



Part 5: Investment and Electricity Cost Calculation

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Investment Cost Modelling

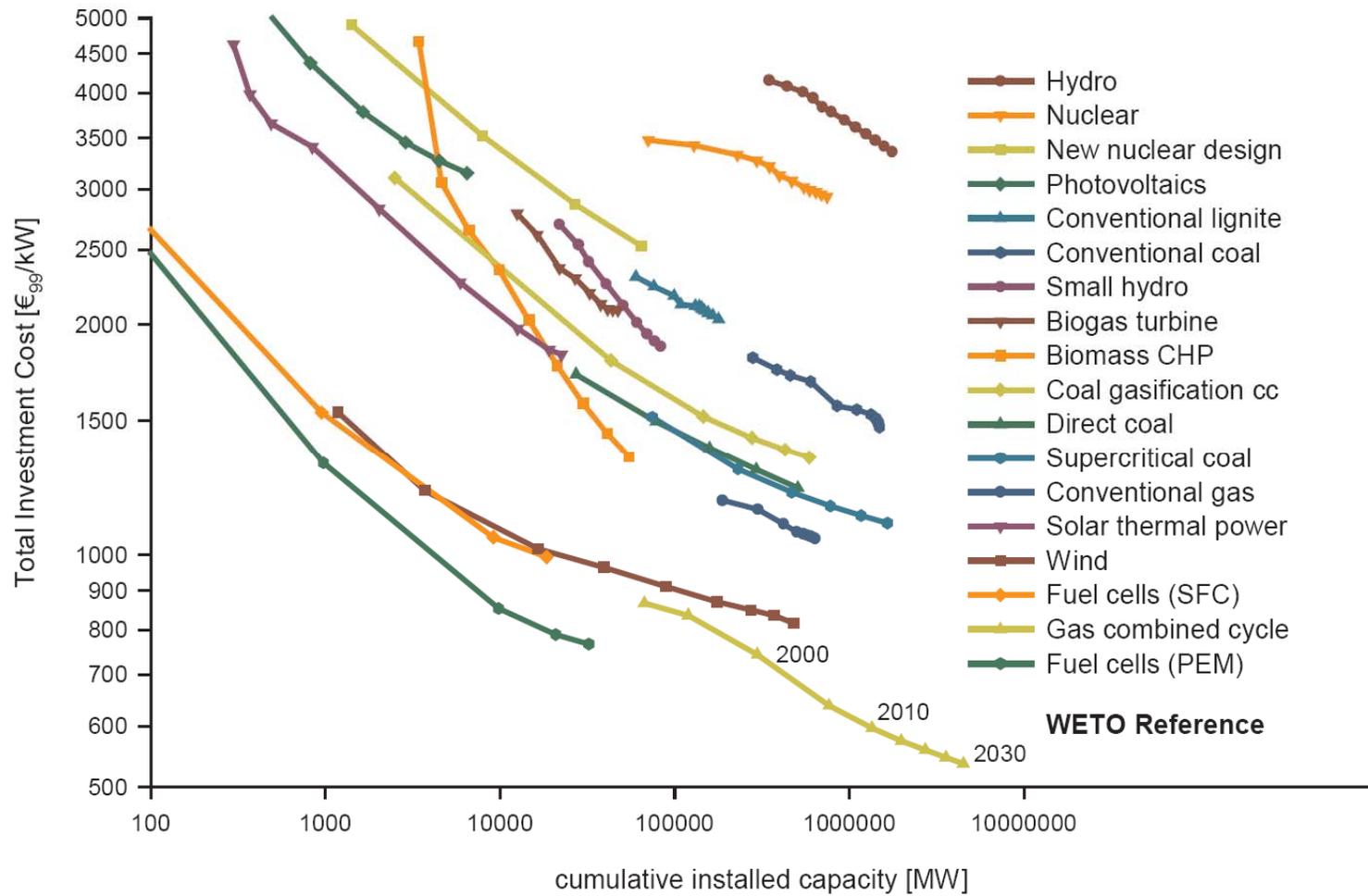


Learning Curves Theory

1. Capital goods become cheaper due to mass production, larger units, advances in research & development and increasing competition.
2. There is no scientific model but a lot of experience that lead to an empirical model function.
3. Each time the installed amount of a product doubles, the investment cost goes down by a rate of $X\%$ (learning rate).
4. If one assumes an expansion rate of a product with time, one can model the progress of investment cost declination of a product over time.
5. Investments are often given in constant monetary value, inflation has to be added if time scales are introduced.



Equipment Cost Learning Curves





Cost Learning Curve Function

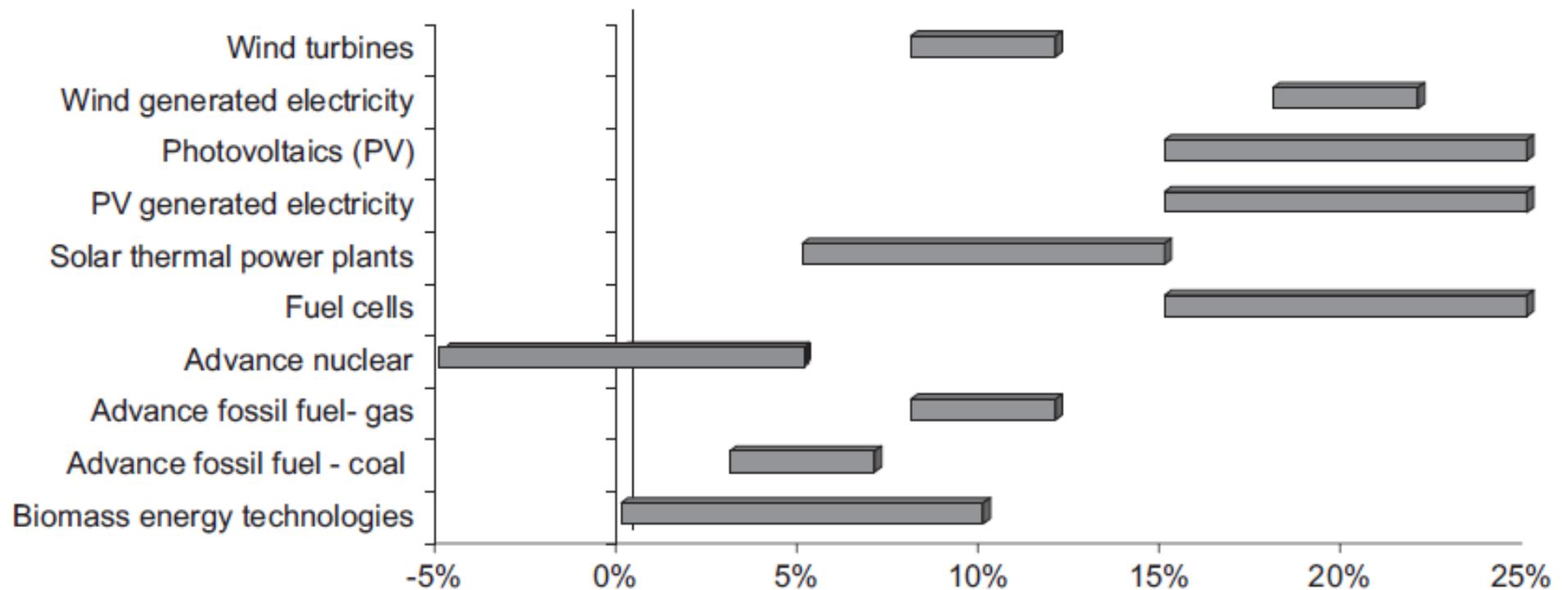
$$C_x = C_0 \left(\frac{P_x}{P_0} \right)^{\frac{\log PR}{\log 2}}$$

- PR progress ratio = (1 – learning rate)
- C_x specific investment at point x
- C_0 specific investment at reference point 0
- P_x cumulated capacity at point x
- P_0 cumulated capacity at reference point 0



Learning Rates for Different Technologies

L. Neij / Energy Policy 36 (2008) 2200–2211





Global Capacity Projections

Source: Greenpeace 2009

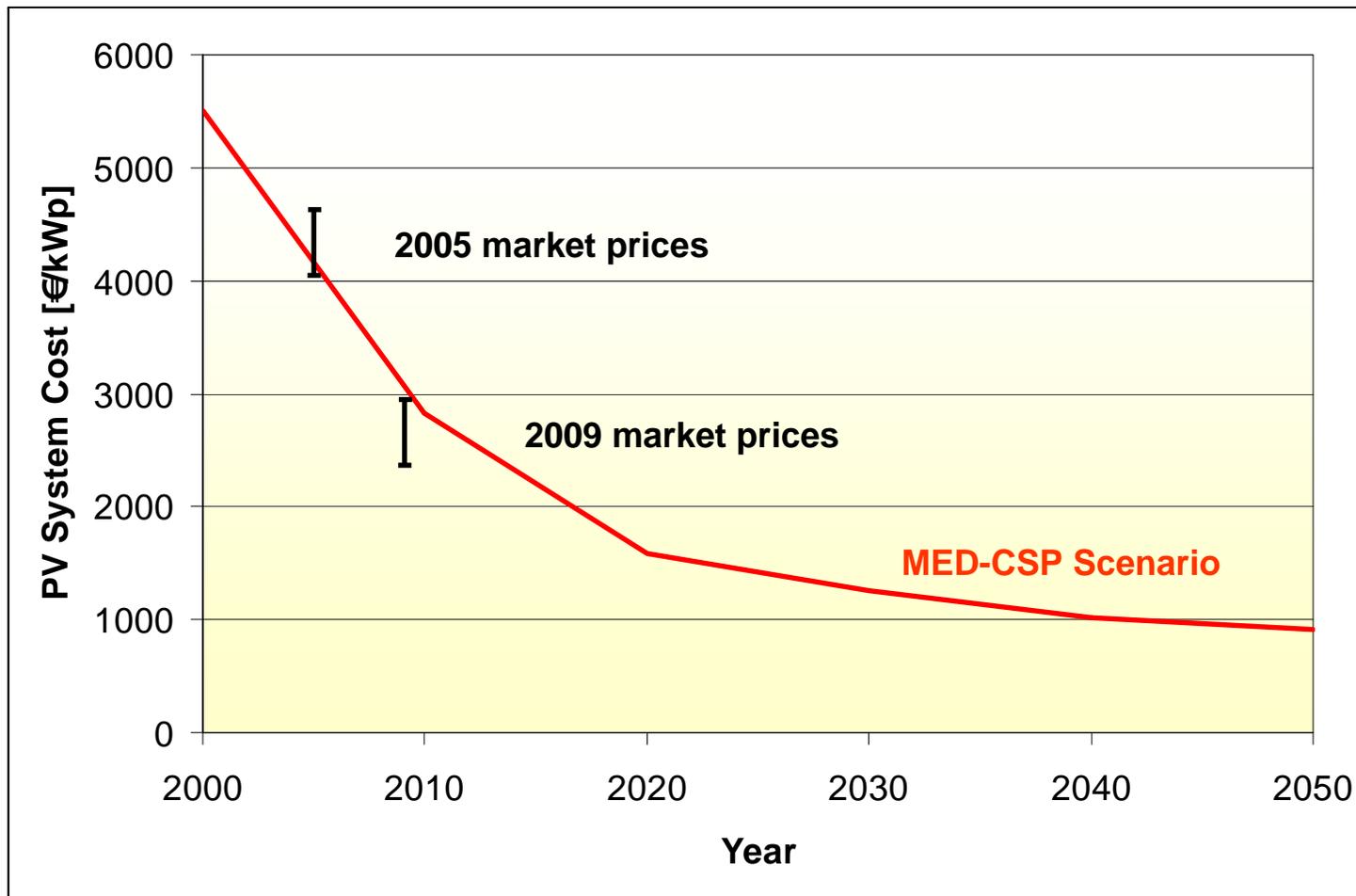
Year	Installed Capacity (GW)		Reference Scenario			
	2005	2010	2020	2030	2040	2050
Photovoltaic	2	10	49	86	120	153
Concentrating Solar	0,35	2	28	150	300	500
Wind Offshore	0	1	35	110	135	160
Wind Onshore	59	124	311	330	390	420
Hydropower	878	989	1215	1400	1560	1710
Biomass Power	21	28	52	72	86	95
Geothermal Power	9	11	17	22	28	33
Ocean Energy	0	0	2	4	7	9

