Potential Role of Fusion Power Generation in a Very Long-Term Electricity Supply Perspective

Case of Western Europe

First IAEA Technical Meeting
on "First Generation of Fusion Power Plant - Design and Technology

Dr. Edgard Gnansounou, *edgard.gnansounou@epfl.ch*
Denis Bedniaguine, *denis.bedniaguine@epfl.ch*
Laboratory of Energy Systems **LASEN / ICARE / ENAC**

LASEN

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Objectives

Main Goal

Techno - economic and environmental (CO_2) evaluation of selected technology mixes for electricity generation in a very long-term perspective worldwide

Benchmarking

Case of Western Europe

Objectives

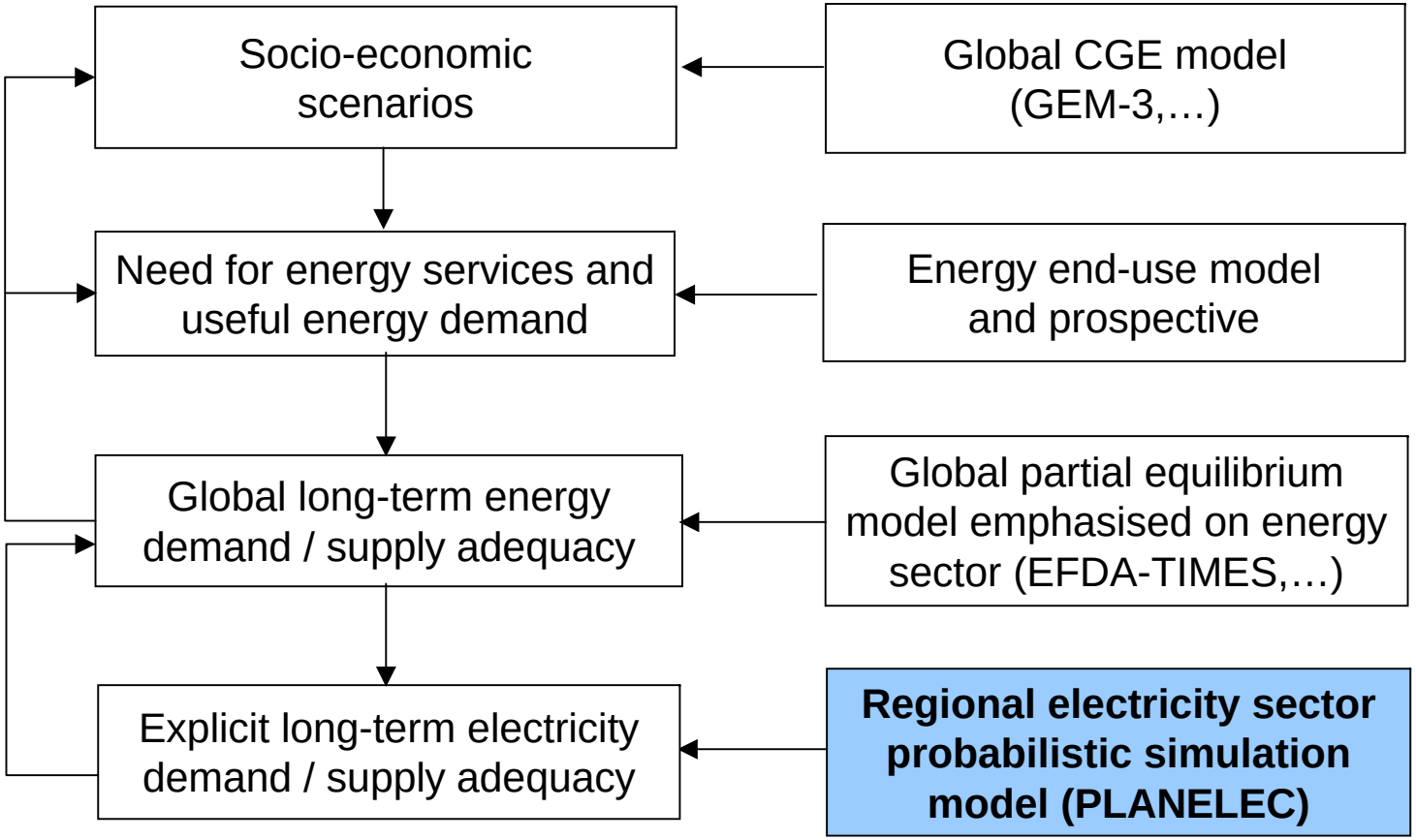
Specific tasks

- Building of credible scenarios of future electricity supply
- Estimation of possible shares in total electricity production of different power generation technologies, including Fusion
- Analysis of selected scenarios with the use of PLANELEC model to assess economic and environmental performance of Fusion power generation

Main Issues

- Projection of future energy demand, electricity supply, fuel prices, technical and economic parameters of main types of power generation technologies
- Competition of Fusion with conventional fossil fuel power generation technologies (nuclear fission, coal, natural gas)
- Competition of Fusion with emerging renewable / advanced fossil fuel technologies (wind, solar, biomass, coal with CO_2 sequestration etc.)
- Necessity for robust quantified assessment of advantages and drawbacks of evolving share of Fusion in total electricity supply

Analytical Framework



Approach

Simulation with a least cost electricity system planning model PLANELEC of different technology mixes corresponding to the selected scenarios of future electricity supply

