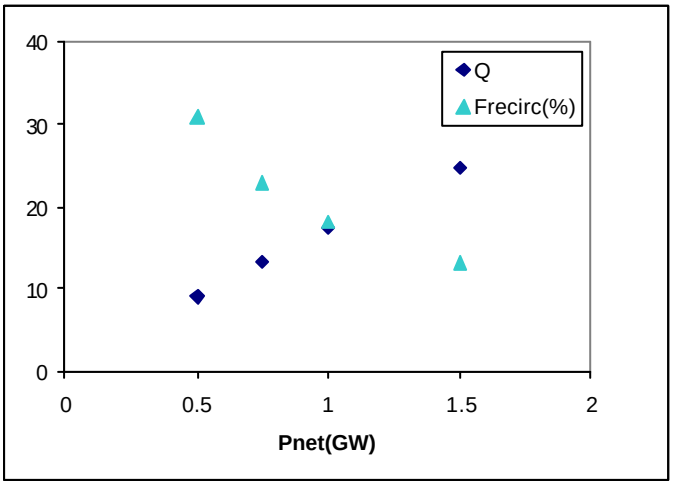
Etc.

C3.1 – International benchmarking studies of fusion costs



EU and US cost assessments similar overall for the same assumptions. Some notable exceptions in detailed breakdown of components

C3.2 – Can a fusion power plant load-follow?



Yes

(Economic penalty at operating below design power)

C3.3 – Direct cost (Methodologies??)

The production cost of fusion electricity depends on physics and engineering assumptions of commercial power plants available in the second half of this century. It may range from 70 to 130 US$(1996)/MWh.

In comparative terms it might range between the cost of electricity produced by the best future coal or fission plants and twice as much.

This uncertainty is smaller than seasonal price fluctuations experienced by several customers around the world in recent years.

C3.4 – Direct cost of other power plants

According to other long term evaluations, the Cost Of Electricity (COE) including CO2 sequestration for fossil power plants in US$(1999)/MWh might range

- 35-75 for coal burning plants,
- 35-85 for coal gasification plants,
- 30-65 for natural gas combined cycle plants,
- 45-75 for advanced fission reactors,
- 70-110 for fusion reactors,
- 20-55 for wind energy converters.

C4 – Life Cycle Assessment & External cost

Direct cost analyses have been complemented by the evaluation of the external costs of producing electricity with several long term technologies.

This requires first the computation of emissions, concentrations, burdens and impacts with the techniques of Life Cycle Assessment: very detailed, rich of information (probably more useful than the final stage of conversion of different damages to the same unit, economic evaluation in $).

Comparing fusion with power plants concepts possibly available 50 years from now has been difficult: far less data have been found for advanced fission or fossil fuel power plants.

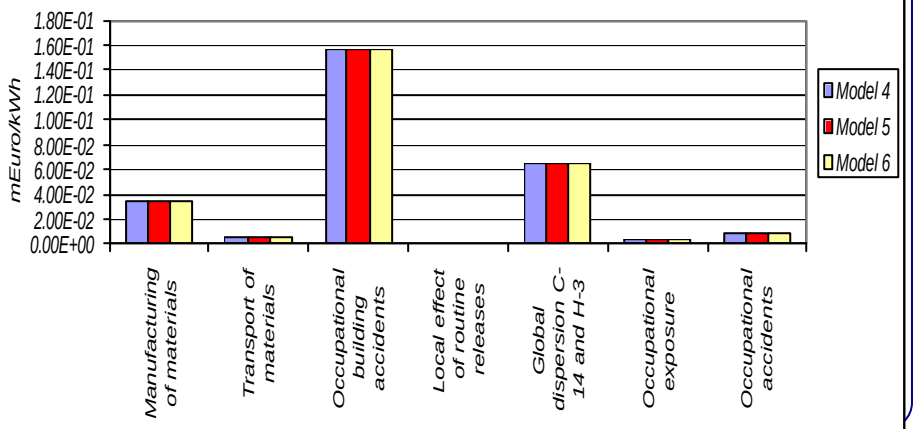
C4.1 – External cost of electricity

The ExternE methodology, previously developed for the European Commission, has been used for evaluating in a standard way the external costs of electricity generation by different fuel cycles.