Source: Greenpeace 2009

Year	Installed Capacity (GW)		energy (r)evolution scenario			
	2005	2010	2020	2030	2040	2050
Photovoltaic	2	21	269	921	1800	2900
Concentrating Solar	0,35	5	83	200	468	800
Wind Offshore	0	1	35	110	135	160
Wind Onshore	59	164	858	1512	2085	2573
Hydropower	878	978	1178	1300	1443	1565
Biomass Power	21	35	56	65	81	99
Geothermal Power	9	12	33	71	120	152
Ocean Energy	0	1	17	44	98	194

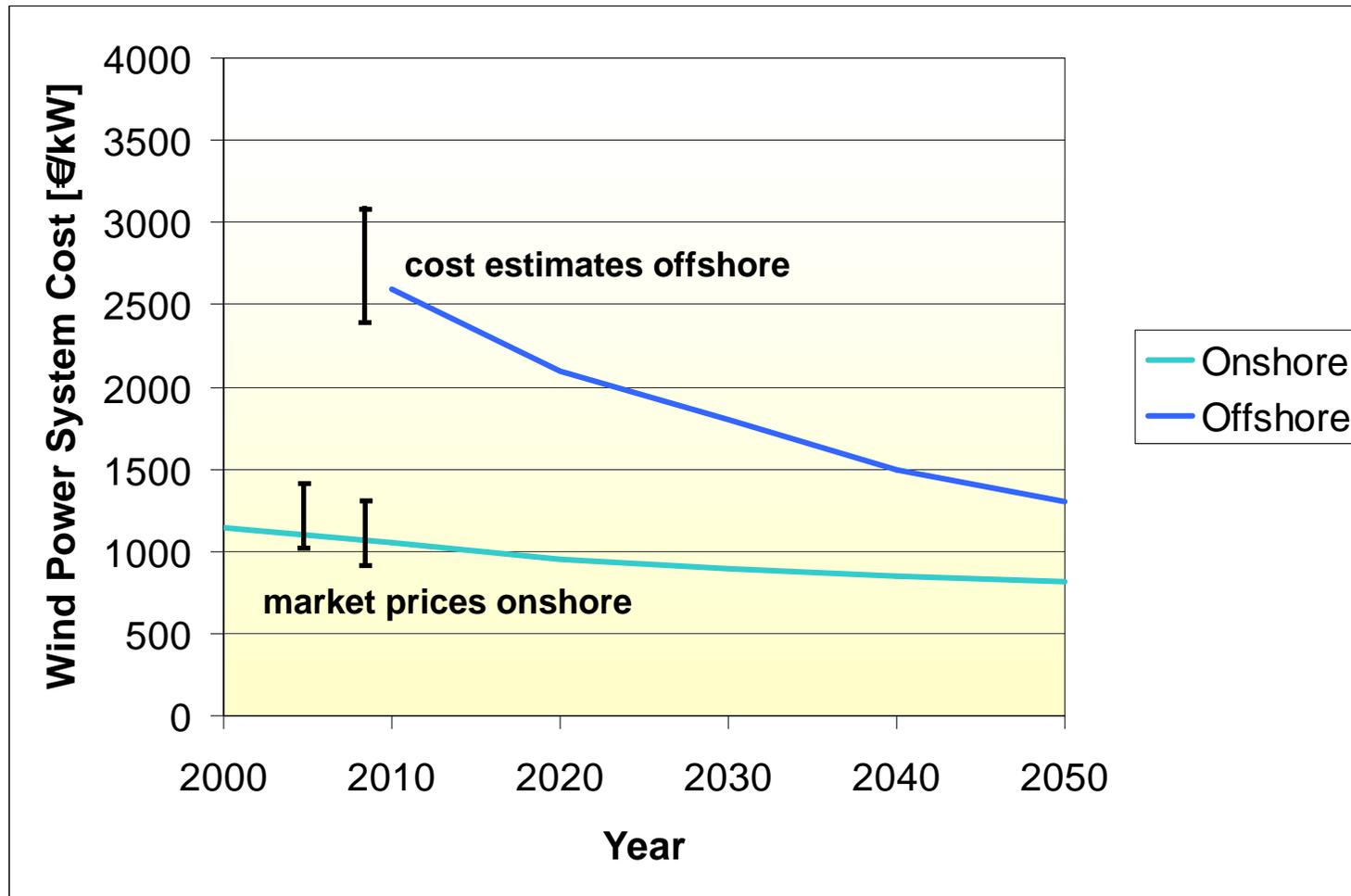


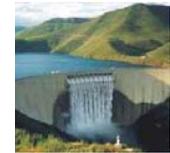