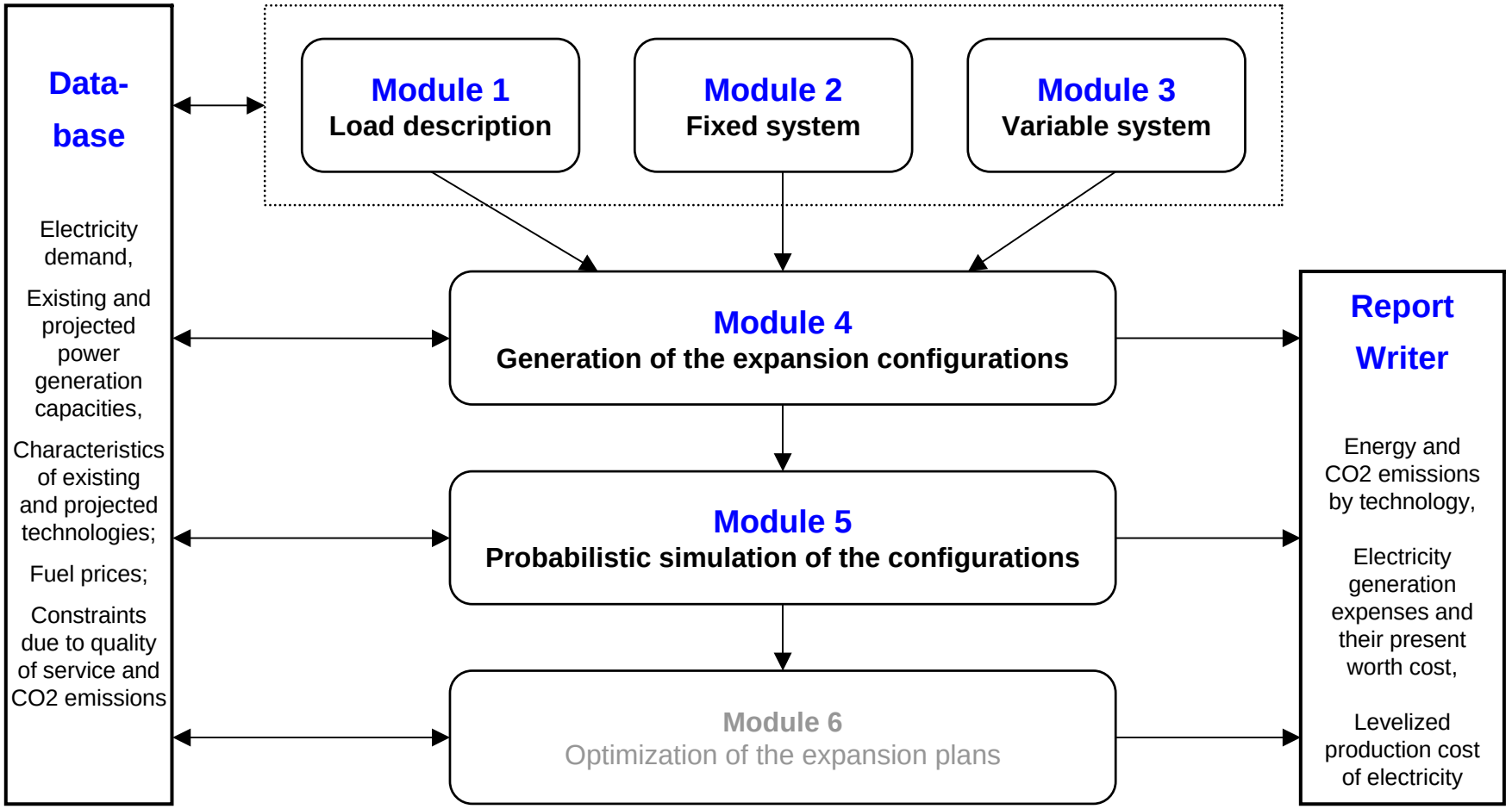
Main indicators

- Impact of the evolving share of Fusion power on the levelized electricity generation cost
- Total discounted cost of the expansion plan
- Cumulated reduction of CO_2 emissions
- CO_2 abatement cost

PLANELEC Model

- Least cost probabilistic simulation and dynamic programming model for electricity systems expansion planning
- Technology explicit (≈ 30 electricity generation technologies, exogenously defined learning rates for investment and O&M costs)
- Fuel prices, electrical load, structure of the existing electricity generation system, technical and economic parameters of existing and anticipated power generation technologies - as main inputs
- Time-frame: 2000 - 2100 (5 sub-periods x 20 years)
- Annual discount rate: 5% (for each sub-period relative to the first year of the sub-period)
- Environmental policy options: CO_2 tax or quantitative constraint

PLANELEC Model



PLANELEC Model

Fuel Prices (average values over 20 yrs sub-periods, € $_{2004}$ / GJ)

	Coal	Fuel Oil	Nat. Gas	Biomass	U (Pu) fuel	DT + Li
2000-2020	*1.26*	*5.04*	*3.88*	*2.60*	*1.06*	*0.014*
2020-2040	*1.38*	*7.46*	*4.90*	*2.85*	*1.16*	*0.016*
2040-2060	*1.68*	*10.48*	*5.91*	*3.18*	*1.35*	*0.018*
2060-2080	*2.16*	*14.91*	*7.77*	*3.62*	*1.67*	*0.020*
2080-2100	*2.51*	*20.96*	*10.13*	*4.21*	*2.19*	*0.022*

Data sources: *Author's calculation based on IEA Coal - Oil - Natural Gas Information 2004, IIASA MESSAGE model, EUBIONET, UxC, Nuclear Fuel Cost Calculator, Varandas*