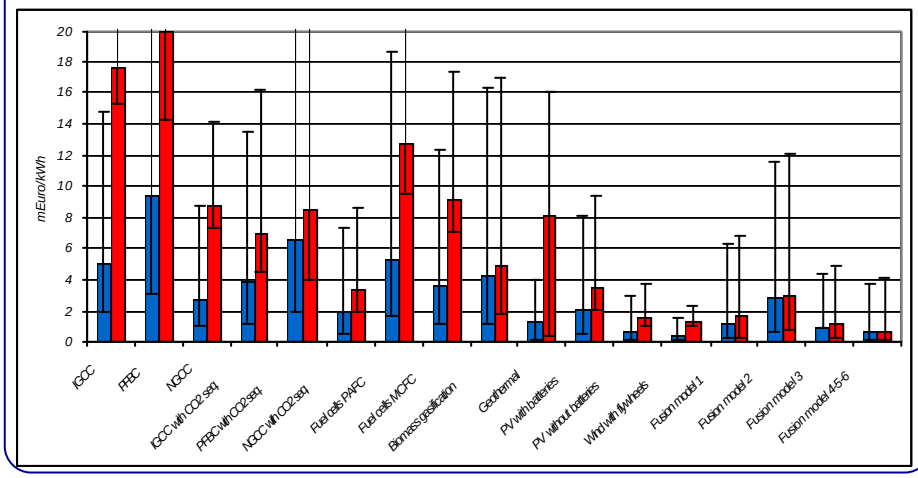
The external cost of future fusion electricity is in the order of a few € per MWh, twice less than present nuclear fission electricity, five to ten times less than oil and gas thermal electricity, nearly twenty times less than coal electricity.

An effort is starting to make LCA and ExternE methods sensitive to time developments and scenarios.

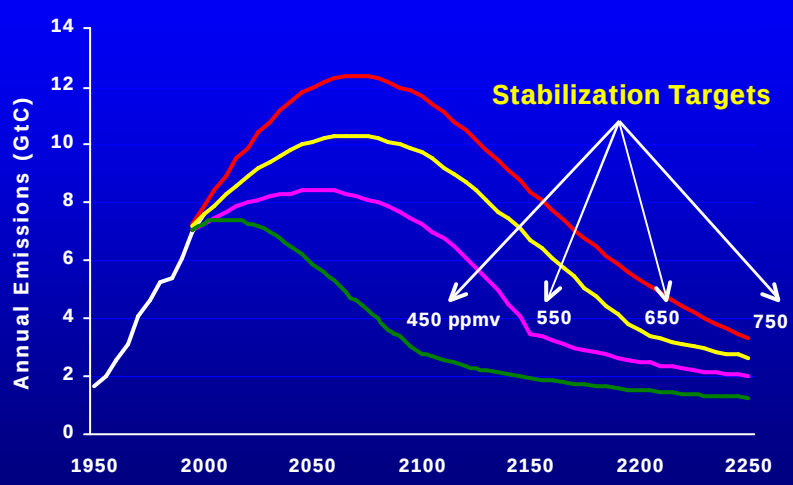
C4.2 – The construction of conventional items makes the largest contribution to externalities



C4.3 – Fusion externalities are low



Greenhouse gas emission scenarios



C4.5 – "Soft landing" paradigms

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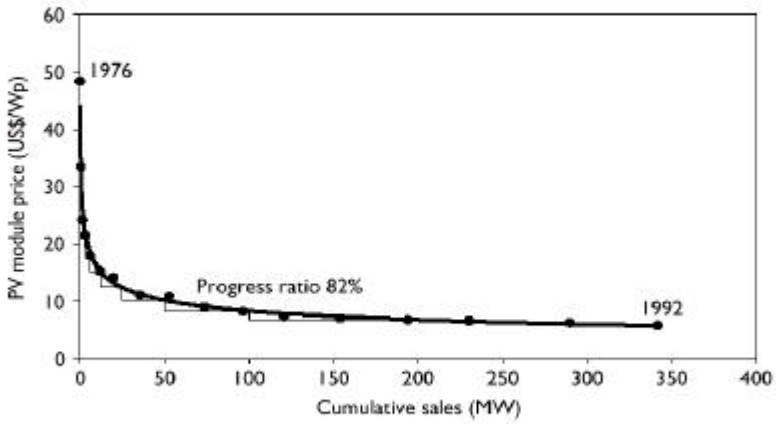
C5.1- Experience curves: linear