Photovoltaic System Cost Perspectives



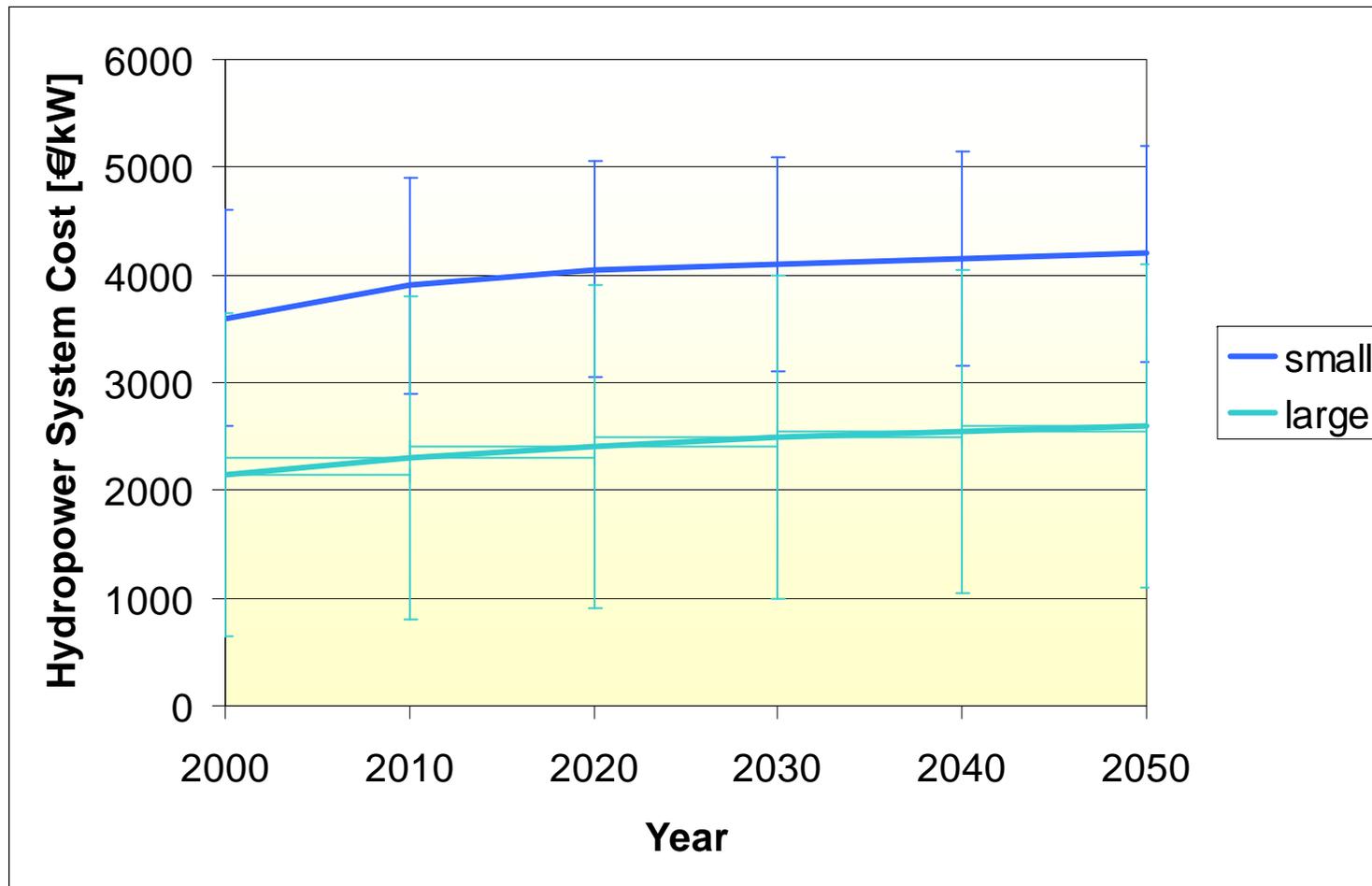


Wind Power Investment Cost Perspectives



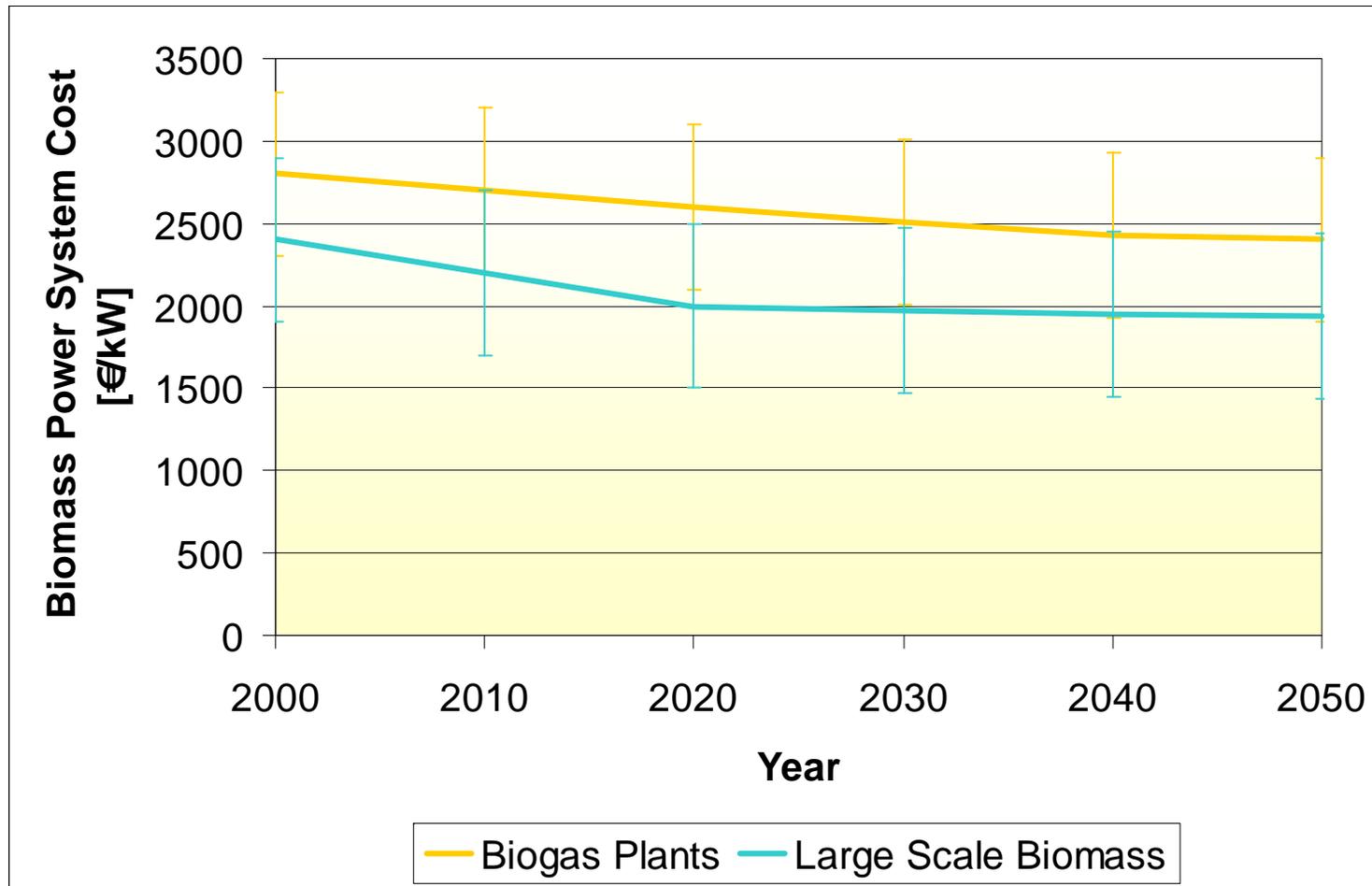


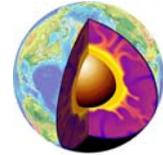
Hydropower Investment Cost Perspectives



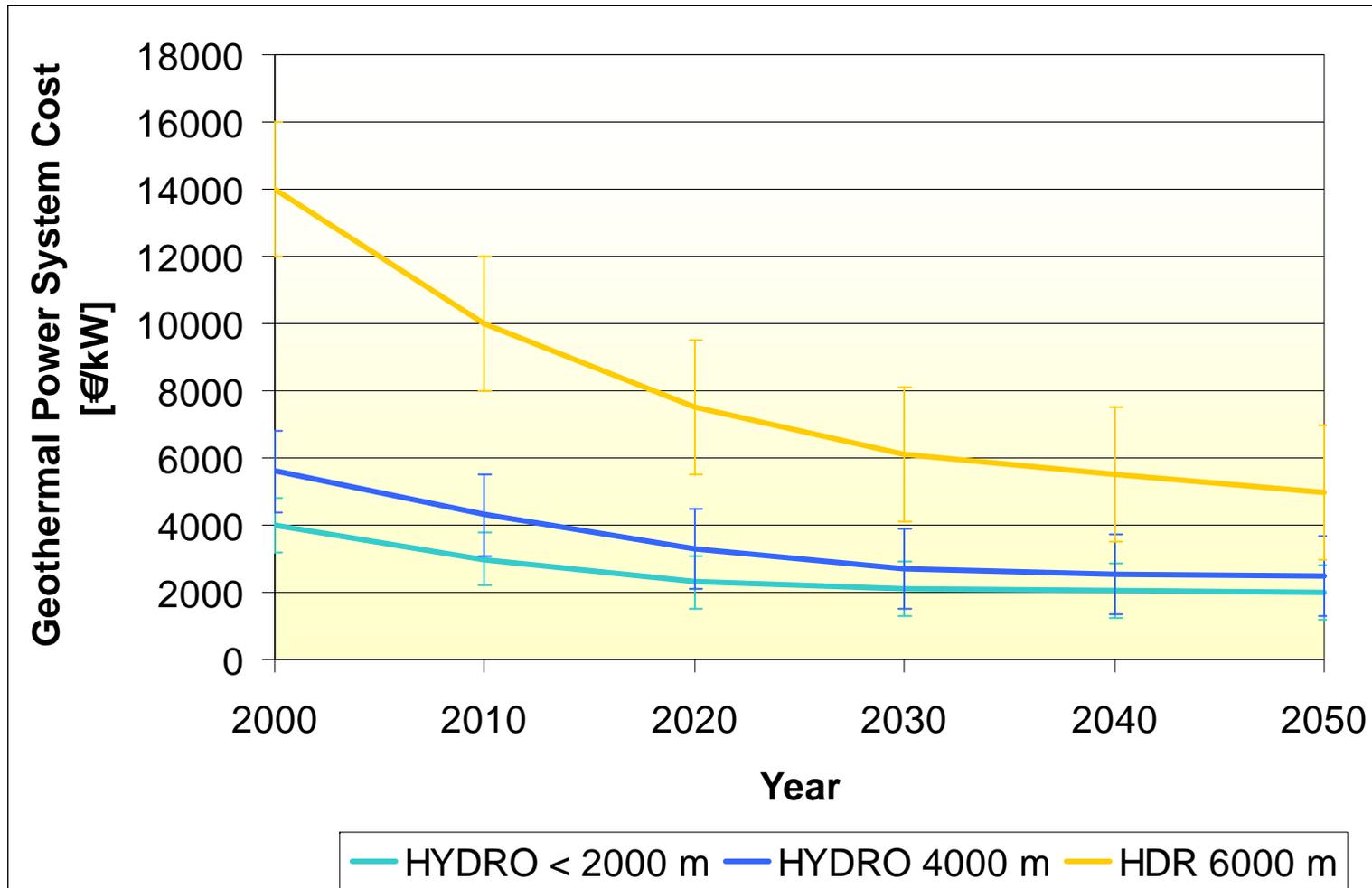


Biomass Investment Cost Perspectives





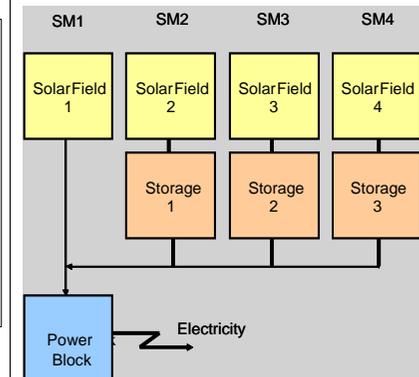
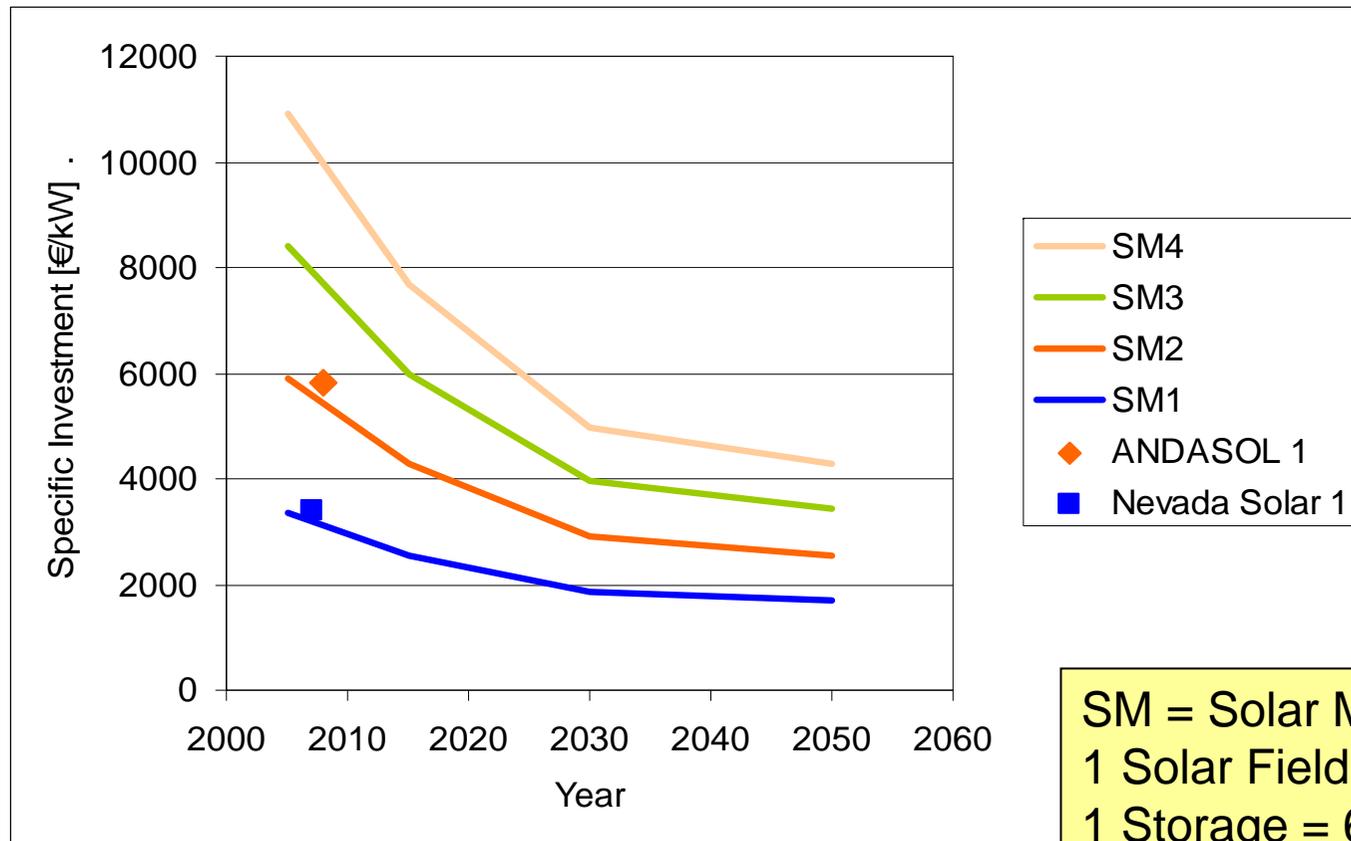
Geothermal Power Investment Cost Perspectives