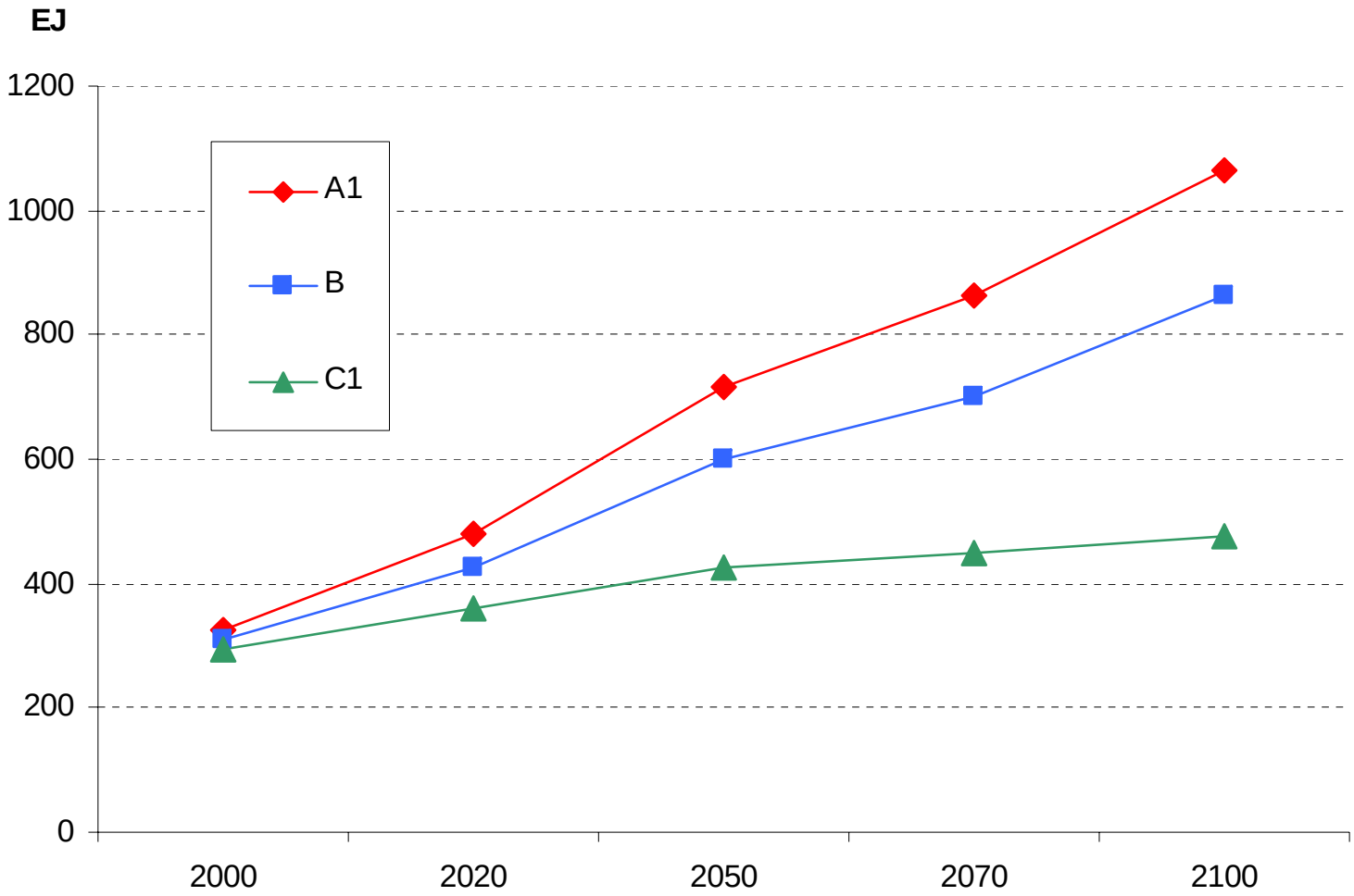
PLANELEC Model

Technology Assessment (average Cost of Electricity, € $_{2004}$ / kWh)

	2000-2020	2020-2040	2040-2060	2060-2080	2080-2100
NGCC	*0.034*	*0.038*	*0.042*	*0.050*	*0.062*
Coal IGCC	*0.031*	*0.028*	*0.028*	*0.029*	*0.030*
IGCC + CCS	*0.056*	*0.050*	*0.046*	*0.044*	*0.043*
Nuc. Gen III + IV	*0.032*	*0.031*	*0.031*	*0.032*	*0.034*
Wind	*0.037*	*0.029*	*0.023*	*0.020*	*0.017*
Solar PV	*0.216*	*0.128*	*0.080*	*0.053*	*0.038*
Biomass	*0.050*	*0.047*	*0.045*	*0.044*	*0.045*
Fusion			*0.115*	*0.076*	*0.054*

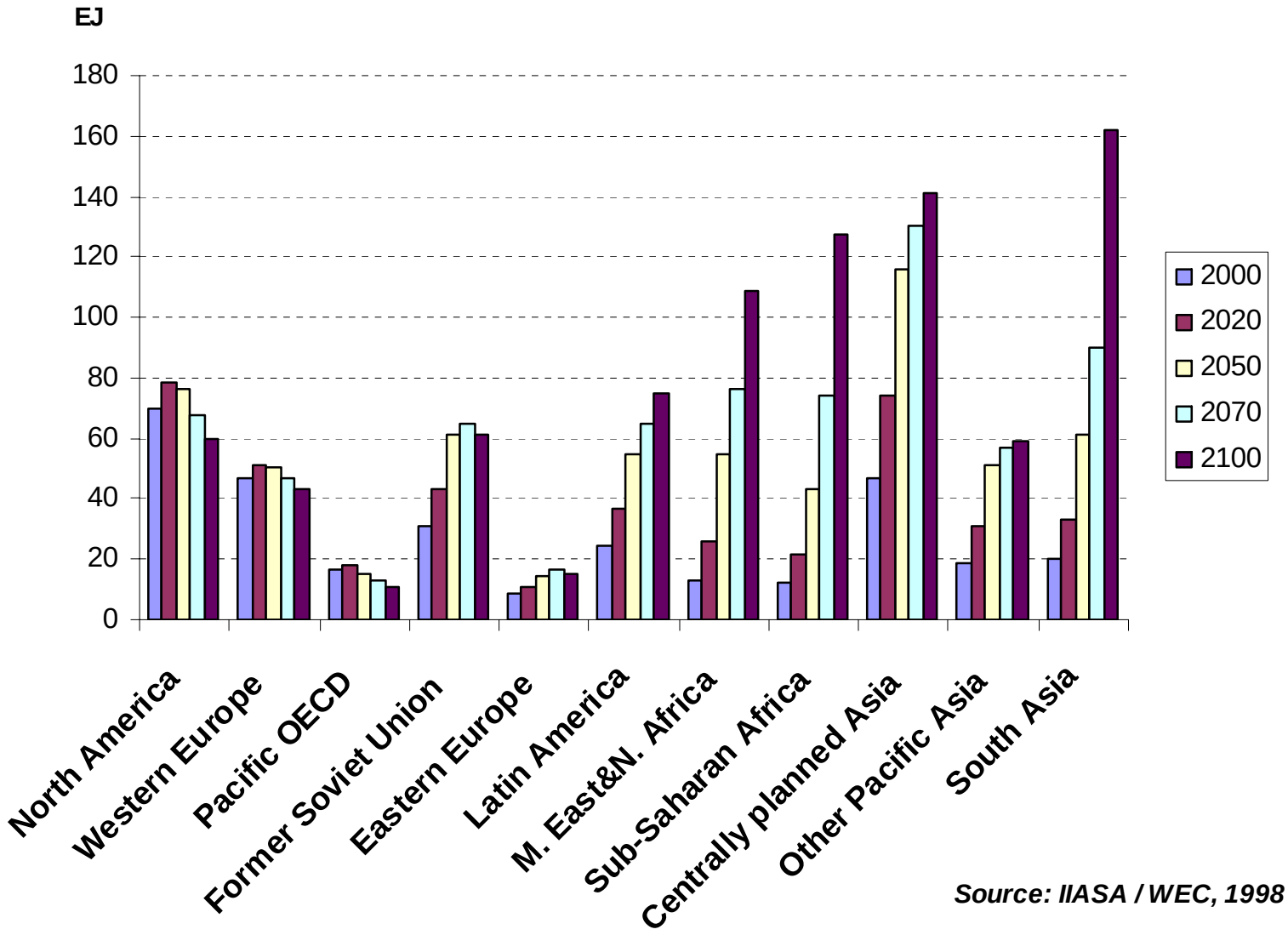
Data source: *Author's calculation based on various studies*

World Final Energy Consumption (IIASA-WEC)



Source: IIASA / WEC, 1998

Final Energy Consumption by Region
(IIASA-WEC, Scenario B)