Figure A.1. Experience Curve for Photovoltaic Modules, 1976-1992

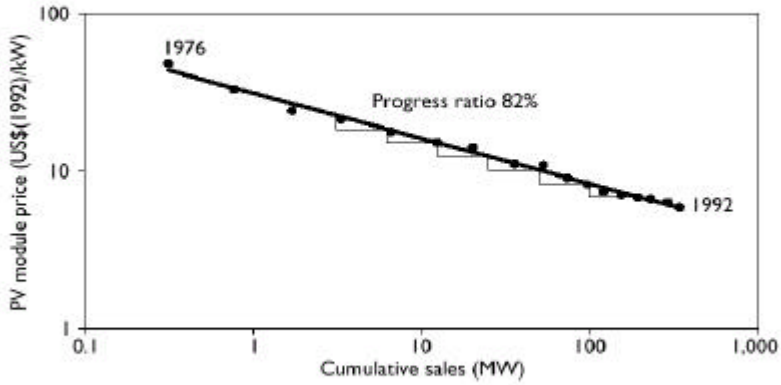


Linear representation of an experience curve.

C-O Wene, IEA, 1999

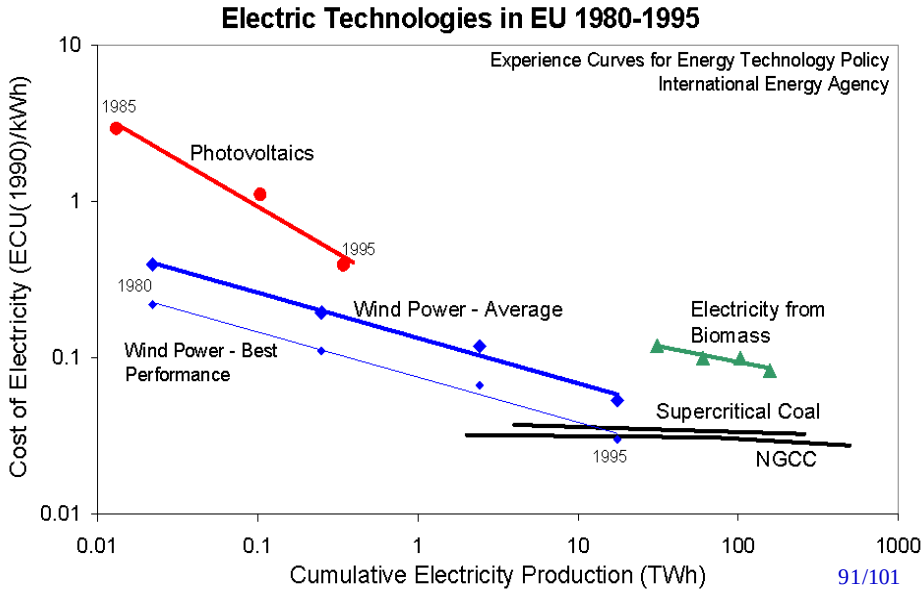
C5.2 – Experience curves: double logarithmic

