5 The ERJ Supply Models

Area: about 373,000 sqkm
residential area: approx. 5 %
Agricultural area: approx. 14 %
Woodland: approx. 67 %

Population: approx. 127 million; on average 338 inhabitants per sqkm
Most populated: Kanto district, approx. 46 milion
Capital: Tokyo, 577 sqkm, approx 8.5 Mill. inhabitants

Figure 18 : Map of Japan

Any energy supply system must guarantee sufficient production and distribution of electricity, heat and fuels to meet the demand for energy at any time throughout the year, usually using different energy conversion technologies. The ERJ Supply Models use renewable energy sources, incorporating a wide variety of renewable energy technologies in order to supply the energy needs described in the ERJ Demand Model.

Energy is supplied in the form of electricity, heat or fuels. Heat and fuels have the advantage that they can be stored for later use and can be easily transported. So it is not necessary to consume heat and fuels immediately or in the place they were produced. Heat can be stored in thermal reservoirs and distributed via district heating networks. Both heat and fuels dissipate with time, which sets a limit to storage time and distribution distance. As for fuels from biomass or hydrogen, there is no limitation in storage time or in transport (depending on the fuel type - solid, liquid or gaseous) but storage losses must be considered.

The situation is completely different with electricity. The necessity of producing enough electricity, on demand and on time, makes this type of energy the most critical component in an energy supply system. While electrical transport via the public grid is quite unproblematic, storing electricity directly on a large scale is material- and cost- intensive. However, storage in batteries and accumulators can involve the use of toxic substances. Therefore this option is not considered here as it is not appropriate for a sustainable energy supply system. Indirect storage is used in the study by utilising hydrogen and pumped storage.

An energy supply system which is based solely on renewable sources increases the focus on timely energy provision due to the fluctuating nature of some renewable energy sources, such as solar and wind. Including such fluctuating sources into the public electricity supply means that the proportion of electricity produced by those sources might decrease suddenly. Of course electricity production from fluctuating sources can be estimated by weather forecasting but a portion of uncertainty still remains. Fortunately, there are other renewable technologies with the ability to deliver energy on demand; hydropower and geothermal power plants give direct access to renewable sources, cogeneration and other energy sources can use fuel from renewable sources (e.g. hydrogen or biomass).

5.1) Designing the Supply Model

The challenge in designing a reliable fully renewable energy system was to find a combination of technologies where the pros of some types balanced out the cons of the others. A reserve capacity is necessary as a backup for fluctuating sources, especially in the electrical system. This capacity can be minimised by designing a combination of renewable technologies where fluctuations in production match a varying demand, such that any fluctuations in supply never lead to electrical production that cannot meet the demand.

The focus in designing the ERJ Supply Models was therefore on the electrical subsystem, as this is the most (time) critical component of supply. The electrical supply model was designed to deliver electricity throughout the year using domestic Japanese energy sources as much as possible. The heat and fuels supplying system was then designed. Finally, variations on Scenario One were presented.

The supply of electricity, heat and fuels is described here in more detail:

5.1.1) Electricity

Sources capable of constantly producing electrical energy are most suitable for supplying the base load (the amount of energy that is always needed). Fluctuating sources can contribute to the peak load, but have to be supported by fast reacting power plants due to the uncertainty of energy production. Cogeneration plants are included as a highly efficient energy technology. Cogeneration plants use fuels to produce heat and electricity at the same time and with high efficiency. The capacity of cogeneration plants ranges from small units (CHP), capable of covering the heat demand of single households or small companies, to large plants that contribute to heat and electricity supply in industry. The mode of operation can be set according to the primary demand. If, for example, heat is most important, the production rate is determined by heat demand while the simultaneously produced electricity contributes to public electricity supply.

A reliable electrical supply system will sometimes produce more energy than is required. This is unavoidable due to the inclusion of renewable sources that might deliver much energy during times of low demand. These surpluses do not have to be lost however; they can be used to produce fuels such as hydrogen that can contribute to energy supply on time and in the form required by that sector.