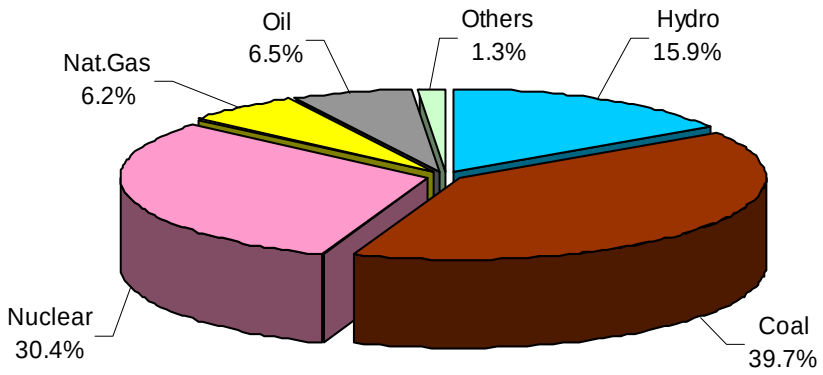
Source: IIASA / WEC, 1998

Electricity Share in Final Energy Consumption
(IIASA-WEC, Scenario B, %)

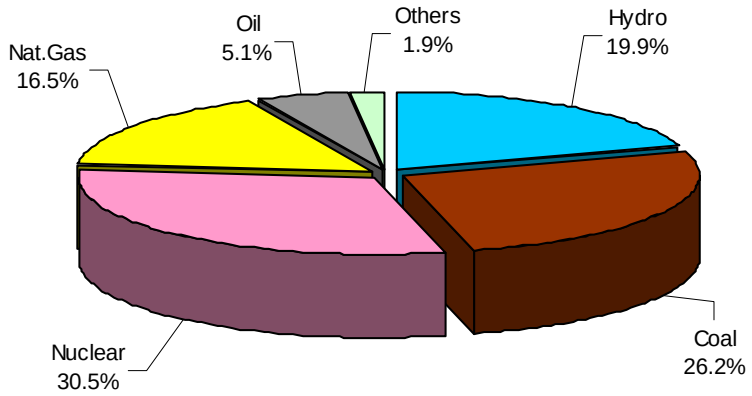
	2000	2020	2050	2070	2100
North America	*18.4*	*23.8*	*30.7*	*36.0*	*45.6*
Western Europe	*19.0*	*24.2*	*33.5*	*38.1*	*45.8*
Pacific OECD	*22.2*	*25.8*	*33.2*	*36.9*	*39.0*
Former Soviet Union	*12.3*	*12.2*	*14.0*	*16.5*	*24.3*
Eastern Europe	*13.3*	*14.8*	*17.2*	*20.4*	*28.5*
Latin America	*9.2*	*9.1*	*11.1*	*13.8*	*24.9*
M. East & N. Africa	*7.5*	*7.9*	*8.7*	*10.6*	*17.3*
Sub-Saharan Africa	*9.4*	*7.9*	*10.3*	*12.1*	*17.4*
Centrally planned Asia	*7.2*	*7.2*	*9.6*	*12.5*	*17.7*
Other Pacific Asia	*8.7*	*10.2*	*14.4*	*19.8*	*28.4*
South Asia	*6.3*	*7.6*	*10.8*	*15.9*	*23.1*
World average	*13.3*	*14.3*	*16.2*	*18.5*	*24.2*

Structure of Electricity Generation by Fuel Type, 2000 – 2020

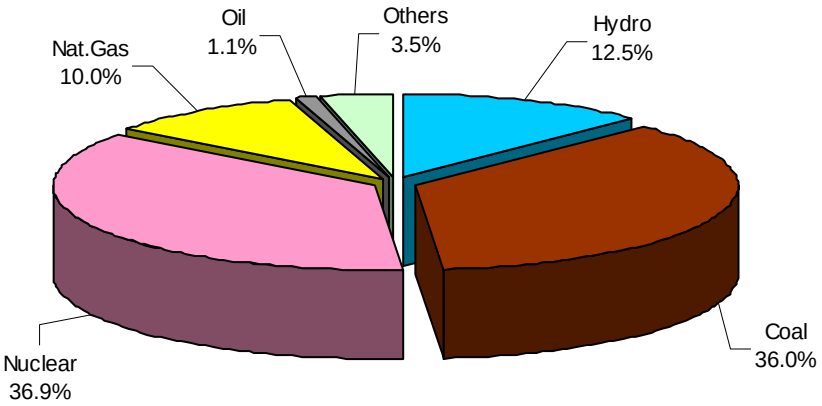
Total Electricity Generation in 2000 : 2859 TWh
(IIASA/WEC - Scenario "B")



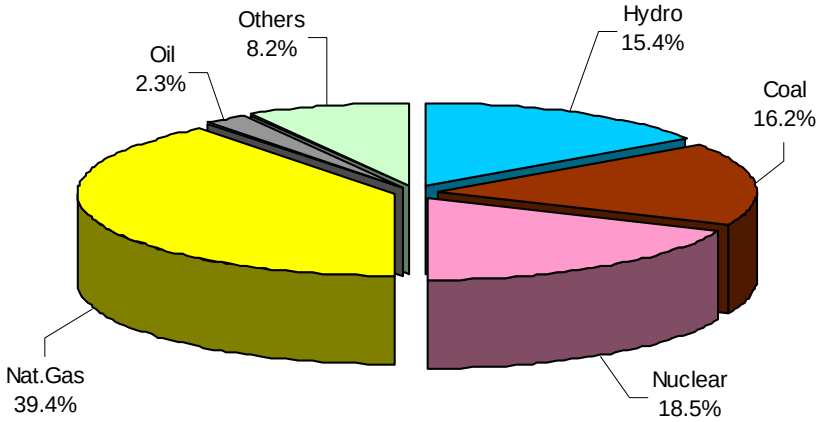
Total Electricity Generation in 2000 : 2798 TWh
(EURPROG 2002)



Total Electricity Generation in 2020 : 3867 TWh
(IIASA/WEC - Scenario "B")

