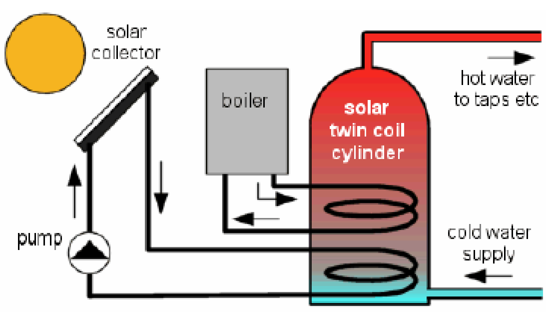
The potential for solar power in the UK derives from two main systems, solar thermal systems to provide domestic water heating (DWH) and photovoltaic electricity generation (Figure 1 a, b). Solar energy could be a relatively substantial contributor supplying energy to the domestic and industrial sectors. Consequently there would be a displacement of energy derived from more traditional supply sources, like gas and electricity provided by the national grid (Stainforth *et al*. 1996), and the UK would be striving further to meet the 10% renewable energy target for 2010, set by the government under the Renewables Obligation. These analyses consider the domestic sector provisions of solar energy from the aforementioned rooftop systems, but not passive solar energy. Passive solar energy contributions were excluded from the analyses because without substantial alterations to the current housing stock, which is extremely impractical, and to future house design, passive solar energy is not expected to contribute significantly more energy by 2030.

This report outlines projections for the potential supply of solar energy in the UK up to 2030 before proceeding to consider the energy payback times (EPBT) and cost payback times (CPBT). Considering these factors simultaneously will provide a greater insight into the realistic potential of solar energy and the techniques required to promote its uptake.

a).



b).

Figure 1: The solar systems available in the UK; a). Solar thermal, b). photovoltaics

Energy projections: 2010-2030

These projections consider the potential energy supply from the domestic sector by studying the possible contributions that could be made from the current house stock by retrofitting solar thermal and PV systems onto rooftops and from integrating them in new house design. In calculating these projections many assumptions were made about the roof areas available for development, energy outputs and installation rates. The current house stock is about 25 million (ODPM, 2005a) and it was assumed that 10 million of those homes would be suitable for solar installations. Figures from the Office of the Deputy Prime Minister (2005b) indicate that the average rate of completed new houses since 2000 is about 180,000 a year. For the purpose of calculating the potential supply of solar energy from these houses it was assumed that half of these properties would be suitable.

When considering retrofitted thermal and PV systems, realistic installation rates were estimated (Table 1) and used to project the consequent additional output availability. Installation rates for retrofitting systems were initially assumed to be the same as for new homes, therefore 90,000 per year, but were increased throughout the period rates to take into account presumed developments in the industry (Table 1). The installation rate is limiting on the amount of energy that could be provided by thermal and PV systems. Currently the solar industry in the UK is relatively small, so a workforce of installers would need to be trained up to increase the rate of installation. This means that there is a great potential for developments in the manufacturing business.

Table 1: Estimated installation rates of solar systems

	Installation rate (per year)
2005-10	90, 000
2010-15	110, 000
2015-20	160, 000
2020-25	250, 000
2025-30	400, 000

Projections for each type of solar system (thermal/PV) were based upon different assumptions when considering array sizes and energy outputs, therefore this report will show the analyses separately.

Solar Thermal Systems

The assumptions made for the outputs of these systems were that each suitable house would have 3 sq meters of thermal panels with an output of 350 kWh/m^2/year providing a total output per house of 1050 kWh/year. The output figure was derived from data collected by Dr N.K. Tovey, a participant in the Broadsol Project, Norwich, for the installation on his house over a whole year. This gives a more realistic output that the 500kWh/m^2/year stated by the manufacturer (Broadsol, 2003). The projections made for solar thermal contributions assume that the outputs from these systems remains constant over the period, because unlike the PV industry there does not seem to have been much recent technological progression that could significantly enhance system performance.

