Preface

This book is based on the work done by the authors that began in the mid-1970s on the topics of solar thermal power plants, long-distance power transmission, and solar hydrogen – in particular, on a study for the European Association for Renewable Energy (Eurosolar) carried out in 1996–1998. In the face of considerable resistance from the scientific and especially from the political communities, the authors have attempted since the early 1980s to introduce the concept – of importing solar-thermally generated electrical energy from sunny regions – into the public debate on energy. Over many years, this concept, in spite of support from well-known public figures, including Professor Werner Buckel (former president of the German Physical Society) and Hermann Scheer (president of Eurosolar, Member of the German Parliament), has been almost completely ignored. A gradual change in the political perception (initially in Germany) began to make itself felt when in the year 1995, the German Physical Society took up the topic of "Solar thermal power plants and imported electric power" in an energy memorandum and continued to publicize it with increasing emphasis in the following years. At the beginning of the new millennium, the German Federal Ministry for the Environment then recognized the significance of solar thermal power plants and also of the concept of importing solar thermal power; in the year 2003, this concept was taken up by the Club of Rome in cooperation with the German Aerospace Center (DLR) (under the new appellations "TREC" or "Desertec"). This then opened the way to a broader political acceptance worldwide and also to the initiation of concrete projects. In this phase, it seemed expedient to us to describe the whole topic of solar thermal power plants and a future world energy supply based largely on them in a comprehensive and thorough manner. In particular, it is our aim to present to a broad spectrum of readers the enormous but still underestimated potential of solar thermal power generation for the general energy supply, as well as the developments required to make this vision a reality.

Large-Scale Solar Thermal Power. Werner Vogel and Henry Kalb
© 2010 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim
ISBN: 978-3-527-40515-2

Preliminary Remarks and Summary

The Significance of the Rapid Deployment of Solar Thermal Power Plants for Energy Policy

Solar thermal power plants have been barely considered by a wider public until a few years ago. This is all the more surprising since they not only offer the promise of relatively low power costs (under mass production), but also have a notable advantage over other large-scale energy technologies: owing to their rather simple structure, consisting of conventional, straightforward components such as mirrors, systems of piping, insulated containers, and steam power plant blocks, they could be produced in large numbers within a fairly short time. If necessary, available production capacities from many branches of industry could be utilized for the fabrication of the individual components. After the completion of the required further development program, which if carried out rapidly could be finished within around 4 years, the replacement of today's coal- and natural gas-fired power plants for the base-load power supply could be started. With a "crash program" (maximum speed with strong time pressure), this would take 10–15 years. If the necessary preconditions for such a rapid implementation were met, the whole "energy turnaround" including the development program could be completed within ca. 15–20 years.

The energy carriers which would then be freed up and thus far have been used in fossil fuel power plants (in particular coal) could then make an important contribution to the substitution of the present imported energy carriers outside the electrical power generating sector. Coal can be converted into fuel gas at a relatively low cost. Worldwide, including the USA, the amounts of coal burned in power plants, and thus the potential amounts of gas which could be produced, are enormous. Solar energy would thus make an *indirect* contribution to the substitution of oil and natural gas. Such a reasonably priced alternative to natural gas is significant both for Europe, with its high proportion of imported gas, as well as for the USA, where the gas reserves are limited. Since the supply of gas would then be increased, oil could be substituted as well.

Solar hydrogen and gas from coal gasification could furthermore together form the basis for the large-scale manufacture of liquid fuel ("sun methanol"). In view

Large-Scale Solar Thermal Power. Werner Vogel and Henry Kalb
© 2010 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim
ISBN: 978-3-527-40515-2

of the nearly unlimited production potential for such a substitute fuel in the USA in terms of the solar regions (hydrogen) and a sufficient supply of coal, this fuel could become a major *direct* alternative to petroleum. With a successful development of solar technology, sun methanol made with US coal should cost about 90 $/barrel of oil equivalent. Given the enormous potential capacities – in principle, the world's oil consumption could be supplied from the USA alone – in the medium term the price of crude oil could even be limited to parity with the cost of this fuel (a "price brake" for crude oil).

Next, we give a brief explanation of the following aspects:

1. Costs

Solar thermal power plants offer favorable conditions for economical power generation. Using heat-storage systems, they can deliver power 24 h per day. Transmission of the power over a distance of, for example, 3000 km is possible with only minor losses (11.5%) using present-day modern transmission technology (800 kV direct current, HVDC). The power plants could thus be located in regions with a high and uniform insolation, for example, in Spain, North Africa, or in the southwest USA (providing power to the East Coast). As backup power plants, the substituted natural gas and coal-fired plants, or also new, relatively low-cost gas plants would be available. They would perform the task of bridging over gaps in the solar power supply due to weather conditions. In Morocco and the USA, this would correspond to about 20% of the overall power generated; in Spain, it would make up 25–30%.