CSP Investment Cost Perspectives

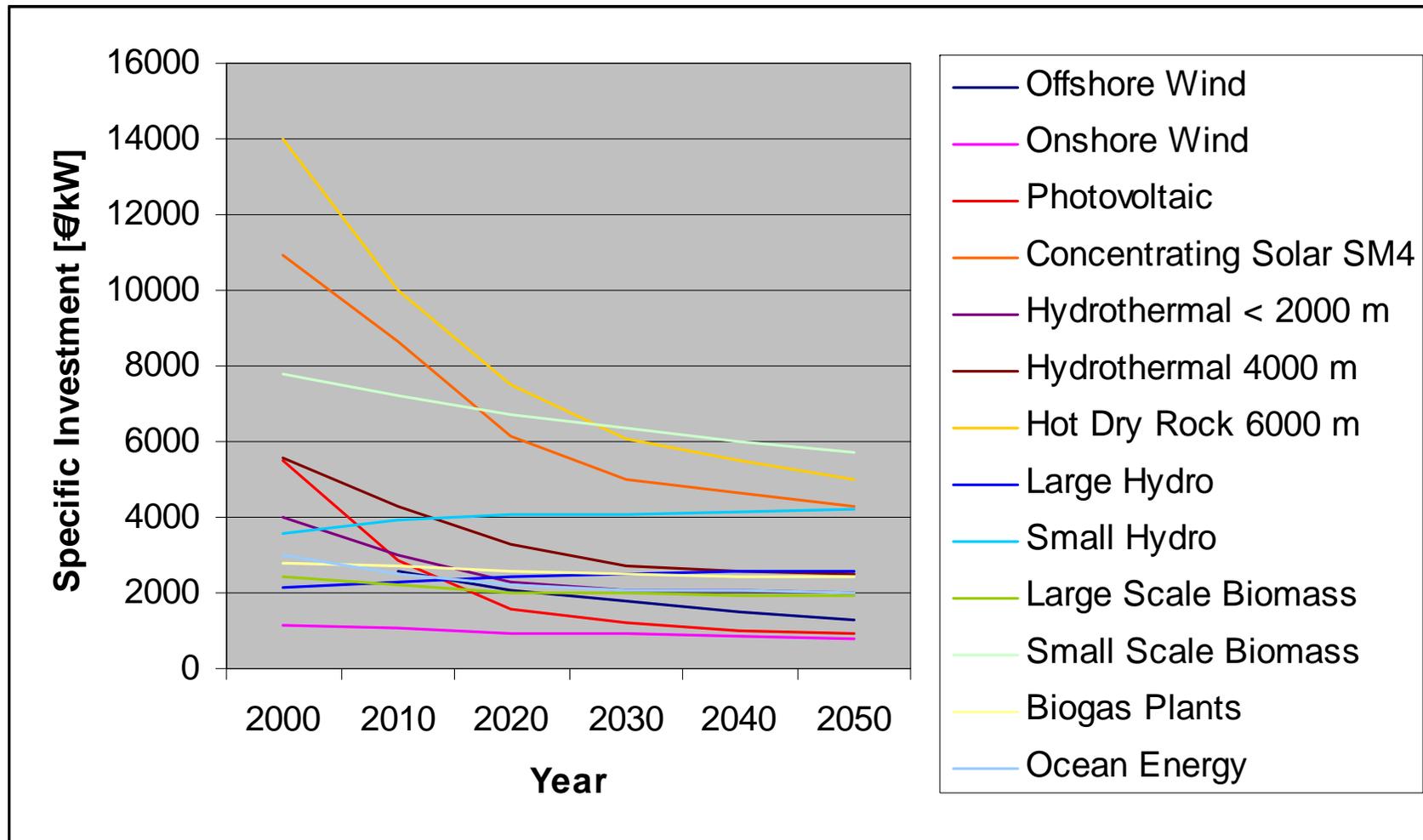
Year	PR	2005	2015	2030	2050	Unit
World CSP Capacity		354	5000	150000	500000	MW
Solar Field	90%	360	241	144	120	€/m ²
Power Block	98%	1200	1111	1006	971	€/kW
Storage	92%	60	44	29	25	€/kWh



SM = Solar Multiple
 1 Solar Field = 6000 m²/MW
 1 Storage = 6 hours (full load)



Specific Investment Cost as Function of Time





Specific Investment Cost as Function of Time

	2000	2010	2020	2030	2040	2050
Offshore Wind		2600	2100	1800	1500	1300
Onshore Wind	1150	1050	950	900	850	820
Photovoltaic	5500	2830	1590	1250	1010	910
Concentrating Solar SM4	10920	8675	6152	4982	4640	4299
Hydrothermal < 2000 m	4000	3000	2300	2100	2050	2000
Hydrothermal 4000 m	5600	4300	3300	2700	2550	2500
Hot Dry Rock 6000 m	14000	10000	7500	6100	5500	5000
Large Hydro	2150	2300	2400	2500	2550	2600
Small Hydro	3600	3900	4050	4100	4150	4200
Large Scale Biomass	2400	2200	2000	1970	1950	1940
Small Scale Biomass	7800	7180	6700	6350	6000	5700
Biogas Plants	2800	2700	2600	2510	2430	2400
Ocean Energy	3000	2500	2250	2100	2050	2000

values in €₂₀₀₅/kW



Electricity Cost Modelling



Levelised Electricity Cost Model

$$C_{el} = \frac{Inv \cdot FCR + O \& M + F}{E_{year}}$$

$$FCR = \frac{(1+i)^n \cdot i}{(1+i)^n - 1}$$

C_{el} levelised cost of electricity in €/kWh in constant present monetary value

Inv investment cost in €

FCR fix charge rate as function of interest rate (i) and economic lifetime (n) in %/y

$O\&M$ net present value of annual operation, maintenance and insurance in €/y

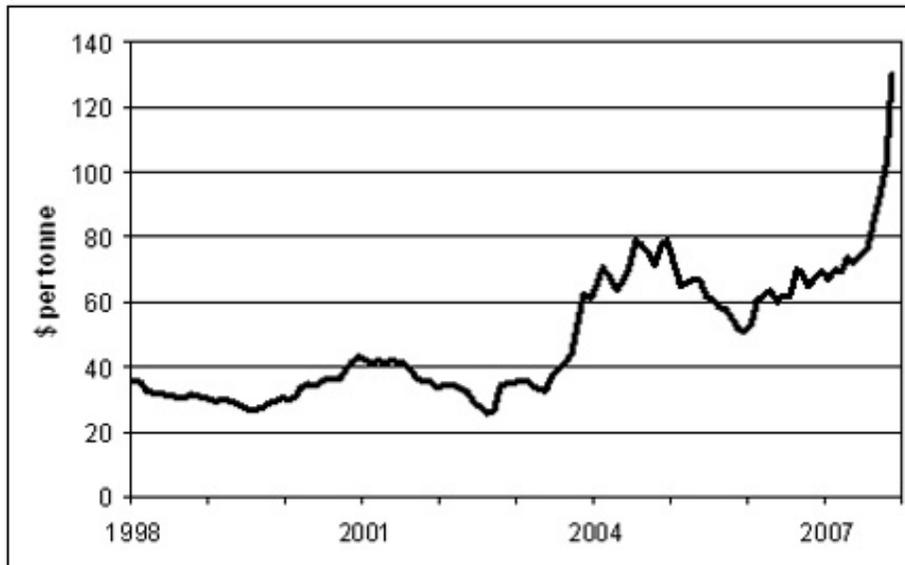
F net present value of annual fuel cost in €/y

E_{year} electricity generated per year = installed capacity (kW) · annual full load hours (h/y)

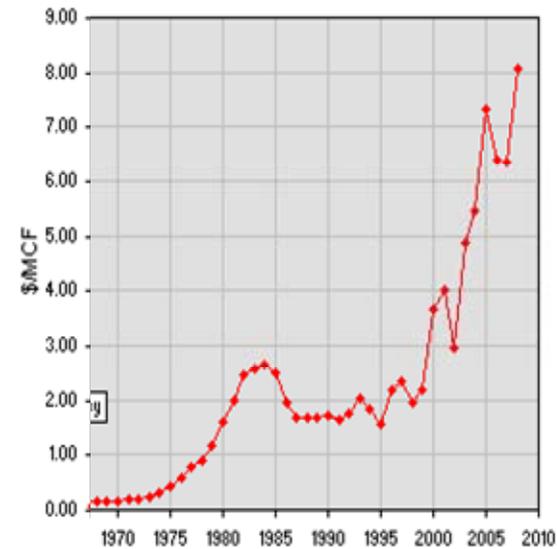


Fuel Cost Perspectives?