The number of installations was multiplied by the system outputs per house to project the potential energy supplies for 5 year intervals (Table 2). It was calculated that an additional 1.7 PJ of energy could be provided by solar thermal systems on new houses in each interval leading to 8.5 PJ in total by 2030 by which time a further 19 PJ could be provided by retrofitted systems.

Table 2: Cumulative projections for solar thermal energy supply, 2010-2030, (not including energy contributions from currently operational systems).

By…	**New Houses (PJ)**	**Retrofitted Systems (PJ)**
2010	1.7	1.7
2015	3.4	3.8
2020	5.1	6.8
2025	6.8	11.5
2030	8.5	19.1

The current level of energy provided by solar thermal systems (based on 2003 figures) is ~0.83PJ (DTI, 2004). This figure will be included in the overall projected contributions for solar thermal energy. In the UK currently about 100,000 systems are in operation, with ~10,000 being installed a year (DTI, 2005). Although a small market for solar thermal technology has been established in the UK, it needs to be expanded substantially to provide the energy contributions projected in this report.

PV

A similar procedure was used to calculate the possible electricity supply that could be generated by PV roof installations on domestic properties, but a subtle difference between these projections and those made for solar thermal energy was taken into consideration. This difference is that research and development (R&D) in the PV industry is continually leading to increasing energy outputs (Alsema & Nieuwlaar, 2000), whereas R&D in the solar thermal industry seems relatively static in comparison. The PV analyses assumed that outputs will double over the next 25 years (Table 3) to take technological advances of component parts and manufacturing procedures into consideration.

Table 3: Projected outputs from PV cells (m^{-2}) 2010-2030

	Output (kWh/m^2/yr)
2005-10	100
2010-15	120
2015-20	150
2020-25	180
2025-30	200

To project the potential energy supply differences in the area of PV arrays that could be installed were also taken into consideration. It was assumed that 15sq m would be installed on new homes, whereas retrofitted installations would cover an area of 12sq m. These differences in area take into account the roof structures of the properties because new homes could integrate the system into the design at the construction stage and therefore the optimal area could be achieved, but on older properties the existing roof structure may constrain the area available. Obviously the roof areas available will vary, but these values were taken to be the average areas that could be occupied by the new style of PV cells like solar roof tiles that are compact and designed to fit onto UK roof battens to try and maximize the utilised area (Solar Century, 2005). The same installation rates were assumed for PV as for solar thermal systems. These assumptions project that by 2030 new homes could provide about 18 PJ of energy and retrofitted homes 37 PJ (Table 4).

Table 4: Cumulative projections for PV electricity supply 2010-2030

By…	**New Houses (PJ)**	**Retrofitted Systems (PJ)**
2010	2.4	1.9
2015	5.3	4.8
2020	9.0	10.0
2025	13.4	19.7
2030	18.2	37.0

The current PV energy contribution in the UK is ~0.01PJ (DTI, 2004), which is extremely low, therefore energy projections were based upon a current level of 0PJ.

Overall solar energy contribution

The projections show a steadily accelerating energy contribution that could be made from solar energy over the period 2010-2030 (Table 5, Figure 2), which looks very promising as long as the measures can be successfully implemented. The overall potential energy supply by 2030 from the two solar systems considered in these analyses is 83.6 PJ.