The best possible combination of renewable sources, regarding electricity production and reliability, was determined by optimising the supply model using a computer simulation model. This model calculated and optimised the supply to meet the electricity demand. The optimisation process calculated installation based on the highest possible production of electricity from regional renewable sources while maintaining the rules of sustainability. Actual weather data from more than 150 weather stations in Japan was used in the simulation and the country divided into 12 regions in order to achieve a system, which was adapted to Japan's climate and geographical conditions for each technology.

The optimisation process used a bottom-up approach described as follows:

After defining an initial energy supply system, the simulation calculated the electricity production and compared the results to the demand. To prove the system's reliability in supply, electrical production and electrical demand had to be calculated and compared at short intervals. In the simulation this was achieved by calculating the electrical production over periods of a quarter of an hour and a 15-minute time-resolved electrical demand model (for details, refer to the chapter on simulation). The supply system was revised if any supply shortages were detected. This process was repeated until the mixture of technologies and locations of installation met the demand without shortages of electricity.

In Scenarios Two to Six, additional electricity producers were included to produce hydrogen using domestic sources, as Scenario One already covered all the required electricity.

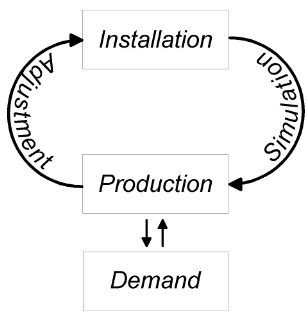


Figure 19 : The optimisation of installed capacities in the ERJ Supply Model

There is no demand management implemented in the supply models. The concept of demand management is to avoid peak loads in the supply system. This can be obtained by shifting a part of electricity consumption to times with generally low demand. While some electric appliances, such as refrigerators can be shut down for a while (modern refrigerators stay cool for hours without electricity), the operation of others can be delayed until the demand falls below critical levels. Demand management was excluded to keep the model's approach conservative and credible.

5.1.2) Heat

The limitations in transporting heat necessitate that any generated heat has to be consumed locally, that is near to the production plant. The heat supply structure reflects this fact, as consumers themselves also produce heat. The ERJ Supply Models keep the focus on the self-sufficiency of consumers but switch heat generation from fossil fuels to renewable sources. Therefore the ERJ Supply Models use cogeneration plants and solar-thermal collectors in the industrial, commercial and residential sectors.

Similar to fluctuating sources in electrical supply, the production rate of heat from solar-thermal collectors cannot be foreseen in terms of how much energy will be produced. Heat produced by solar-thermal systems has to be used immediately and sometimes heat production will far exceed heat demand. This is the point where heat storage becomes important. Heat can be stored for a long period of time, so it is not necessary to consume heat at the time it is produced. Of course the storage of heat is affected by storage loss, but it is even possible to store heat for several months with an acceptable loss in temperature and with acceptable prices. In the commercial and residential sector, this so-called long-term heat storage makes heat that is produced in summer available for use in autumn or even in winter, thus giving the opportunity of supplying a high share of heat demand from solar energy. Short-term and mid-term storage, capable of storing heat for periods up to one week or one month, can guarantee sufficient heat supply to buildings during times of bad weather conditions.

The main use for heat in the commercial and residential sectors is for warm water and heating. Solar collectors or small cogeneration systems (CHP) based on motors or fuel cells can easily produce the required temperatures. In the ERJ Supply Models these systems are combined in district heating networks with decentralised short-term heat storage and centralised mid-term to long-term heat storage. This approach increases system efficiency and minimises system costs.

Many processes in industry require heat at a temperature level above 150°C (high temperature heat). Producing heat at this temperature from solar energy would require systems that concentrate solar radiation. Such systems are expensive and not efficient under Japanese climate conditions. Therefore Scenario One only utilises cogeneration systems using steam turbines and heating plants for the production of high temperature heat. Both types of plants use fuels from renewable sources.

Low temperature heat (below 150°C) is sufficient for many applications in the industrial sector, such as hot water, heating and some industrial processes. In the ERJ Supply Model non-concentrating solar-thermal systems and motor-based cogeneration plants produce this heat.