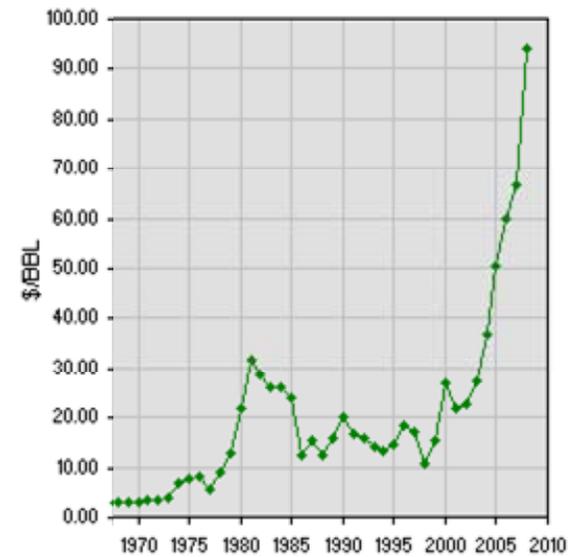
Coal Price



Natural Gas Price



Crude Oil Price





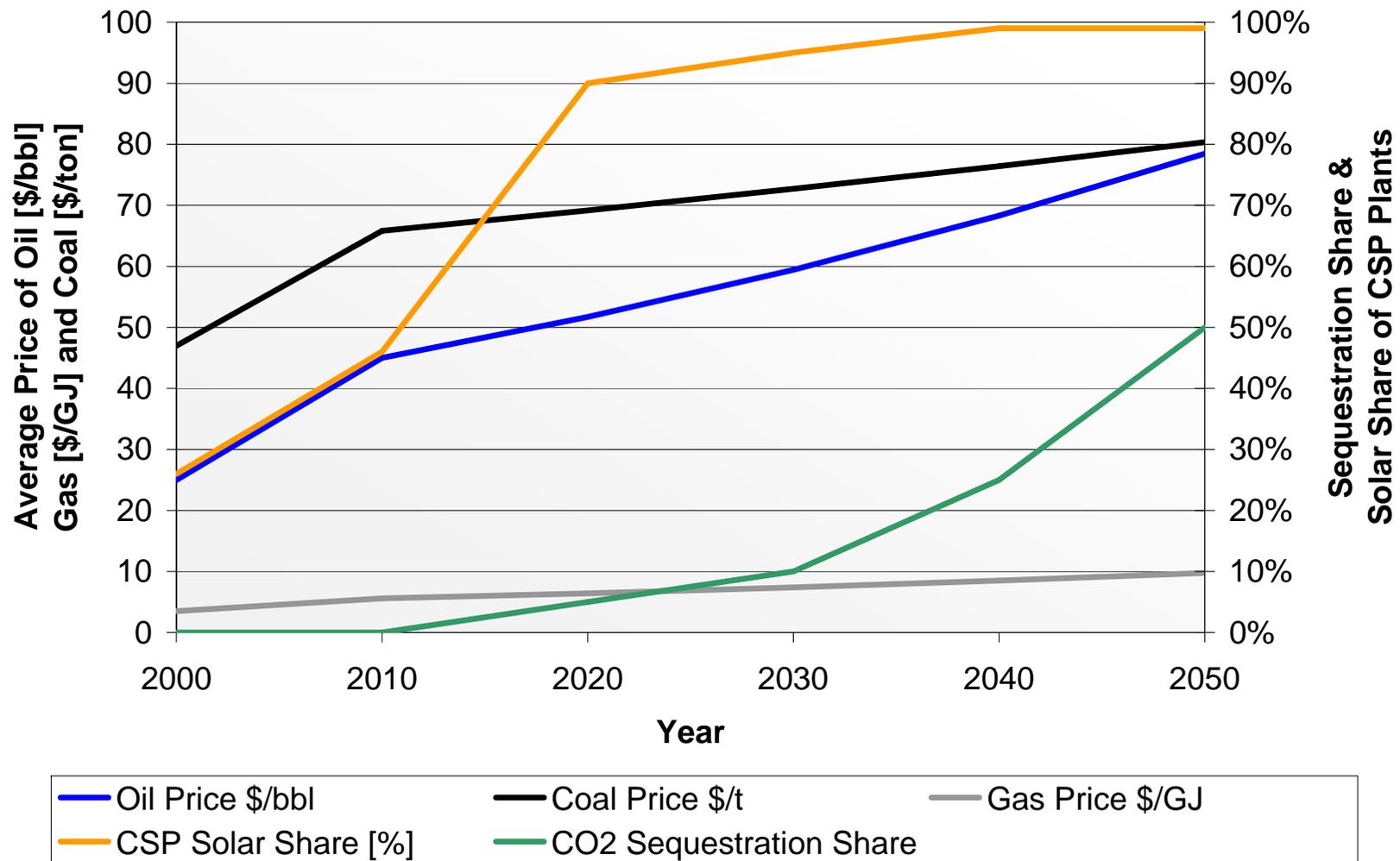
Parameters for Levelised Electricity Cost Model

	Economic Life years	Efficiency % *	Fuel Price Escalation %	Operation & Maintenance % of Inv./y	Annual Full Load Hours hours/year*
Steam Coal Plants	40	40%	1.0%	3.5%	5000
Steam Oil Plants	30	40%	1.0%	2.5%	5000
Combined Cycle Natural Gas	30	48%	1.0%	2.5%	5000
Wind Power	15			1.5%	2000
Solar Thermal Power	40	37%	1.0%	3.0%	8000
Hydropower	50	75%		3.0%	2600
Photovoltaics	20	10%		1.5%	1800
Geothermal Power	30	13.5%		4.0%	7500
Biomass Power	30	35%		3.5%	3700