Table 5: Total energy projections for the two types of solar system (PJ)

	Solar Thermal	PV	Total (PJ)
2005	0.8	0	0.8
2010	4.2	4.3	8.5
2015	8.0	10.1	18.1
2020	12.7	19.0	31.7
2025	19.1	33.1	52.2
2030	28.4	55.2	83.6

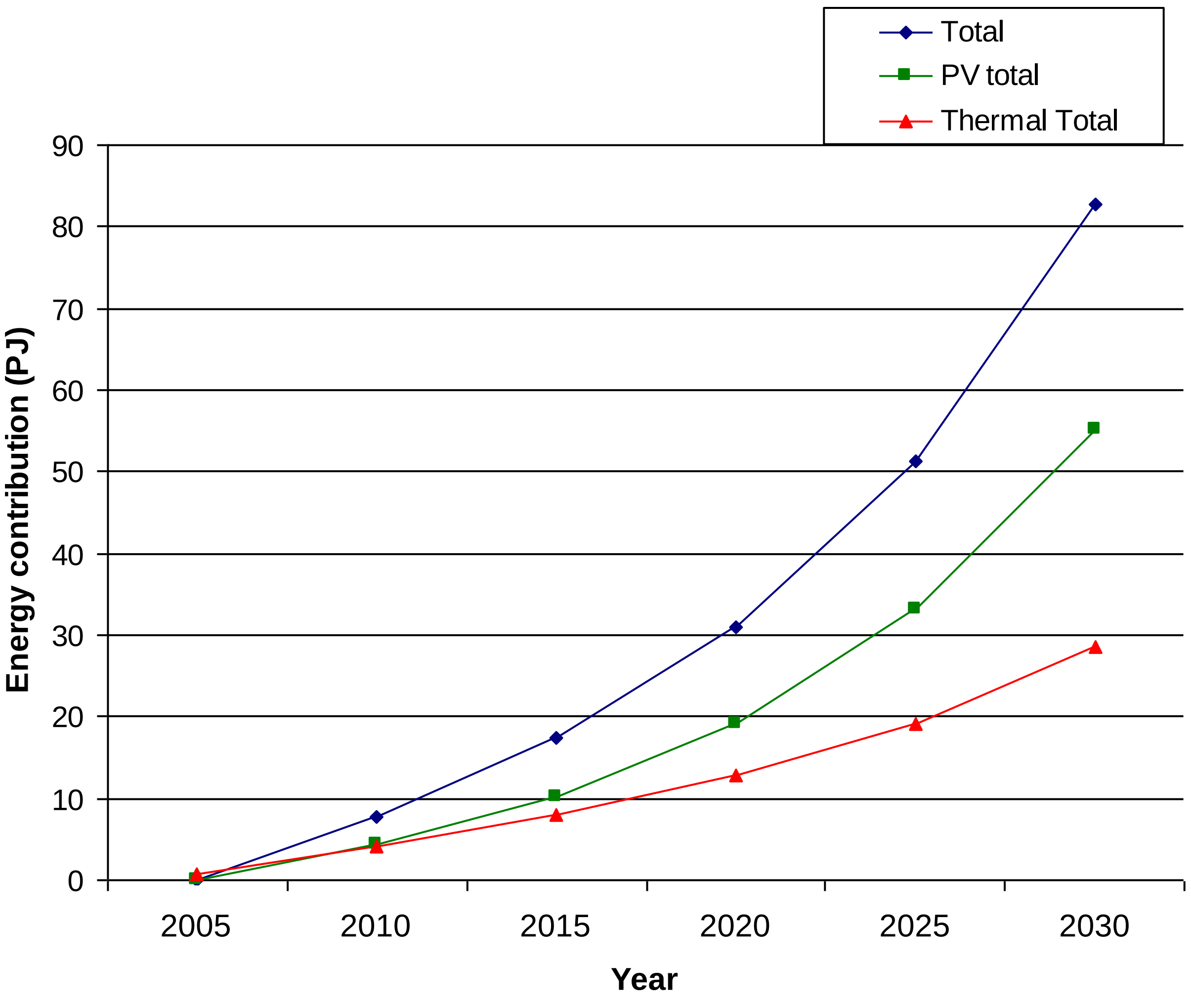


Figure 2: Solar technology projections for the UK, 2005-2030.