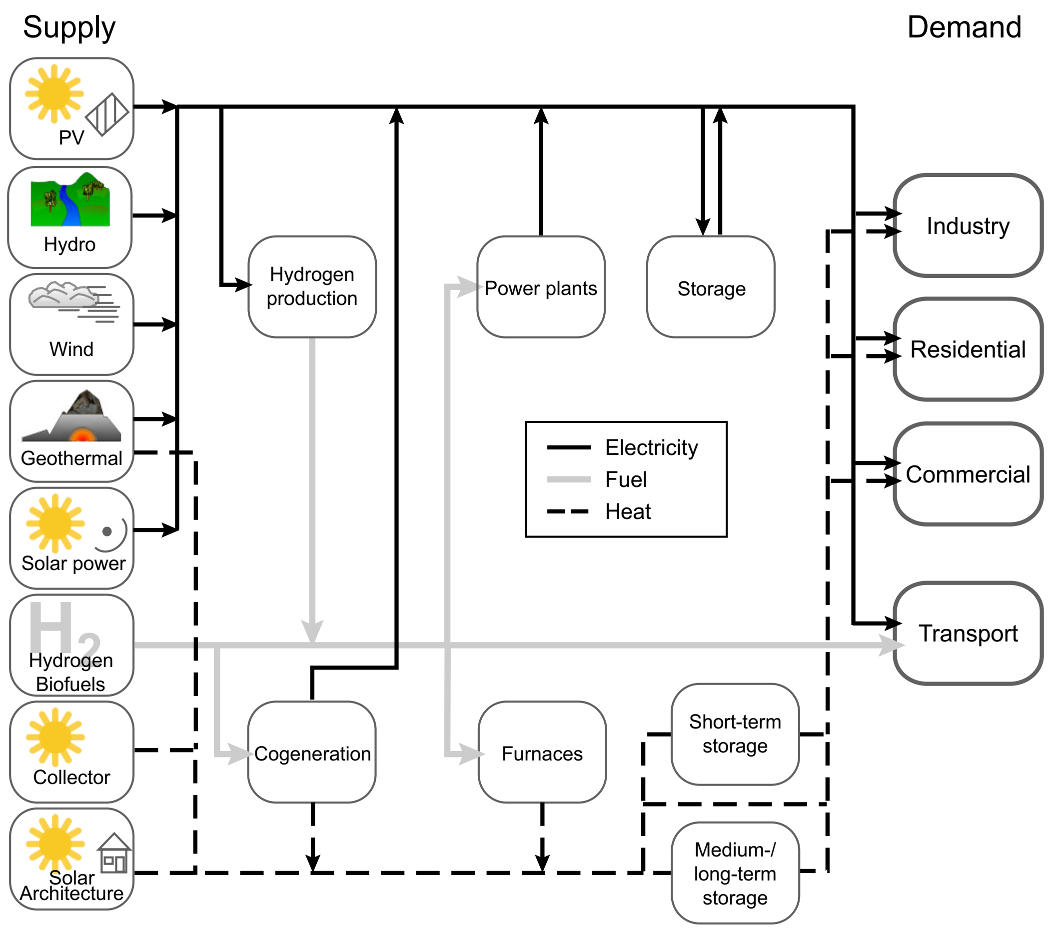
Cogeneration plants in industry are operated in two different modes. If electricity is most important for fabrication, the cogeneration plants are controlled to meet electricity demand, while the simultaneously produced heat can contribute to the heat demand. This mode of operation makes short-term heat storage necessary. The greatest demand for electricity and heat does not always occur simultaneously. Short-term heat storage can be used to make heat consumption independent of heat production in terms of time. Surpluses in heat production can be distributed via district heating networks to supply other industrial processes or buildings close to the site. If the demand for heat is vital for production, cogeneration plants are operated to produce the heat needed. Simultaneously produced electricity can contribute to the public supply if not needed for fabrication.

5.1.3) Fuels

The ERJ Supply Models consider fuels in all sectors although only the transport sector is strictly dependent on fuels. While the fuel demand in the transport sector is taken from the ERJ Demand Model, fuel consumption in the other sectors depends on the installed capacities and utilisation ratio of fuel consuming technologies in the ERJ Supply Models, for example cogeneration plants. The amount of fuel required was calculated by simulation.