* vary for different countries and sites



Further Parameters for Levelised Electricity Cost Model



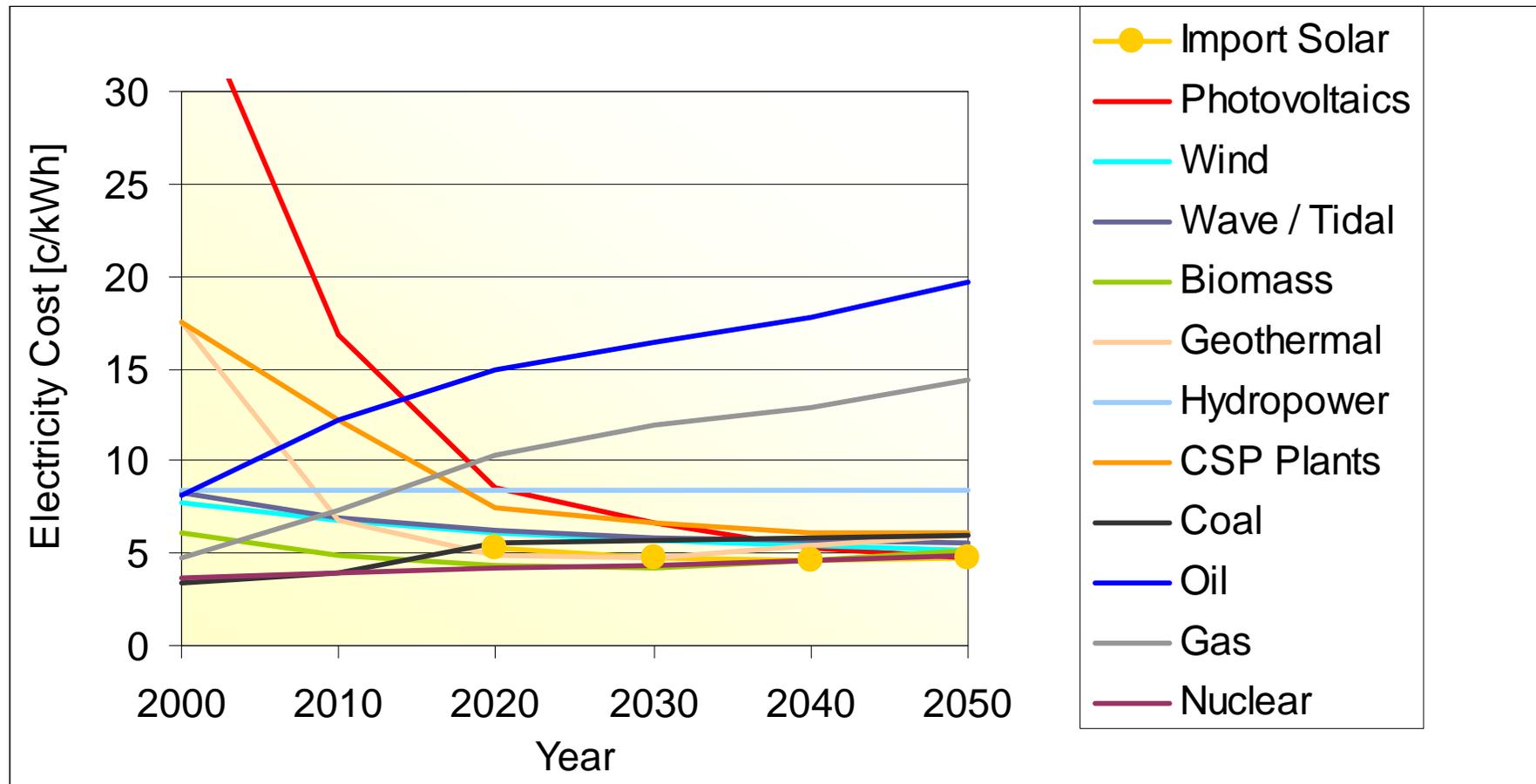


Performance Parameter: Representative Full Load Hours

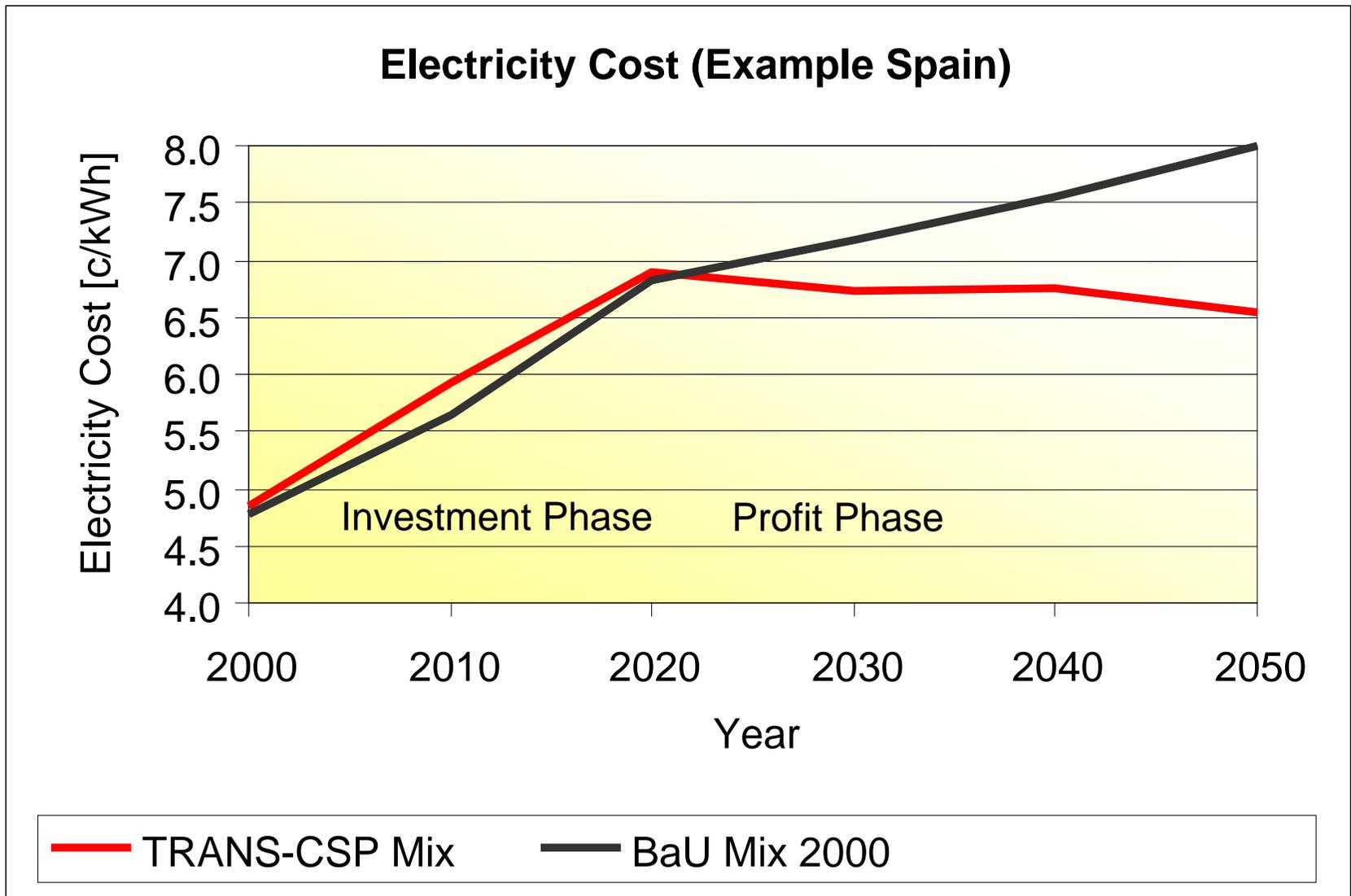
Full Load Hours h/a	2000	2010	2020	2030	2040	2050
Load	6005	6005	6005	6005	6005	6005
Wind	2325	2359	2393	2427	2460	2494
Photovoltaics	1353	1515	1677	1697	1707	1717
Geothermal	7500	7500	7500	7500	7500	7500
Biomass	2800	2800	2800	2800	4000	3500
CSP Plants	1900	3500	4500	5000	5000	5000
Wave / Tidal	4000	4000	4000	4000	4000	4000
Hydropower	1705	1705	1705	1705	1705	1705
Oil / Gas	3261	2533	2240	1787	1517	1225
Oil	2458	2185	2427	1537	686	686
Gas	4805	2707	2173	1856	1707	1225
Coal	6202	6202	6202	6202	6202	6202
Nuclear	8367	8367	8367	8367	8367	8367
Import Other (incl. Solar)	4920	4667	3500	2800	1333	533
Import Solar HVDC)	0	0	6000	6250	7000	5625



Electricity Cost Learning Curves (example Spain)



discount rate 5%/y at constant monetary value





Allowable Cost of Different Power Segments

Segment	Source / Technology	Min. Rev. ct/kWh	Max. Rev. ct/kWh
Peak Power	Pump Hydro Storage	10	25
	Fuel Oil		
	Gas Turbine		
	Biomass		
	Geothermal		
	CSP		
Intermediate Power	Coal	5	12
	Gas Combined Cycle		
	CSP		
	Biomass		
	Geothermal		
Base Load	Coal	3	6
	Lignite		
	Nuclear		
	River Run-Off		
	Gas Combined Cycle		
	Co-generation		
	Wind		
	Photovoltaics		
	CSP		
	Geothermal		