Energy Payback Times

The time that it takes for the systems to payback the manufacturing energy inputs is an increasingly important consideration to make as issues of sustainability are becoming more widely acknowledged concepts. EPBT's seem relatively reasonable in comparison to their lifetimes of between 20-30 years in contrast to the CPBT (excluding subsidisations), especially for PV installations. Currently the EPBT for solar thermal systems is about 2.8 years, whereas PV systems take longer (about 14 years).

The manufacturing energy inputs into solar thermal systems is not expected to have changed greatly in recent years because components mainly consist of mass produced copper, steel and glass parts. Chapman (1975) calculated that for a $40m^2$ roof 39, 000 kWh of energy was required to produce the various materials and component parts, the energy used by equipment and installation energy inputs. This figure was scaled down, and it was calculated that for a 3 sq m array 2925 kWh would be required. The solar panel array would presumably produce the equivalent of 1050 kWh/year to heat water and therefore an EPBT of 2.8 years is derived. This estimate is possibly slightly overestimated because there may now be greater efficiencies in production.

The EPBT for PV solar cells is considerably longer than for solar thermal systems mainly because of the high energy inputs required for silicon purification and the production of the silicon wafers (Alsema & Nieuwlaar, 2000). However, Alsema and Nieuwlaar (2000) have projected substantial energy savings over the next 15 years. The analysis presented here has assumed that over the next 15 years the energy inputs into PV installations would fall from ~5000 MJ/m^2 to 2500 MJ/m^2 (not quite as optimistic as Alsema and Nieuwlaar's estimate of 2600 MJ/m^2 by 2020). Even accounting for the possible underestimation in production improvements it suggests that an EPBT of 3½ years could be possible by 2030.

Table 6: Projected EPBT's for PV cells 2010-30

	Energy for production ($MJ/m^2/yr$)	**Energy Payback Time (Years)**
2005-10	5000	14
2010-15	4000	9.0
2015-20	3500	6.5
2020-25	3000	4.5
2025-30	2500	3.5

Cost Payback Times

The cost payback times look a lot more unfavourable than the energy payback times, especially for PV systems, when no subsidisation is taken into account. Each type of system is considered separately.

Solar thermal systems

In 2004 Boyle stated that PV systems cost about £1000 m^{-2}, whereas solar thermal systems range from £1000 for a DIY job or new house installation up to £6000 for a professionally installed, retrofitted solar thermal system. The analyses carried out assumed that solar thermal systems in new houses cost £1000 between 2005 and 2010 and the energy output of the system to be 1050 kWh/year. The solar energy was assumed to be displacing 80% gas and 20% electricity. The prices of gas and electricity used in the calculations were £0.02 and £0.07 respectively, based on the average UK fuel prices of 2002 (Boyle, 2004). It was calculated that solar energy output per house was equivalent to £31.50 in a year, indicating a payback time of about 32 years for a £1000 system (Appendix A). A subsidy of about £200-250 per house could reduce this time to about 24-25 years making it more of a feasible option. However, a statutory regulation to integrate solar technologies wherever suitable on new properties may reduce subsidisation contributions due to bulk purchasing.

Additional costs are incurred by retrofitted systems and consequently payback times will be longer, they could easily double. Overall costs may be saved if both solar thermal and PV installations occur simultaneously because it should mean less overall labour costs and overheads. Substantial subsidies would be needed to a much greater extent to provide incentives for these systems to be implemented in our society (Appendix A). If a retrofitted system was to cost £3000, a subsidy of at least £2250 (75%) would be required to make it financially beneficial to the household.

PV systems

PV systems are still very expensive capital investments, with the majority of the costs building up in the production of the silicon cells themselves. Due to the developing technology and manufacturing procedures as well as increased production the calculations for CPBT's have been based upon assumptions of price reductions from £900-£550 per m^2 over the next 25 years. Without subsidisation, the current cost payback time 128 years (2002 electricity prices), reducing to 40 years in new homes by 2030 (similar timescales for retrofitted systems). The CPBT's calculated for retrofitted systems included an £800 surcharge to cover additional costs that will be incurred by having to work on an older building (eg. Scaffolding costs and extra maintenance work). This charge was not included onto retrofitted thermal system CPBT because it was assumed that both types of system would be installed simultaneously.