Figure A.2. Experience Curve for Photovoltaic Modules, 1976-1992

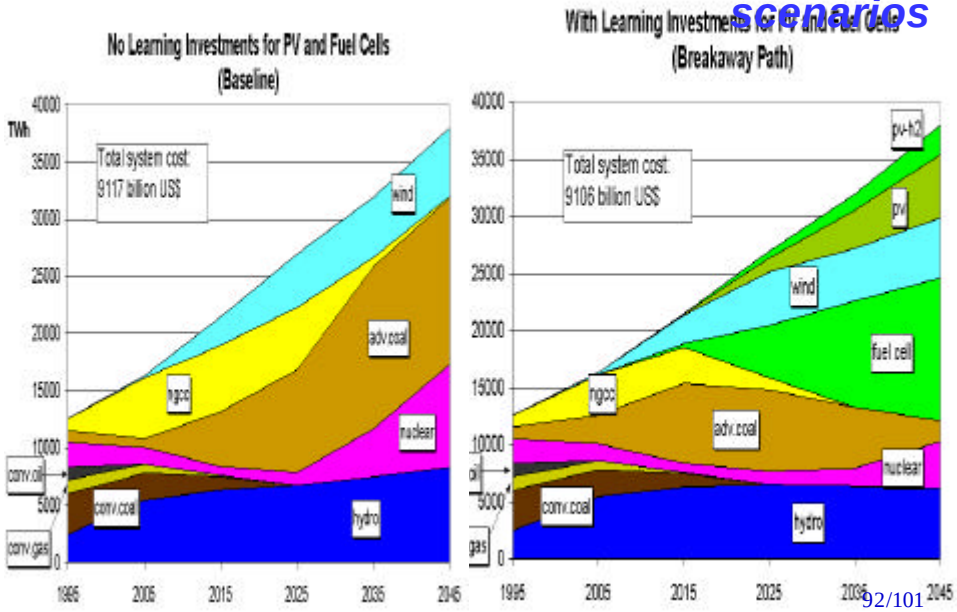


Double-logarithmic representation of an experience curve (same as in Figure A.1).

C5.3 – Examples of learning curves

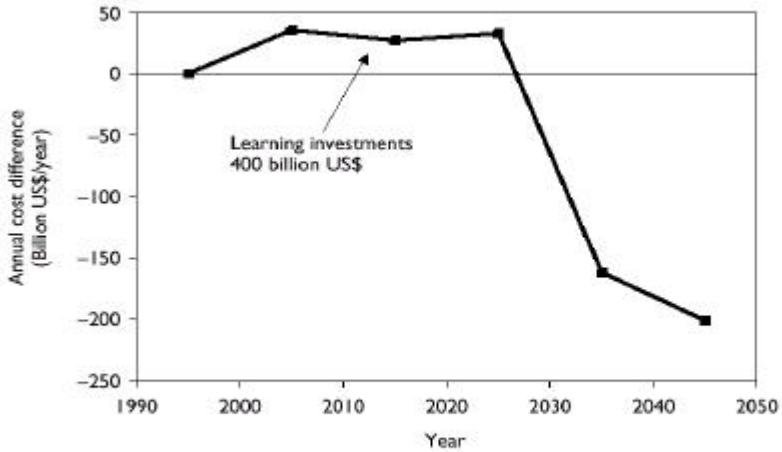


C5.4 - GENIE: baseline vs. learning scenarios



C5.5 – Learning investments

Figure 4.8. Cost Difference between Breakaway Path and Baseline

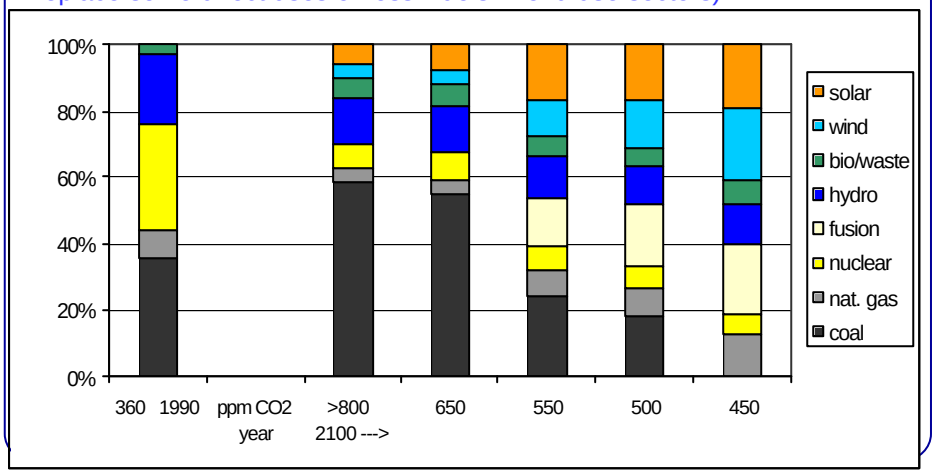


The cost difference between the breakaway path and the baseline from 1995 to 2025 is equal to the learning investments required for the breakaway path.