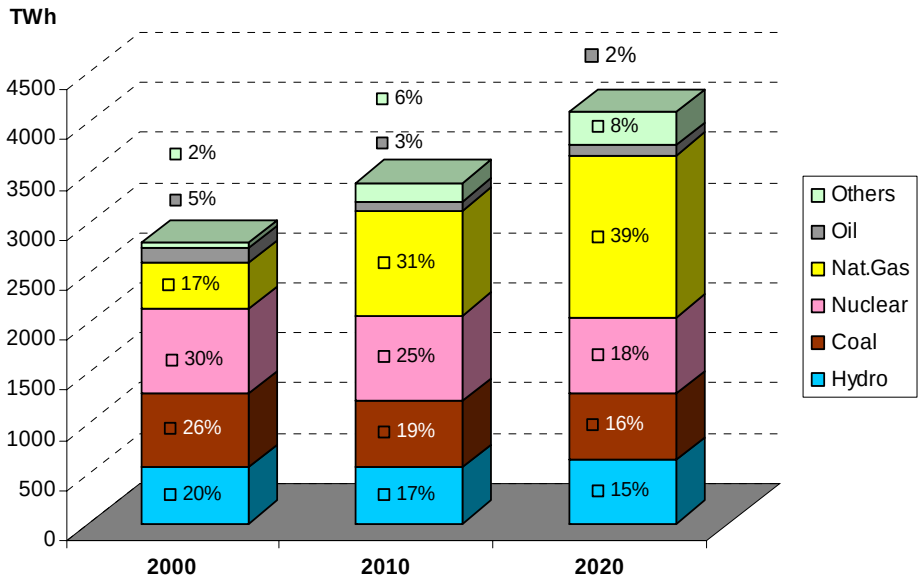


Total Electricity Generation in 2020 : 4108 TWh
(EURPROG 2002)



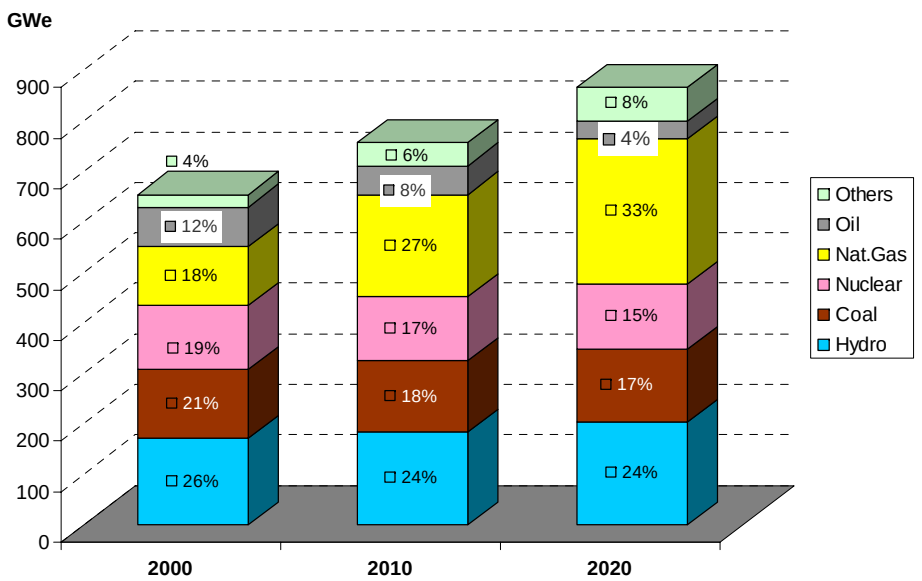
Calibration of PLANELEC Model

Projected structure of electricity generation (2000 – 2020)



Source: Authors' estimation based on EURPROG 2002

Projected structure of installed power generation capacities (2000 – 2020)



Source: Authors' estimation based on EURPROG 2002

Levelized electricity production cost: 0.034 € / kWh (for the first study period 2000 – 2020)

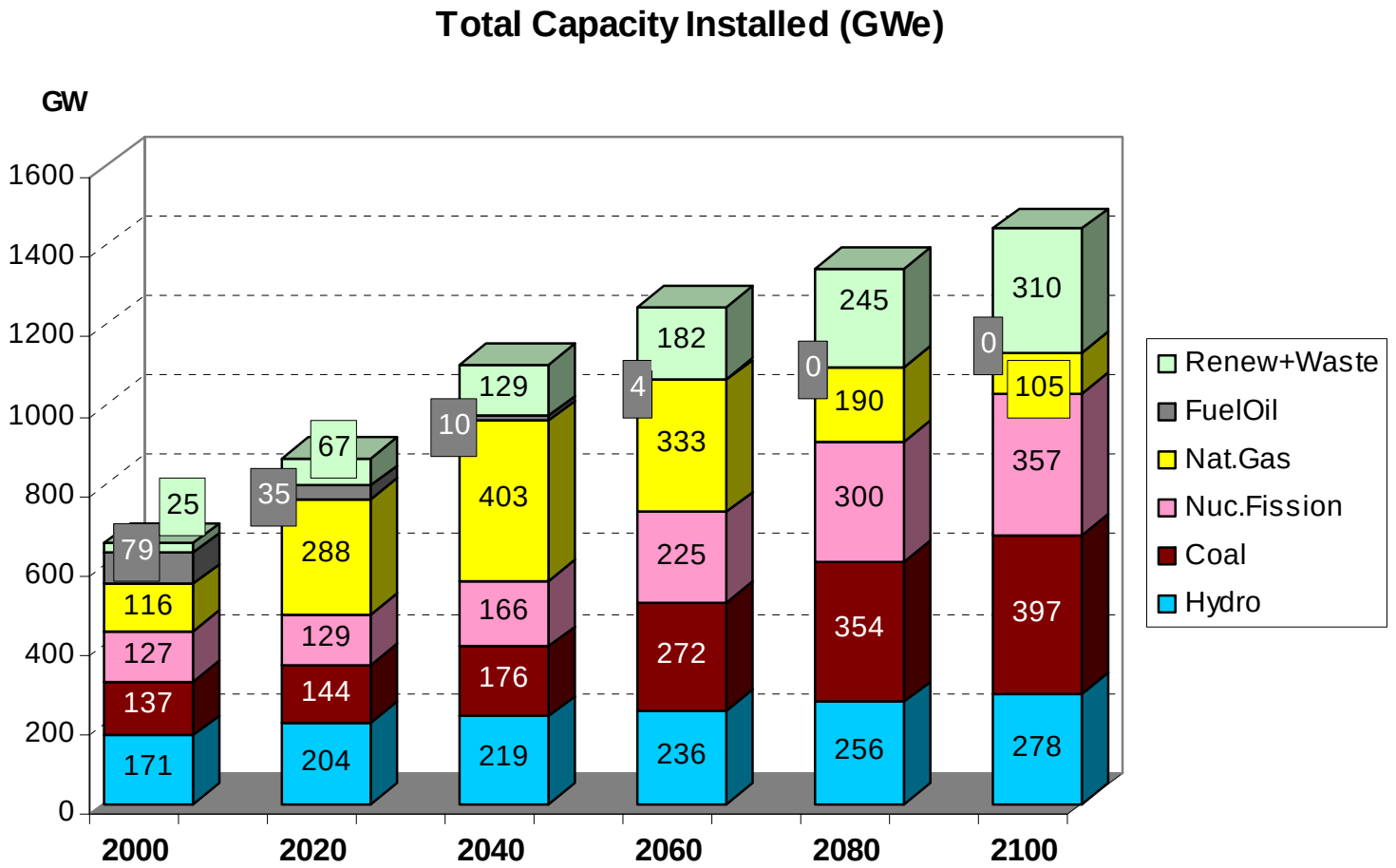
Growth of Electricity Production in Western Europe