As we describe in detail in this book, based on current knowledge, solar power from mass-produced plants would not be much more expensive than the present-day power, which is generated mainly in fossil fuel plants: about the same as from natural-gas CCGT plants at today's gas prices. For the power supply of Europe from Spain, the cost including backup power (from new gas-fired plants) would be about 5.2 ¢/kWh, and in the USA, it would be around 4.7 ¢/kWh (all prices quoted in US cents at the monetary value of the year 2002). This can be compared with the cost of energy from natural-gas CCGT base-load plants (4.8 ¢/kWh) or from newly constructed nuclear plants (3.1 ¢/kWh). The latter value would decrease in the case of large-scale deployment, possibly to as little as 2.4 ¢/kWh (without including the societal costs). The increased costs to the national economies for solar energy as compared to nuclear energy would be readily tolerable, even with a very large-scale deployment of solar plants, as we shall show.

2. The time required – The need for a special development program

Solar power plants, due to their extremely simple technology, can not only be produced rapidly and in large numbers, but also, for the same reason, they can be quickly developed and optimized. It must, however, be considered that not just a *single* type of solar power plant, but rather several families of plant types, and within them, a multiplicity of technological branches will have to be developed. For it is not yet clear which variant will achieve the lowest costs under mass production. However, nearly all the individual technologies represent relatively simple development tasks. Insofar as all the different branches are developed in *parallel*, the time required will not be increased. In each case, the economic potential under mass production must be explored; within the overall development program, this represents a special task for each case.

Thus, although the individual development problems are simple as a rule, the large number and wide variety of process steps make a broadly conceived and tightly enforced development program essential, if we wish to reach our goal as quickly as possible. This, in turn, presupposes a suitable organizational structure, which is adapted to these particular goals for the planning and execution of the program. Thus, it must be guaranteed that each new problem that arises, in whatever technical field it may lie, can be countered by a rapid and flexible reaction within the development program.

As we shall show in the discussion of the individual technologies, the greatest portion of the development tasks could be accomplished within about 4 years, insofar as the organizational preconditions are met. This will require not only an efficient organization but also an unhampered access to the necessary resources. The rapid development of solar energy thus requires a similarly structured and optimized approach ("crash program") as, for example, the Apollo space program, although with a much more modest financial effort.

Some of the developmental tasks will require more time. With a correspondingly intensive program, the last of these should be completed within around 8 years. Thus, if rising (or even exploding) oil prices force us to act as quickly as possible, for example, already after 6 years (assuming completion of the main phase of the development after 4 years), the mass production of solar plants could be started. In the case of a few particular components, one would then begin with suboptimal versions and would allow further improvements in the course of development to enter successively into the ongoing production process; for solar tower plants, this applies, for example, to receivers optimized for maximum efficiency. A comparable program for nuclear energy would require at least twice this time for completion: in the case of this complex and *security-relevant* technology, a rapid increase in the production capacity would be incomparably more difficult, especially in terms of obtaining the necessary highly qualified personnel capacities. This aspect has always been emphasized in connection with the nuclear energy debate. Even with the greatest possible haste, it would presumably require 30–40 years for the completion of a full conversion to nuclear power.

While the USA has a practically unlimited potential for solar energy at its disposal, the resources in Europe are more scant. Precisely for Europe, however, a conceivable combination with other renewable energy sources should be considered. Most probably, offshore wind energy, for which there are favorable conditions and a great potential in the North Sea, would also lead to low-cost power. This renewable energy source could also be relatively quickly developed and deployed if necessary. It has, however, the disadvantage that power generation is less uniform so that by itself, it does not represent an alternative to solar energy for generating base-load power. In combination, solar and wind energy would complement each other in terms of seasonal variations. If the expected costs for wind energy prove correct, Europe's future power supply could be mainly based on renewable sources, consisting of one-third solar power from Spain, one-third solar power from Morocco, and one-third offshore wind power. (Two-thirds of the power would then be generated on European territory.) If one wished to replace today's total base-load power consumption (EU-25), then in Spain, a solar power plant capacity of ca. 100 GW_{el} would have to be deployed. If necessary, that is, accepting somewhat less favorable plant sites, an area for up to four times this capacity should in any case be available in southern Spain. Without wind energy, thus presuming half of the solar capacity to be in Spain and half in Morocco, each location would require a generating capacity of 150 GW_{el}.