C6.1 – EU energy scenarios (1/2)

Power generation by source in 2100

(in CO2 constrained scenarios more carbon free electricity is supplied to replace some direct uses of fossil fuels in end use sectors)



P Lako et al., ECN, 1998

C6.1 – Fusion in EU energy scenarios (2/2)

A study for Europe has shown that at the end of the century fusion may supply 20% of the market in the presence of some main conditions:

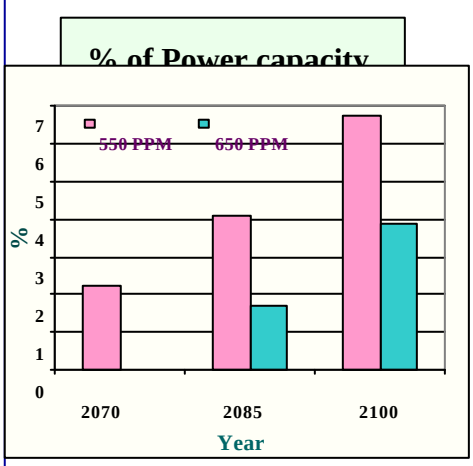
1- climate changes are mitigated, reducing GHG concentration to 550 ppm or less;

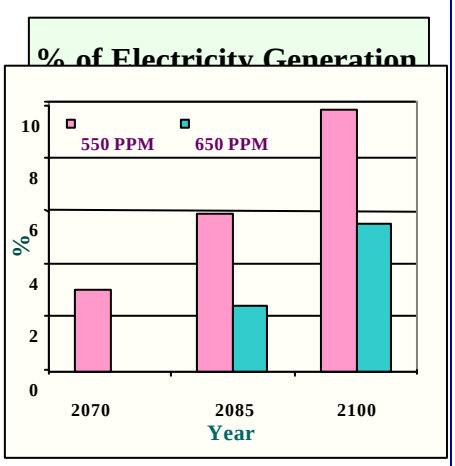
2- fusion is the natural evolution of fission (present fission power plants are phased out);

3- fusion and intermittent renewables are supplementary.

In the 550ppm scenario, total discounted mitigation costs increase from 810 to 900 B€ without fusion

C6.2 – Fusion Technology in India (1/2)





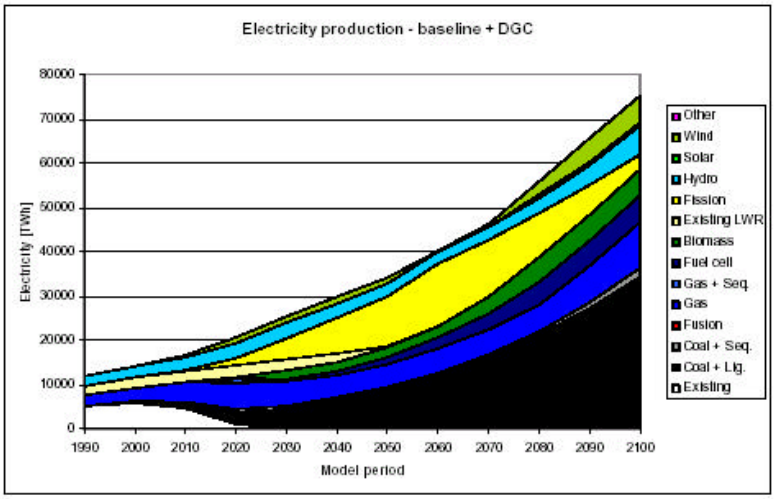
Prof. Shukla, 2002, Indian Institute of Management, Ahmedabad, Max Planck Institute for Plasma Research, Netherlands Energy Research Foundation (ECN)

C6.2 – Fusion scenarios for India (2/2)

Long term energy - environment scenario for India with partial equilibrium technology detailed models has confirmed the finding: fusion contributes substantially to the production of electricity as soon as GHG emissions have to be reduced and nuclear fission is constrained.