To meet the installation level targets of what could be implemented in this time period a substantial amount of subsidy will need to be provided to encourage people to invest in this technology. Initial subsidy levels need to be high, possibly 70-80% between 2005-15 due to the current low electricity prices, but these levels could drop to below 10% by 2025 if the price of electricity is going to increase (to £0.15 kWh^{-1}) (Appendix B), as many people predict due to the availability and viability of burning fossil fuels.

Table 7: Assumed prices of PV cells (per m^2) 2010-2030

	Price (m^{-2})
2005-10	900
2010-15	750
2015-20	650
2020-25	600
2025-30	550

Presuming an increase in electricity prices from 7p/kWh from 2005-15, to 10p/kWh from 2015-25 and 15p/kWh from 2025-30 the levels of subsidy required, to make PV systems financially worthwhile investments, will decrease. Based on these assumptions (decreased module prices and increased electricity prices) ideal subsidy levels could drop from 80% to less than 5% over the next 25 years.

The UK government currently subsidises solar technologies under the Clear Skies scheme (solar thermal) and the Major Photovoltaics Demonstration Programme (PV). Subsidy levels are currently £400 per solar thermal system (Guthrie, 2004) and up to 50% grants for PV systems (EST, 2005), but many systems may not be cost effective from a financial prospective.

Conclusions:

Solar energy is a potentially very valuable contributor of energy in the UK. About 35% of the hot water heating demand could be supplied by solar thermal systems and an increasing proportion of domestic electricity demand being met by PV systems, if schemes are successfully implemented to meet the projected levels. However, to implement these schemes a substantial amount of government support, most likely through subsidisation, will be necessary especially for retrofitting schemes, to encourage investment.

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Appendix A: Cost payback times for solar thermal systems across the range of possible total installation costs.

Cost of system (£)	Payback time (Years)
6000	190
5000	159
4000	127
3000	95
2000	63
1000	32
900	29
800	25
750	24
700	22
650	21
600	19
550	17
500	16
450	14

Appendix B: PV systems, at each equivalent assumed electricity price i). 7p/Kwh, ii). 10p/kWh, iii). 15p/kWh, results of the calculations of the costs of systems at each subsidisation level (%) are presented.

i). Electricity = 7p/kWh

NEW HOMES 7p/kWh 15m2 PV

					Subsidy Level- years for payback			
	£ per house	**En produced/m2_kWh**	**Electricity costs saved (£)**	**Years payback**	**80%**	**70%**	**60%**	**50%**
2005-2010	13500	1500	105	128.6	25.7	38.6	51.4	64.3
2010-2015	11250	1800	126	89.3	17.9	26.8	35.7	44.6
2015-2020	9750	2250	157.5	61.9	12.4	18.6	24.8	31.0
2020-2025	9000	2700	189	47.6	9.5	14.3	19.0	23.8
2025-2030	8250	3000	210	39.3	7.9	11.8	15.7	19.6

RETROFITTING PV 7p/kWh 12m2 PV_+standard £800 fitting charge in all years

					Subsidy Level- years for payback			
	£ per house	**En produced/m2_kWh**	**Electricity costs saved (£)**	**Years payback**	**80%**	**70%**	**60%**	**50%**
2005-2010	11600	1200	84	138.1	27.6	41.4	55.2	69.0
2010-2015	9800	1440	100.8	97.2	19.4	29.2	38.9	48.6
2015-2020	8600	1800	126	68.3	13.7	20.5	27.3	34.1
2020-2025	8000	2160	151.2	52.9	10.6	15.9	21.2	26.5
2025-2030	7400	2400	168	44.0	8.8	13.2	17.6	22.0

Appendix B.

ii).