An even more rapid reaction to increasing energy prices is possible only through energy-saving measures. A combination of energy conservation with solar plants, which would be rapidly available on the energy-economic timescale (possibly combined with wind energy), thus probably represents the quickest path to a restructuring of the energy supply.

3. The importance of substituted power plant coal for the supply of gas

Coal can be converted into gas (syngas) at a very favorable price using conventional technology, insofar as one dispenses with CO_2 sequestration, that is, the separation and deposition of CO_2. However, also the production of pure hydrogen from coal – including sequestration – would appear to be possible in the future at a relatively favorable price. According to the report of the US National Energy Technology Laboratory, on which the major American hydrogen study of 2004 is also based, hydrogen from cheap American coal should cost around 2.5 ¢/kWh, and in Europe, from imported coal, 3.4 ¢/kWh; this, however, refers to a future advanced technology. Syngas made with current technology would cost ca. 2 ¢/kWh in the USA, and in Europe, from imported coal, ca. 2.8 ¢/kWh; utilizing low-cost German lignite, it would cost only about 2 ¢/kWh, as in the USA. This gas would thus be cheaper in the USA and in Germany (from lignite) than the natural gas as a fuel for power plants (USA, Germany: 2.5 ¢/kWh in 2007); its cost corresponds to that of imported natural gas in Europe (2.0 ¢/kWh in 2007).

Both syngas as well as hydrogen are thus considerably cheaper than the cost of oil in the year 2008. If we take, for example, 100 $/barrel as a benchmark for the future increased crude oil price (in 2008-$), this corresponds (in 2002-$, the reference year used in this book) to 5.3 ¢/kWh. Given the low cost of gas from coal, the latter thus appears to offer an important alternative to oil and natural gas; indeed either using syngas as produced today, or in the future (with improved technology) using "CO_2-free" hydrogen. The barriers to development of this advanced technology will, however, not be negligible. This applies to the same extent also to coal power plants with integrated gasification and CO_2 sequestration, which are under lively discussion at present. (Syngas, the raw (desulfurized) product gas of coal gasification – a mixture of CO and H_2 – has similar technical characteristics to those of pure hydrogen. Both gases differ in these characteristics from natural gas, and therefore require conversion of consumer appliances, in particular of gas burners and meters.)

With the quantities of coal which will be consumed in power plants in the coming years if the current power-generating strategy utilizing coal-fired plants is continued (including the expected worldwide increased power consumption from coal-fired plants by the year 2030), and taking into account the amounts of coal required for backup power generation in the case of a theoretically complete and worldwide substitution of the coal-fired base-load power plants, a quantity of substitute gas equivalent to 3000 GWa could be produced. This is more than the total gas consumption at present (2900 GWa), and that is 60% of today's worldwide petroleum consumption. Starting from the *current* coal consumption, that is, without considering the expected strong increase in coal consumption for power generation, and including the natural gas from substituted gas-fired power plants, ca. 1200 GWa of gas could be produced or replaced; this corresponds to 55% of the natural gas consumption at present outside power plants, or 25% of the petroleum consumed. In the USA, it would correspond to ca. 65% of today's gas consumption (outside power plants) or ca. 30% of the petroleum consumed. In Europe, comparatively little coal is employed for electric power generation; the substituted quantities would, therefore, be smaller. The gas that could be produced from coal corresponds there to ca. 40% of the current natural gas consumption (outside power plants) or ca. 20% of the petroleum consumed. Worldwide, but also in the USA, the replaceable coal thus represents significant quantities in terms of the energy economy. This also holds for the corresponding contribution to the CO_2 emissions. Even without separation of the CO_2 (syngas), the CO_2 emissions would be reduced by the substitution of oil and natural gas; utilizing hydrogen (with CO_2 sequestration), they would be completely avoided.

Petroleum thus far represents the only alternative to imported natural gas. For this reason, the gas price is currently tied to the oil price. With the use of coal gas, however, the possibility would open up of producing a replacement gas in very large quantities. In price negotiations with gas exporters, this replacement gas would then represent a significant competitor to natural gas. The new gas would then define the upper limit for possible price demands. This presumes, as stated, that coal thus far used in power plants be substituted; only then could the new gas be manufactured in large quantities without a massive increase in coal production (and thereby even in the case of syngas without a major increase in the CO_2 emissions).