Electricity generation (TWh)	2000	
IIASA / WEC scenario “B”	*2859*	(forecasted)
EURPROG	*2798*	(actual)

Annual growth rate (%)	2000-2010	2010-2020	2020-2030	2030-2050	2050-2070	2080-2100
IIASA / WEC scenario “B”	*1.5*	*1.5*	*1.5*	*1.8*	*1.0*	*1.1*
EURPROG	*2.0*	*1.9*				

Simulation of Selected Scenarios

“Reference”



Selected Scenarios for Western Europe

"Reference" (*no Fusion*)

"Introduction of Fusion" (*Fusion 90 GWe ~ 6.2 % of total installed capacity by 2100*)

"Fusion (+)" (*Fusion 9 GWe in 2060, 60 GWe in 2080, and 186 GWe in 2100*)

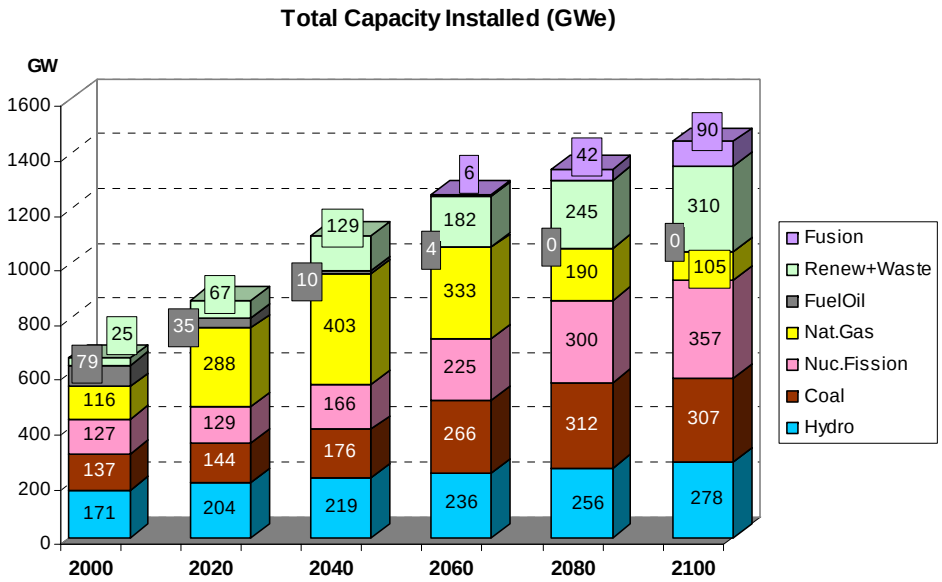
"Coal CCS (+)" (*Coal with CO_2 Capture & Storage 186 GWe ~ 12.8 % of total installed capacity in 2100; no Fusion*)

"Nuclear Fission (+)" (*Fission 186 GWe of additional capacity in 2100; no Fusion*)

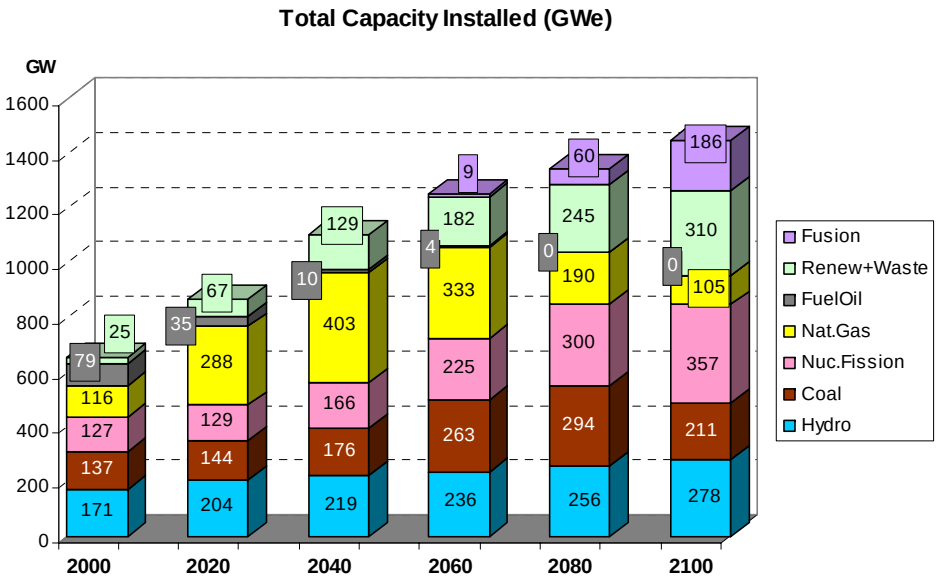
"CO_2 tax" (*the above scenarios with CO_2 tax € 20 and € 50 / t*)

Simulation of Selected Scenarios

“Fusion Intro”

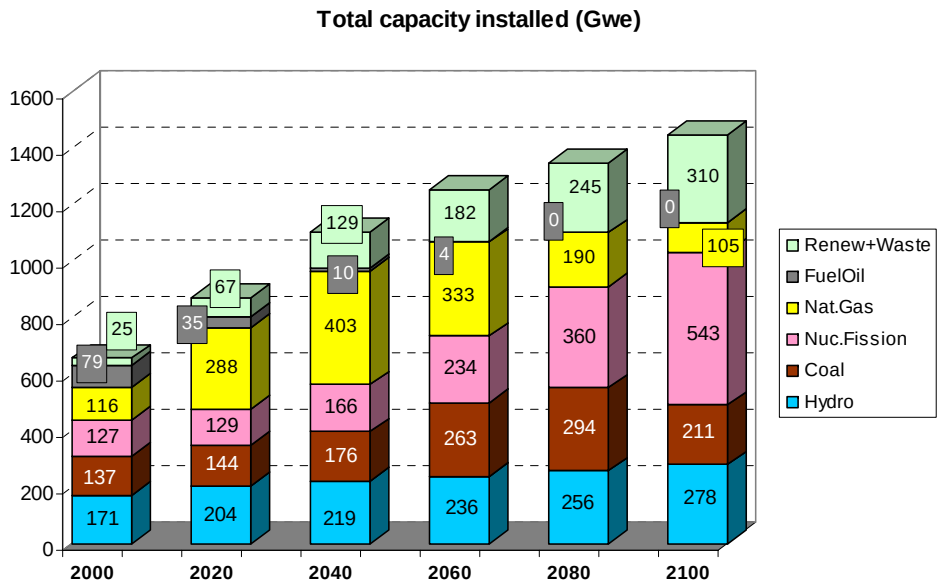


“Fusion (+)”