Electricity = 10p/kWh

NEW HOMES 10p/kWh 15m2 PV

					Subsidy Level (%)- years for payback								
	£ per house	**En produced/m2 kWh**	**Electricity costs saved (£)**	**Payback time (Years)**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**5**
2005-2010	13500	1500	150	90.0	18.0	27.0	36.0	45.0	54.0	63.0	72.0	81.0	85.5
2010-2015	11250	1800	180	62.5	12.5	18.8	25.0	31.3	37.5	43.8	50.0	56.3	59.4
2015-2020	9750	2250	225	43.3	8.7	13.0	17.3	21.7	26.0	30.3	34.7	39.0	41.2
2020-2025	9000	2700	270	33.3	6.7	10.0	13.3	16.7	20.0	23.3	26.7	30.0	31.7
2025-2030	8250	3000	300	27.5	5.5	8.3	11.0	13.8	16.5	19.3	22.0	24.8	26.1

RETROFITTING PV 10p/kWh 12m2 PV_+standard £800 fitting charge in all years

					Subsidy Level (%)- years for payback								
	£ per house	**En produced/m2 kWh**	**Electricity costs saved (£)**	**Payback time (Years)**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**5**
2005-2010	11600	1200	120	96.7	19.3	29.0	38.7	48.3	58.0	67.7	77.3	87.0	91.8
2010-2015	9800	1440	144	68.1	13.6	20.4	27.2	34.0	40.8	47.6	54.4	61.3	64.7
2015-2020	8600	1800	180	47.8	9.6	14.3	19.1	23.9	28.7	33.4	38.2	43.0	45.4
2020-2025	8000	2160	216	37.0	7.4	11.1	14.8	18.5	22.2	25.9	29.6	33.3	35.2
2025-2030	7400	2400	240	30.8	6.2	9.3	12.3	15.4	18.5	21.6	24.7	27.8	29.3

Appendix B

iii).

Electricity = 15p/kWh

NEW HOMES 15p/kWh 15m2 PV

					Subsidy Level (%)- years for payback								
	£ per house	**En produced/m2 kWh**	**Electricity costs saved (£)**	**Payback time (Years)**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**5**
2005-2010	13500	1500	225	60.0	12.0	18.0	24.0	30.0	36.0	42.0	48.0	54.0	57.0
2010-2015	11250	1800	270	41.7	8.3	12.5	16.7	20.8	25.0	29.2	33.3	37.5	39.6
2015-2020	9750	2250	337.5	28.9	5.8	8.7	11.6	14.4	17.3	20.2	23.1	26.0	27.4
2020-2025	9000	2700	405	22.2	4.4	6.7	8.9	11.1	13.3	15.6	17.8	20.0	21.1
2025-2030	8250	3000	450	18.3	3.7	5.5	7.3	9.2	11.0	12.8	14.7	16.5	17.4

RETROFITTING PV 15p/kWh 12m2 PV_+standard £800 fitting charge in all years

					Subsidy Level (%)- years for payback								
	£ per house	**En produced/m2 kWh**	**Electricity costs saved (£)**	**Payback time (Years)**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**5**
2005-2010	11600	1200	180	64.4	12.9	19.3	25.8	32.2	38.7	45.1	51.6	58.0	61.2
2010-2015	9800	1440	216	45.4	9.1	13.6	18.1	22.7	27.2	31.8	36.3	40.8	43.1
2015-2020	8600	1800	270	31.9	6.4	9.6	12.7	15.9	19.1	22.3	25.5	28.7	30.3
2020-2025	8000	2160	324	24.7	4.9	7.4	9.9	12.3	14.8	17.3	19.8	22.2	23.5
2025-2030	7400	2400	360	20.6	4.1	6.2	8.2	10.3	12.3	14.4	16.4	18.5	19.5