In principle, coal gasification *without* substitution of the coal used in power plants can be imagined. This, however, would require an increase in coal production. Such an expansion of coal mining would probably require a similar time as the deployment of solar energy plants. And this strategy would not be acceptable for the future, given the high coal consumption that it would entail. Because of the CO_2 problem, it would also force sequestration of the resulting CO_2, a technology which likewise is still to be developed. The power costs from CO_2-free coal-fired plants cannot be expected from today's standpoint to be lower (not even with future "advanced technology") than the cost of solar power. There is thus no economic motive for the deployment of such power plants. In terms of the price of coal, this strategy would probably also be risky: in view of the expected worldwide increase in power consumption (by 2030) and – without substitution of the coal-fired power plants – of the corresponding increase in coal demand, the coal price would certainly rise, leading to high costs in particular for coal-importing countries. Furthermore, it must be considered that the development of CO_2-free coal-fired power plants ("future technology") may require considerable time, even with an intensified development program, in any case longer than the development time for the technically simpler solar power plants.

If natural gas and coal-fired power plants are to be substituted, the only alternatives for the generation of base-load electric power on a large scale are solar and nuclear energy (with a smaller contribution from wind energy). Since nuclear technology offers no comparable possibility of large-scale, rapid deployment, a rapid response program must focus on solar thermal power plants.

4. Sun methanol production in the USA

Sun methanol is manufactured from equal parts (in terms of energy content) of solar hydrogen and coal gas. For the production of hydrogen using solar power, we assume here that an efficient high-temperature electrolysis process will be developed. With the cost of solar power quoted earlier and the resulting hydrogen price, and assuming the price of coal gas from current technology, we find for the USA a methanol cost of ca. 90 $/barrel of oil equivalent (2008-$); without the new electrolysis process, the cost would be around 100 $/barrel.

Sun methanol from the USA could replace the entire world consumption of oil. Once the technical preconditions for its production were fulfilled and a rapid build-up of the manufacturing capacity thus would be possible, one would no longer accept crude-oil prices higher than those of methanol. Most probably, the establishment of a relatively "limited" manufacturing capacity corresponding to ca. 10–20% of the world's petroleum production would suffice to provide an effective limit to the oil price.

The decisive point for price negotiations is the ability to make a believable threat of strongly increasing methanol production capacity should the negotiations fail to yield an agreement. The coal reserves represent a certain limitation to such a potential expansion of methanol production capacity. The USA has indeed large, but not unlimited reserves of low-cost coal. Without solar hydrogen, methanol production would require twice the amount of coal. (Even in this case, production with nearly no CO_2 emissions would be possible if the CO_2 produced were to be sequestered.) With a methanol production from coal alone corresponding to the worldwide annual consumption of oil, the low-cost coal reserves in the USA would be exhausted after only 20 years, so that the threat of oil substitution by the USA itself would not be convincing. In the case of sun methanol (utilizing solar hydrogen), the lifetime of the coal reserves would be 40 years. In terms of a methanol production rate (still very large) corresponding to only 40% of the world's petroleum consumption, the lifetime of the US coal reserves would be 50 years without solar hydrogen, and 100 years with solar hydrogen.

With a view to a conceivable methanol production using nuclear energy, we must consider the situation regarding uranium reserves – along with the fundamental questions raised by a large-scale expansion of nuclear power generation. In the case of a massive application of nuclear energy, electric power generation would have the first priority. To supply the future worldwide power demand, the uranium reserves, allowing for the acceptance of correspondingly higher uranium mining and extraction costs (given our present knowledge of low-cost reserves and a speculative estimate of those with higher extraction costs) would probably suffice for only *one* generation of power plants. The production of an additional, comparable amount of power for hydrogen manufacture would probably not be possible without resorting to very expensive uranium reserves. Their extraction would furthermore be accompanied by still greater environmental damage owing to the need to mine ever more ore with lower and lower uranium content. Just to meet future demands for electric power (and even utilizing future uranium-conserving technologies), annually ca. six times more uranium would be required than at present.

Near the end of the year 2008, the oil price again decreased. Since then, new hope has sprung up that the energy prices will remain at a moderate level for a certain time. That, however, does nothing to relieve the necessity of rapidly developing new energy systems. On the contrary, this renewed price decrease offers a chance to prepare for the future "emergency situation," which will occur sooner or later. This means not only the full technical development of solar power plants and the additional required technologies, but also – even though initially on a small scale – the substitution of gas and oil by the new energy carriers to provide a practical demonstration of this alternative.