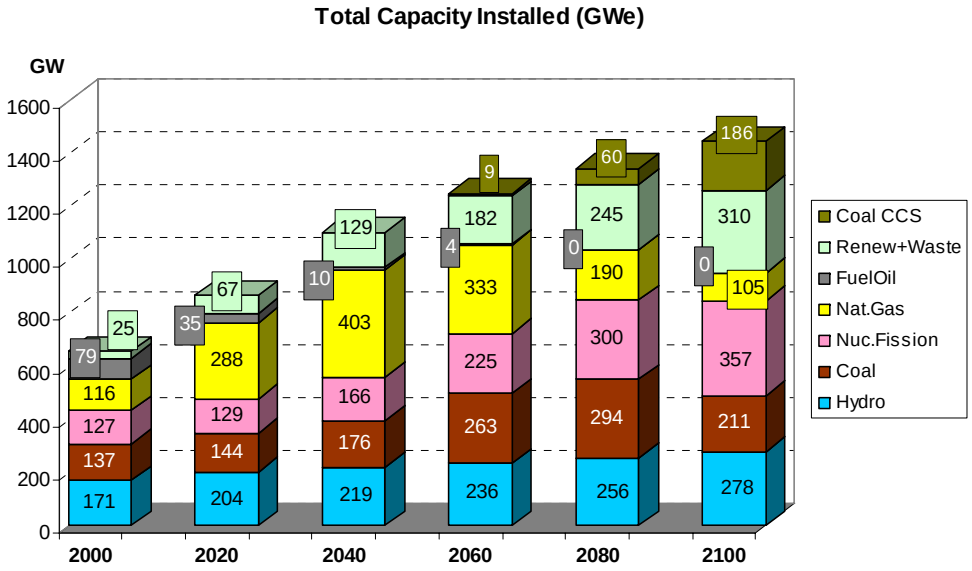


Simulation of Selected Scenarios

"Nuclear Fission"



"Coal CCS"



Levelized Electricity Generation Cost

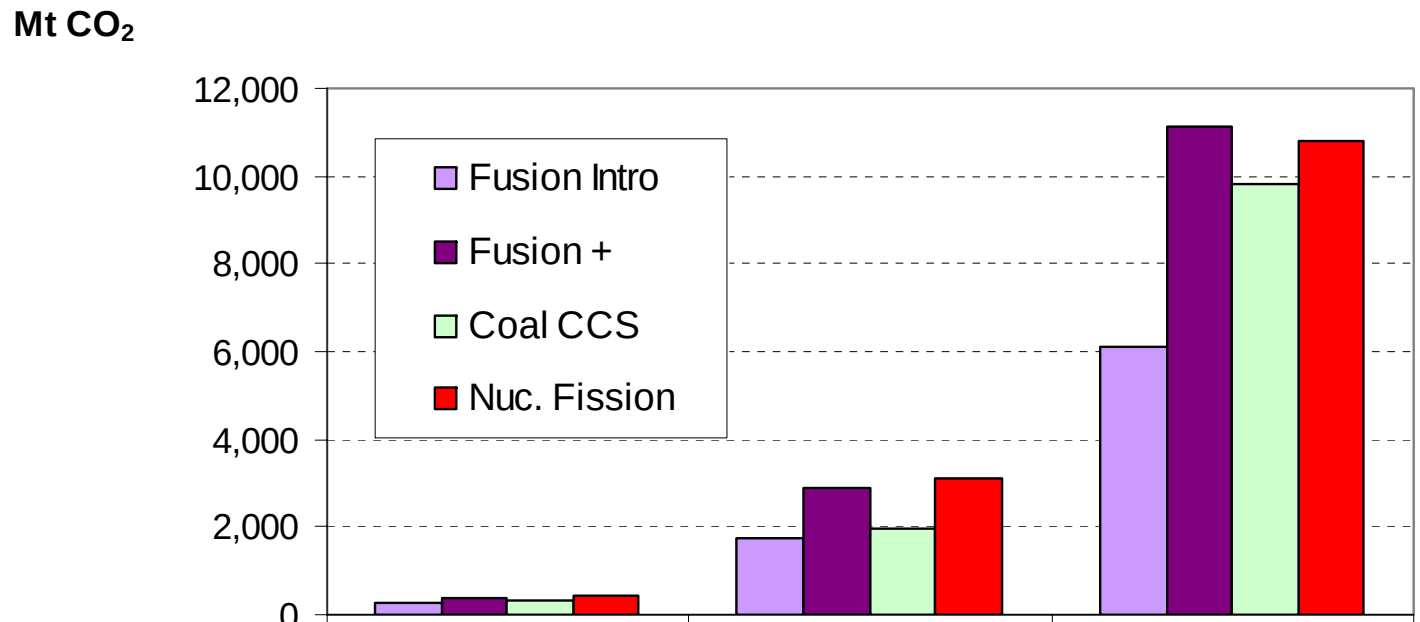
Without CO_2 tax

€ $_{2004}$ / kWh_e

	Reference	Fusion Intro	Fusion (+)	Coal CCS	Nuclear Fission
2000 - 2020	*0.034*	*0.034*	*0.034*	*0.034*	*0.034*
2020 - 2040	*0.036*	*0.036*	*0.036*	*0.036*	*0.036*
2040 - 2060	*0.036*	*0.036*	*0.036*	*0.036*	*0.036*
2060 - 2080	*0.036*	*0.038*	*0.038*	*0.037*	*0.036*
2080 - 2100	*0.035*	*0.038*	*0.039*	*0.036*	*0.036*

Source: Authors' calculation using PLANELEC model

Cumulative CO_2 Emissions Reduction



	2040 - 2060	2060 - 2080	2080 - 2100
Fusion Intro	298	1,738	6,111
Fusion +	375	2,869	11,107
Coal CCS	323	1,943	9,832
Nuc. Fission	413	3,125	10,806

Source: Authors' calculation using PLANELEC model

CO_2 Abatement Cost

Scenario	CO_2 Abatement Cost (2080-2100)
	€ $_{2004}$ / t CO_2
Fusion (+)	€ 26.1
Coal CCS	€ 9.4
Nuclear Fission	€ 4.1