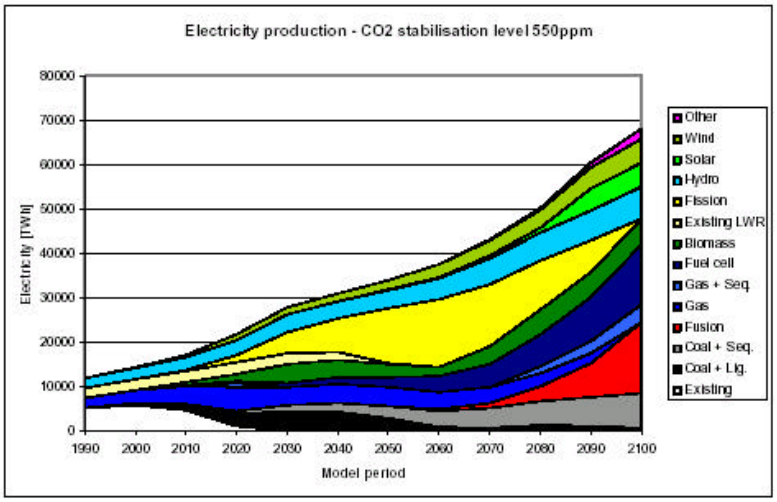
Renewable sources and fusion grow approximately in parallel, with little direct competition, due to their different role as intermittent and base load power sources respectively.

Generated electricity – baseline DGCs



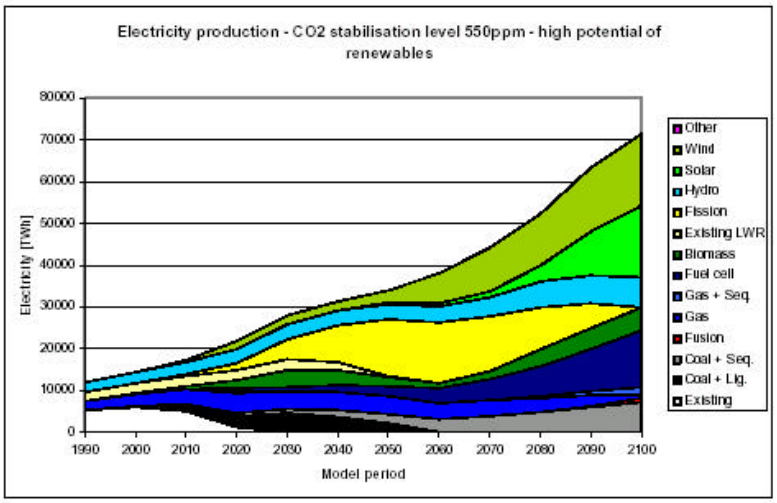
C6.3 – Global single region energy model (1/4)

Generated electricity – CO2 stabilisation level 550ppm (DGC+ED)



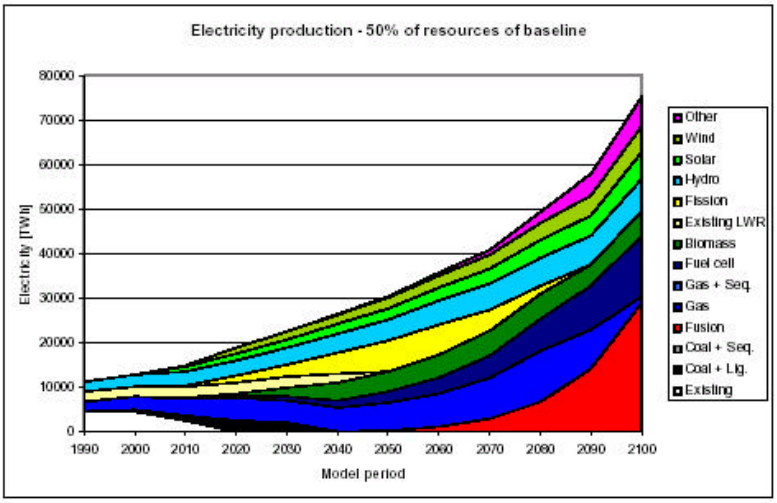
C6.3 – Global single region energy model (2/4)

Generated electricity – CO2 550ppm (DGC+ED) – high renewable



C6.3 – Global single region energy model (3/4)

Generated electricity – 50% of resources of baseline (DGC+ED)



C6.3 – Global single region energy model (4/4)