In this book, all the variants of solar thermal technology are described. The main emphasis is, however, on the cost considerations relating to mass production, applied in particular to solar tower power plants, and to a lesser extent also to parabolic-trough and chimney plants. For each topic, still open questions and concrete research approaches are discussed.

With a view to the cost differences relative to other conceivable energy supply routes, we also treat the new CO_2-free coal-fired power plants as well as modern nuclear plants; in the case of the latter, in particular we discuss the costs to be expected under mass production. And to complete the discussion, we summarize the situation concerning uranium reserves. This book also contains information on coal gasification and methanol production. In the appendix, among other things, the relevant energy-statistical data (for the world, the USA, Europe, and Germany) are presented in a clear form. This book thus intends not only to provide the necessary knowledge for a comprehensive estimate of the economic outlook for solar thermal power plants and the related concrete developmental requirements and possible courses of action but also it provides the information needed to rank this new energy technology within the greater energy-political context. Thus, along with the specialized topics related to solar energy, the general question of the fastest possible conversion from oil to other, more secure future energy sources (and the associated costs) as a whole is discussed. In this connection, the most important elements of the necessary development program are described. The book thus sketches an overall plan for a rapid turnaround of the energy supply, beginning as soon as possible, and is therefore directed not only at readers interested in solar energy, but also at all those who are asking themselves what options are available in view of increasing oil prices and in the face of the increasingly pressing questions of environmental protection and climate change.

Table 4.2 Energy cost from the solar power system with CCGT or coal-fired backup power plants; cost of solar power at the plant and of solar hydrogen.

2002-US$	**Solar power plants**								
	Solar power system (solar plus backup power plants)						**Power at the plant**		**Solar H_2[d]**
	Spain			**Morocco/USA**			**Spain**	**Morocco/USA**	**Morocco/USA**
Backup Plants	**CCGT**	**Coal-fired "annex construction"**	**Coal-fired[c] "replacement"**	**CCGT**	**Coal-fired "annex construction" of plant capacity**	**Coal-fired[c] "replacement"**			
Investment (million $/GW)	5550	6175	5135	5555	6180	5140	3980	3700	5540
Capacity utilization (full load)	8760 h/a (solar 70%, backup 30%)			8760 h/a (solar 80%, backup 20%)			6130 h/a	7010 h/a	7010 h/a
	¢/kWh_{el}								¢/$kWh_{H_2(LHV)}$
Capital costs (4% real interest, 45 a)[a]	3.1	3.4	2.8	3.1	3.4	2.8	3.2	2.6	3.8
(Capital costs at 2% real interest)[a]	(2.2)	(2.4)	(2.0)	2.2	(2.4)	(2.0)	(2.2)	(1.8)	(2.7)
Operation and maintenance:									
Solar plants	0.7	0.7	0.7	0.7	0.7	0.7	0.9	0.7	0.9
Backup plants	0.1	0.4	0.4	0.1	0.4	0.4	–	–	–
Gas (2.5 ¢/kWh_{gas})[b]	1.3	–	–	0.8	–	–	–	–	–
Coal price[b]	–	EU 90 $/t			EU 90 $/t USA 45 $/t	EU 90 $/t USA 45 $/t			

Table 4.2 *Continued.*

2002-US$	Solar power plants											
	Solar power system (solar plus backup power plants)									Power at the plant		Solar H_2[d]
	Spain			Morocco/USA						Spain	Morocco/USA	Morocco/USA
Backup Plants	CCGT	Coal-fired "annex construction"	Coal-fired[c] "replacement"	CCGT	Coal-fired "annex construction" of plant capacity		Coal-fired[c] "replacement"					
Coal	–	0.8	0.8	–	0.5	0.25	0.5	0.25		–	–	–
Energy cost at 4% real interest	5.2	5.3	4.8	4.7	5.0	4.7	4.4	4.1		4.1	3.3	4.7
(Energy cost at 2% real interest)	(4.3)	(4.3)	(4.0)	(3.8)	(4.0)	(3.7)	(3.6)	(3.3)		(3.1)	(2.5)	(3.6)

a) Annuity factor for 45a and 4% real interest: 4.8%; at 2% real interest: 3.4%.

b) Fuel costs:

- Price of natural gas assumed (in 2002-$): 2.5 US-¢/$kWh_{gas}$ (LHV) = 40 $/barrel oil = 6.6 $/MMBTU (HHV). (Compare: 2.5 US-¢/kWh corresponds in Europe – calculated with a purchasing power parity of $1 = 0.96 € – to 2.40 €-cent/kWh).