Source: Authors' calculation using PLANELEC model

Levelized Electricity Generation Cost

with CO_2 tax

€ $_{2004}$ / kWh_e

€ 20 / t CO_2	Reference	Fusion Intro	Fusion (+)	Coal CCS
2040 - 2060	*0.041*	*0.041*	*0.041*	*0.041*
2060 - 2080	*0.041*	*0.041*	*0.042*	*0.041*
2080 - 2100	*0.040*	*0.041*	*0.043*	*0.040*
€ 50 / t CO_2				
2040 - 2060	*0.048*	*0.048*	*0.048*	*0.048*
2060 - 2080	*0.047*	*0.047*	*0.047*	*0.046*
2080 - 2100	*0.047*	*0.047*	*0.048*	*0.045*

Source: Authors' calculation using PLANELEC model

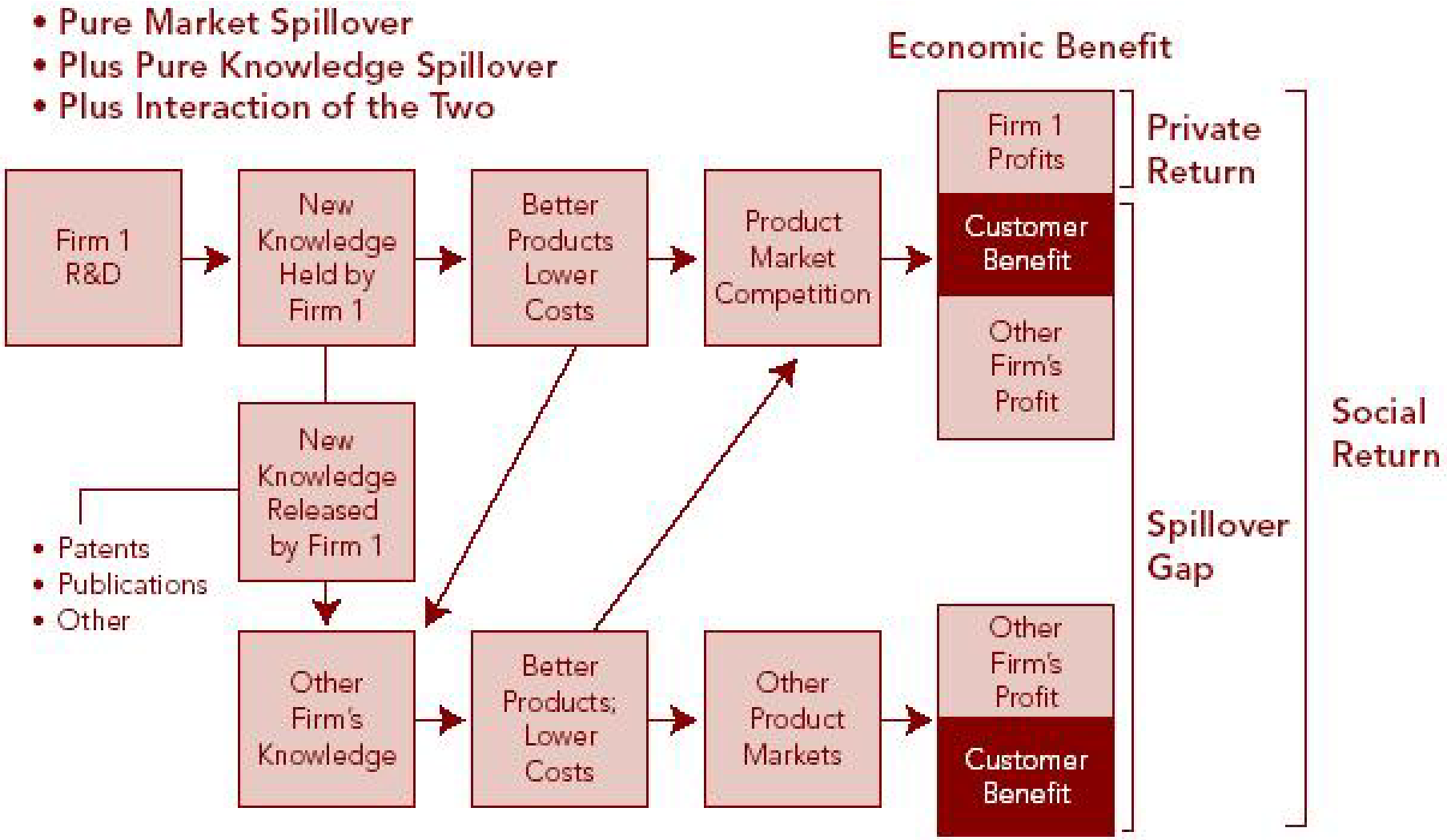
Main Findings

- Deployment of Fusion power in basic case entails a slight increase of the system levelized production cost of the order of magnitude: 2 - 3 € / MWh
- Massive deployment of Fusion leads to a greater increase of electricity production cost: by ≈ 4 € / MWh
- By the end of XXI century Fusion power can be competitive compared to natural gas, but still more expensive than nuclear fission and coal with carbon capture & sequestration
- Under stringent environmental policy regime (CO_2 tax; Cap-and-Trade) Fusion can be introduced into the energy system without any significant welfare loss

Conclusions

- The presented model results are highly dependent on the exogenous assumptions. Therefore,
  - *Additional scenarios shall be simulated differentiating on assumed fuel prices, technologies' learning rates and electricity demand*
  - *Soft linkage with global energy systems model EFDA-TIMES shall be assured* (currently under development within SERF program)
- Economic performance of Fusion depends greatly on the current and future expenses on RD&D activities. Therefore, in order to justify public funding
  - *Socio-economic research on spill-over benefits of Fusion technology RD&D and deployment is vitally needed* !!!
  - *Reasoning in terms of social return vs. private economic return*

Spill-over benefits of R&D programs



Source: A. Jaffe, *Economic Analysis of Research Spillovers*, 1996

Social Rate of Return

SOCIAL AND PRIVATE RATES OF RETURN FROM INVESTMENT IN SEVENTEEN INNOVATIONS

Innovation	Rate of return (percent)	
	Social	Private
Primary metals innovation	17	18
Machine tool innovation	83	35
Component for control system	29	7
Construction material	96	9
Drilling material	54	16
Drafting innovation	92	47
Paper innovation	82	42
Thread innovation	307	27
Door control innovation	27	37
New electronic device	Negative	Negative
Chemical product innovation	71	9
Chemical process innovation	32	25
Chemical process innovation	13	4
Major chemical process innovation	56[a]	31
Household cleaning device	209	214
Stain remover	116	4
Dishwashing liquid	45	46
Median	56	25

Source: E. Mansfield et al., *Social and Private Rates of Return from Industrial Innovations*, 1977

Thank You !