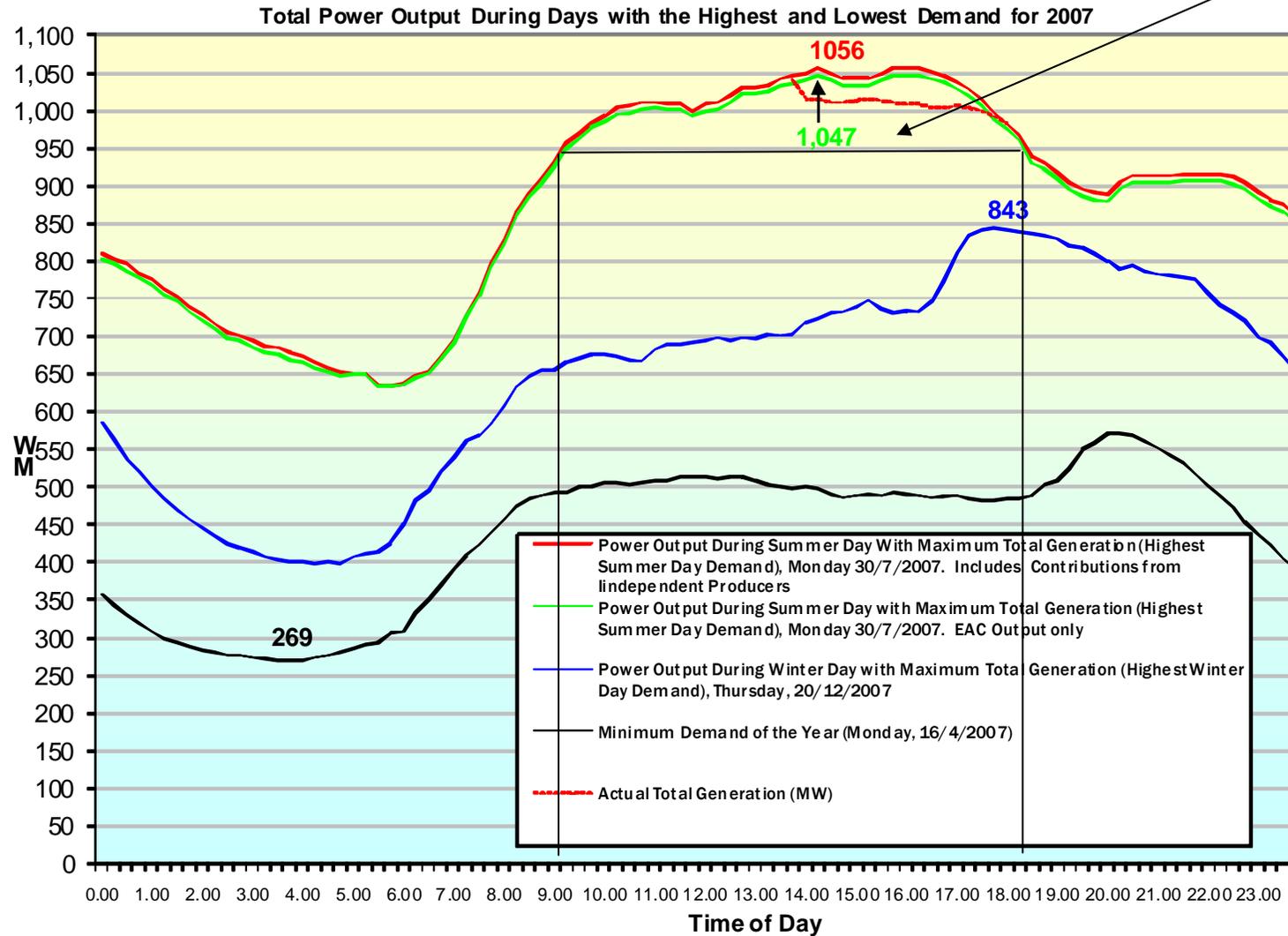
Exercise





Example: Load Curve in Cyprus 2007

**Gas Turbines
fired with Diesel**

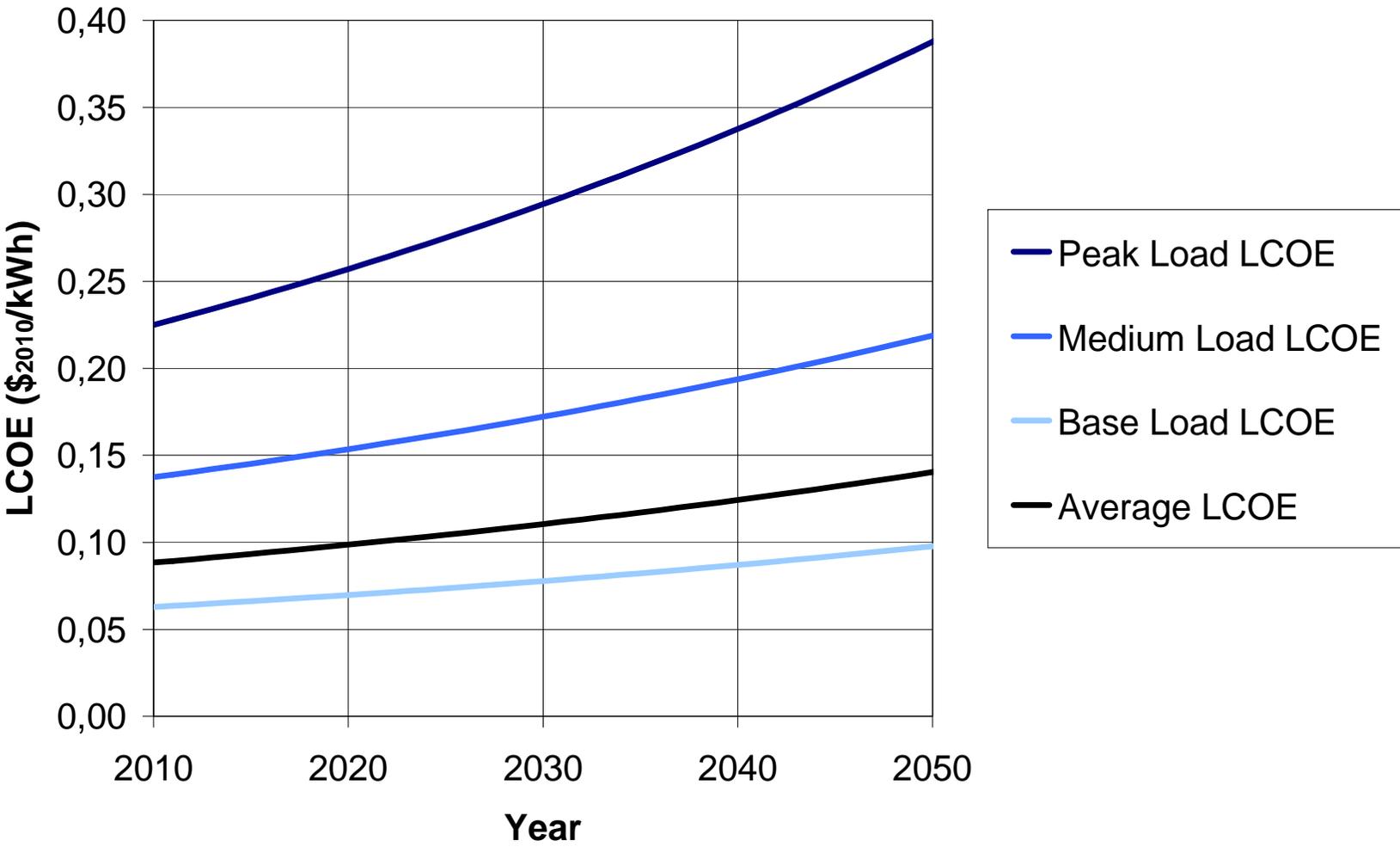


Example of a typical Power Park Structure

Base Load Capacity	MW	4000
Base Load Annual Electricity	GWh/a	30000
Base Load Fuel Cost (Coal + NG + HFO)	\$/MWh	15,0
Medium Load Capacity	MW	2500
Medium Load Annual Electricity	GWh/a	10000
Medium Load Fuel Cost (Coal + Fuel #2)	\$/MWh	35,0
Peak Load Capacity	MW	1000
Peak Load Annual Electricity	GWh/a	2000
Peak Load Fuel Cost (Diesel + Fuel #2)	\$/MWh	60,0
Cost Escalation of Fossil Fuels	%/a	1,5%
Specific Power Block Investment (B+M)	\$/kW	1200
Specific Power Block Investment (Peak)	\$/kW	400
Project Rate of Return	% of Inv./a	10,0%
O&M Rate	% of Inv./a	2,5%
Fuel Efficiency Base & Medium Load	%	35,0%
Fuel Efficiency Peak Load	%	30,0%
Reference LCOE of CSP in 2010	\$/kWh	0,280
Reference Direct Normal Irradiance	kWh/m ² /y	2400
CSP Progress Ratio	%	88,0%
Exchange Rate	\$/€	1,19