  Corresponds in 2007-US$ (×1.152): 2.88 ¢/kWh_{gas} (LHV) = 46 $/barrel oil = 7.6 $/MMBTU (HHV) (in Europe (×1.084): 2.60 €-cents/kWh).

  Note: The gas price assumed corresponds at the current monetary value (2007-US$) rounded off to 3 US-¢/kWh (LHV) or 45 $/barrel oil.

  Note also: In the case of increasing natural gas prices, the backup power plants for the solar power system can be supplied with gas from coal gasification. For large-scale users with a separate gas pipeline, this gas, including transport costs, can be obtained for roughly the same price assumed here for natural gas, 2.5 ¢/kWh (2002-US$); see Table 4.3: Production cost of syngas from German lignite ca. 1.8 US-¢/kWh; from US coal ca. 1.9 ¢/kWh (for more information cf. Section 11.2).

Table 4.3 Energy cost from conventional power plants, cost of nuclear hydrogen, of gas from coal gasification and of crude oil at 100 $/barrel.

2002-$	**Fossil-fuel base-load plants**					**Nuclear power plants**			
	CCGT	**Coal-fired steam plants**		**Coal-fired IGCC advanced technology**[c]		**Nuclear (EPR)**	**Nuclear**	**Nuclear Pools**[f]	**Nuclear H_2**[g]
				With CO_2-capture		**Today**[d]	**Large scale scenario (US nuclear plants)**[e]		
	Electricity								**H_2**
Investment (million $/GW)	615	1200		2120		2000	1100	1890	1950
Efficiency (LHV)	60%	45%		43%					
Capacity utilization	8000 h/a								
	¢/kWh_{el}								¢/kWh_{H_2}
Capital cost (4% real interest, 45a)[a]	0.3	0.7		1.3		1.2	0.7	1.2	1.2
(Capital cost at 2% real interest)[a]	(0.2)	(0.5)		(0.9)		(0.85)	(0.5)	(0.8)	(0.85)
Operating and maintenance costs	0.3	0.7		0.8		1.2	1.0	1.0	1.2
Gas (2.5 ¢/kWh_{gas})[b]	4.1								
Coal price[b]		EU 90 $/t	USA 45 $/t	EU 90 $/t	USA 45 $/t				
Coal		2.5	1.3	2.6	1.3				
Fuel cycle[b]						0.4	0.5	0.5	0.6
Natural uranium (130 $/kg)[b]						0.35	0.2	0.2	0.2
Electricity or gas cost (4% real interest)	4.8	3.9	2.7	4.7	3.4	3.1	2.4	2.9	3.2
(Electricity or gas cost at 2% real interest)	(4.7)	(3.7)	(2.5)	(4.3)	(3.0)	(2.8)	(2.2)	(2.55)	(2.85)
plus cost of storing the CO_2 (10 $/t CO_2)[k]				0.8	0.8				
including CO_2 storage (at 4% real interest)				5.5	4.2				

Gasification of coal[h]								**Oil**[i]
Syngas (conventional technology)		**H_2 (1) (conventional technology)**		**H_2 (2) (conventional technology)**		**H_2 (3) (advanced technology)**		**at 100 $/b (2008-$) = 84.4 $/b 2002-$**
without CO_2-capture		**without CO_2-capture (option 50%)**		**with CO_2-capture**		**with CO_2-capture**		
Syngas		**H_2**						**Oil**
		920		1150		880		
ca. 60–65%		54%		50%		64%		
¢/kWh$_{gas(LHV)}$		¢/kWh$_{H_2(LHV)}$						¢/kWh$_{oil}$
		0.75		0.90		0.70		
		(0.60)		(0.75)		(0.60)		
		0.60		0.70		0.45		
EU 90 $/t	USA 45 $/t	EU 90 $/t	USA 45 $/t	EU 90 $/t	USA 45 $/t	EU 90 $/t	USA 45 $/t	
		2.05	1.0	2.20	1.10	1.75	0.85	
ca.2.8 (Lign[j] ca.1.8)	ca.1.9	3.4 (Lign[j] 2.1)	2.4	3.8	2.7	2.9	2.0	6.3 (2008) 5.3 (2002)[i]
		(3.2)	(2.2)	(3.7)	(2.6)	(2.8)	(1.9)	
–	–	–	–	0.7	0.7	0.5	0.5	
				4.5	3.4	3.4	2.5	