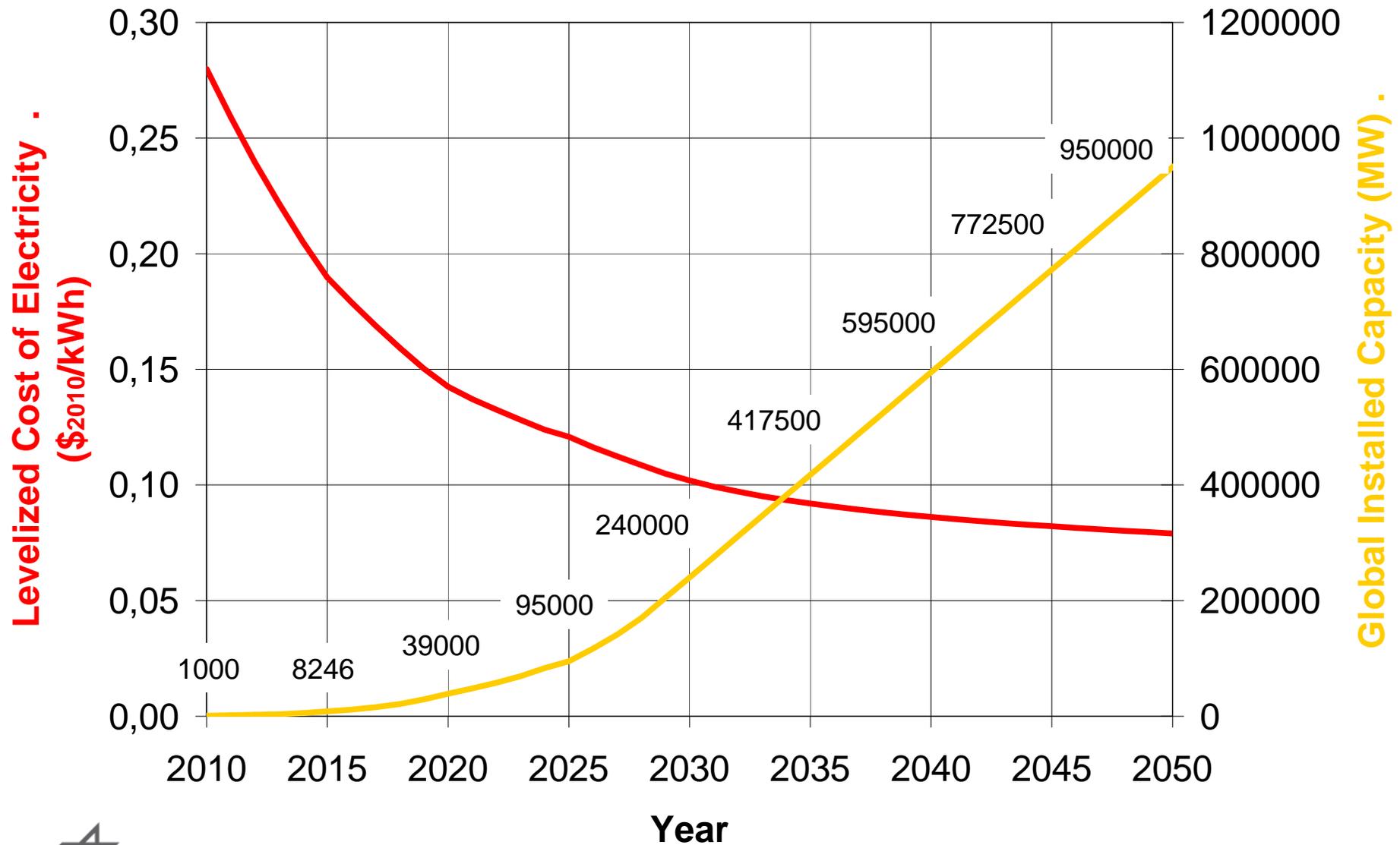


Fuel Powered Electricity Cost Development by Sector



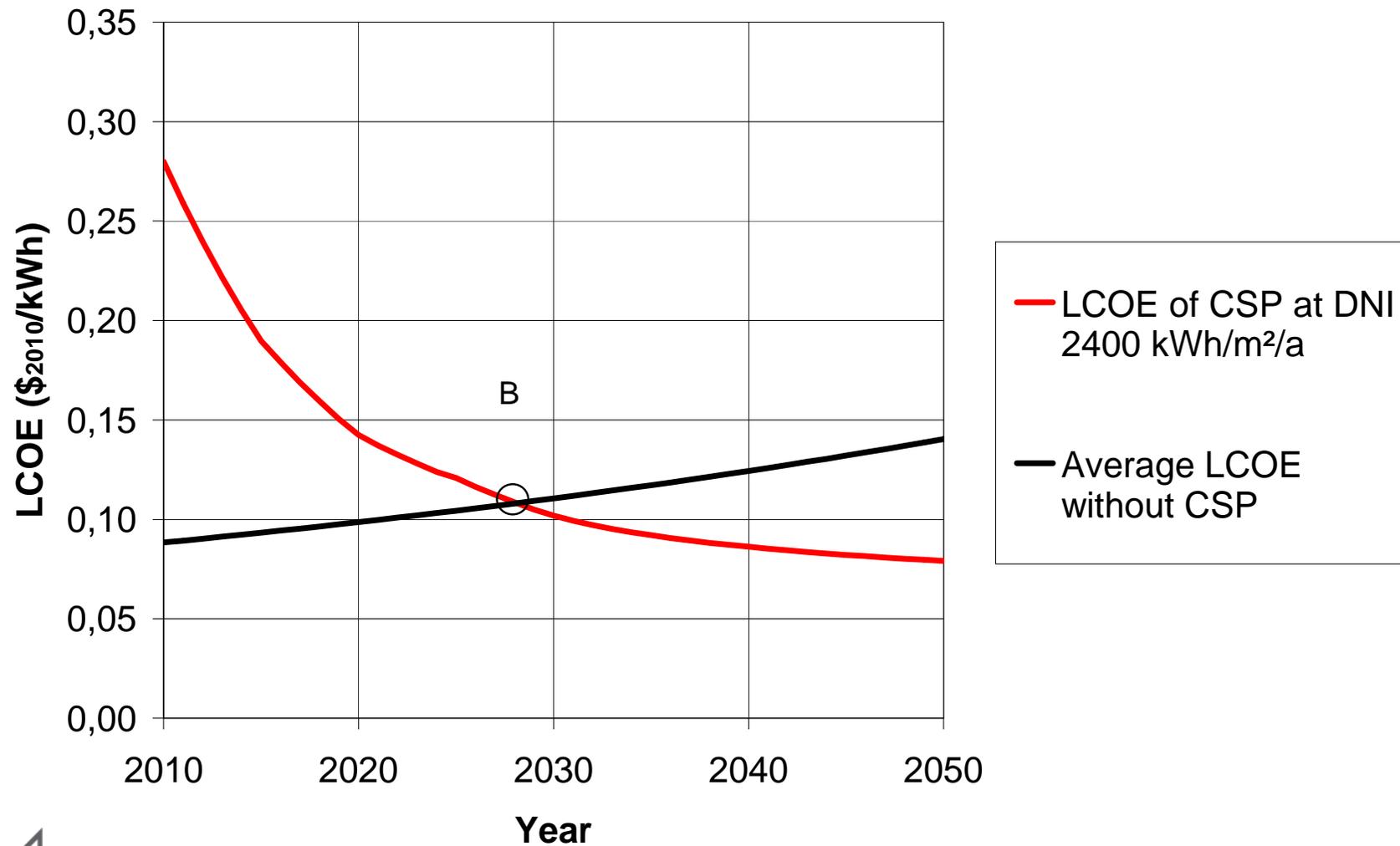


CSP Electricity Cost Learning Curve



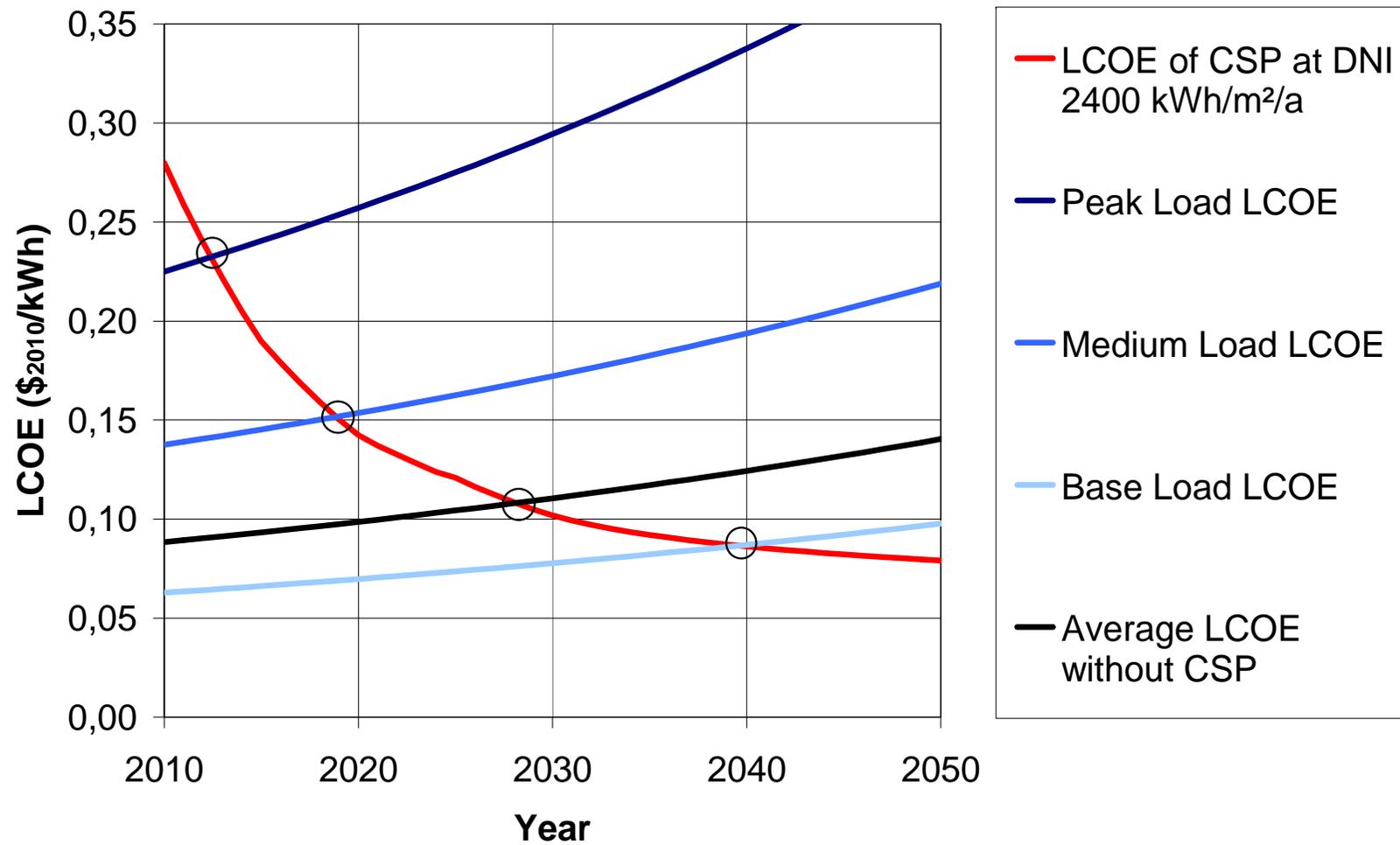


Break Even of Average Electricity Cost



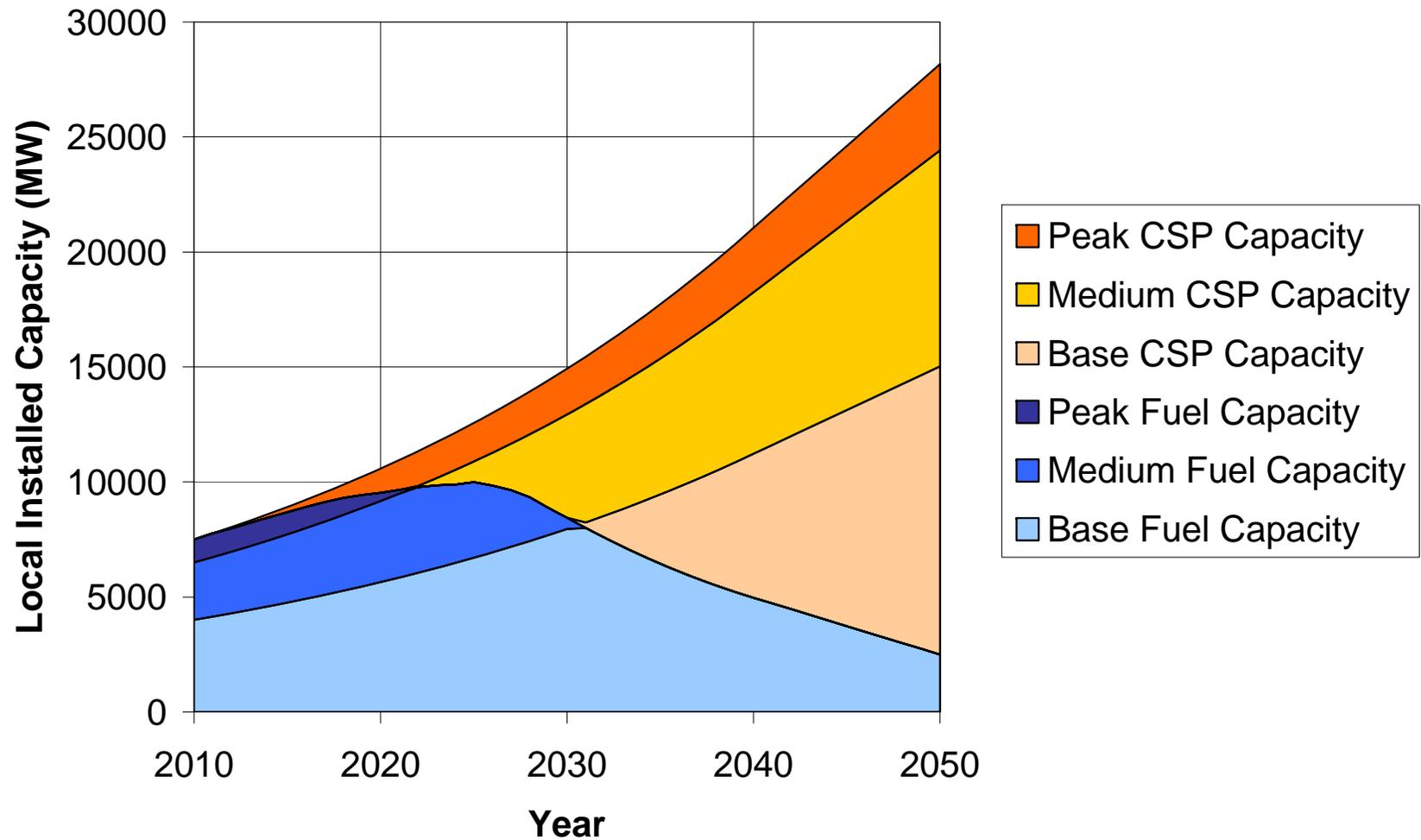


Break Even of Electricity Cost by Sector



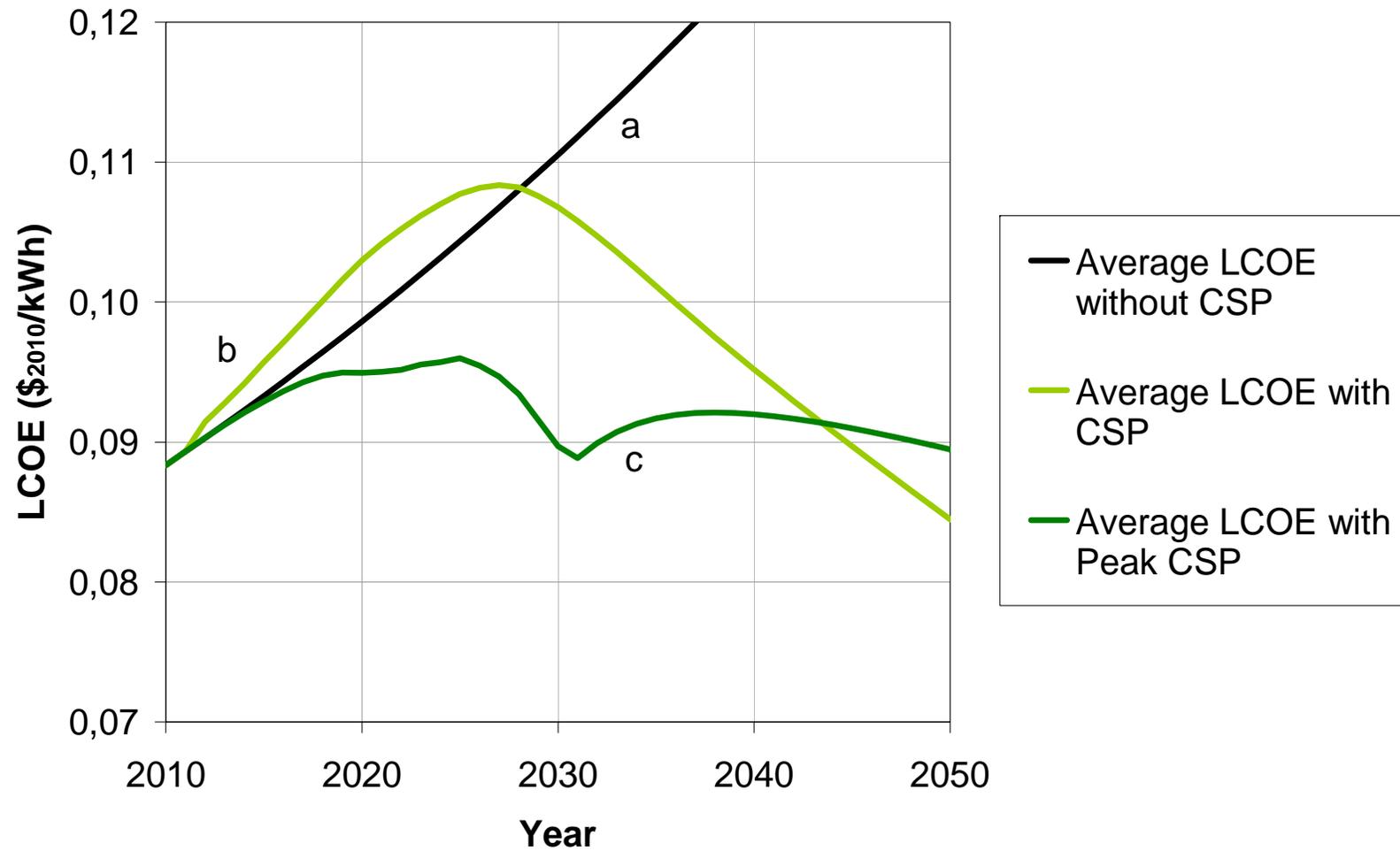


Introduction of CSP by Sector





Additional Cost of Consumers





Conclusions





The Old Paradigm

Renewable sources of electricity are very expensive, most countries are too poor to afford their market introduction.



What has been overlooked:

Renewable sources of electricity become cheaper the more they are used, while fossil fuels become more expensive the more they are used.



The New Paradigm

A fast introduction of renewable sources of energy for power generation is the only way to stabilize the future cost of electricity at a relatively low level.



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