Besides consuming fuels, the system itself produces fuels such as hydrogen by utilising surplus electricity from the supply system, and substitutes fuels that conventional systems need for warm water and heating by using heat from solar-thermal supplies. This approach has two major benefits: surpluses in electrical supply are not lost and the amount of fuels that must be applied from external sources is minimised.

The remaining demand for fuels (calculated as the total fuel demand, minus fuels substituted by solar-thermal systems and the system's hydrogen production) has to be covered by hydrogen or fuels from sustainably produced biomass. The amount quoted in the ERJ Supply Models represents the amount of hydrogen that is not covered by domestic sources in the different designs of the system. More fuels can be covered by sustainably produced domestic biomass, but the exact amount of biomass available in Japan was unknown at the time of publication. A total of six scenarios are calculated, which range from importing a percentage of the remaining demand through to a 100% regional production.



Source: ISUSI (2002).
Figure 20 : Structure of the ERJ Model

5.1.4) Grid Design and Reliability of the System

Renewable energy from large numbers of small-scale local generation sources would require a different type of distribution grid to the large-scale centralised energy supply network in place today. The focus would shift to decentralised energy sources with reliability of supply being dependent on a range of options for coping with intermittency such as increased interconnection, storage technologies and supply/demand management.

A diverse mixture of fluctuating sources, spread across all regions would tend to dampen the fluctuations, as changes in weather do not occur simultaneously in all areas and weather forecasts would allow for measures to ensure supply. Virtual power stations, constructed from a vast number of small suppliers, such as fuel cells in households, would combine, controlled by an Internet-like network, to act as a single unit to supply times of reduced supply.

In conclusion, grid reliability is ensured through a diverse network of decentralised, renewable energy sources, combined with flexible control and the optimal planning and co-ordination of resources. This is shown for Scenario One with the simulation of the electrical system.

5.2) Energy Sources used in the ERJ Supply Model

Scenario One offers the lowest amount of installations to ensure a reliable electricity supply. Other variations require a higher amount of installations in Japan. The renewable energy sources used include:

5.2.1) Solar Energy

The power of solar energy is defined by local solar radiation, which depends on geographical position and weather conditions. The utilisable energy depends on the area that can be used to absorb sunlight. In order to avoid the use of additional surface area, the primary locations for installation are already-used areas, such as roofs and façades. Solar energy can be used to produce electricity using photovoltaic panels and solar power plants, but also heat by using solar-thermal collectors.

Figure 21 : Kiyomino Solar Settlement (Japan); Source : Hakushin Corporation, Saitama.

The per capita installed area for photovoltaic and solar-thermal systems varies according to regional population density and climatic conditions. The maximum available roof area per inhabitant decreases as population density increases. This is due to the fact that in densely populated regions the share of multi-storey buildings and the average height of buildings are much higher than in less populated regions. Investigation into available and suitable areas for the installation of solar energy systems showed an average of nearly seven square meters per capita in the residential sector; the maximum is in Kyushu north with approximately 16 m^2 per capita and the minimum in Kansai with approximately four square meters per capita[65].

Region	**Suitable area (km^2)**	**Population [mill.]**	**Suitable area per capita [m^2/cap]**
Hokkaido West	32.5	2,841	11.4
Hokkaido East	15.0	2,841	5.3
Hokuriku	27.1	2,716	10.0
Tohoku West	58.0	5,499	10.5
Tohoku East	52.5	5,499	9.5
Chubu	90.3	12,892	7.0
Kanto	221.5	45,679	4.8
Kyushu North	109.4	6,723	16.3
Chugoku	56.4	7,732	7.3
Kansai	84.7	21,270	4.0
Kyushu South	103.4	8,041	12.9
Shikuku	29.1	4,154	7.0
Total:	879.7	125,889	7.0

Source: ISUSI.

Table 16 : Regional area in the residential sector that is suitable for the installation of solar cells and solar collectors (five percent of the dwelling area)

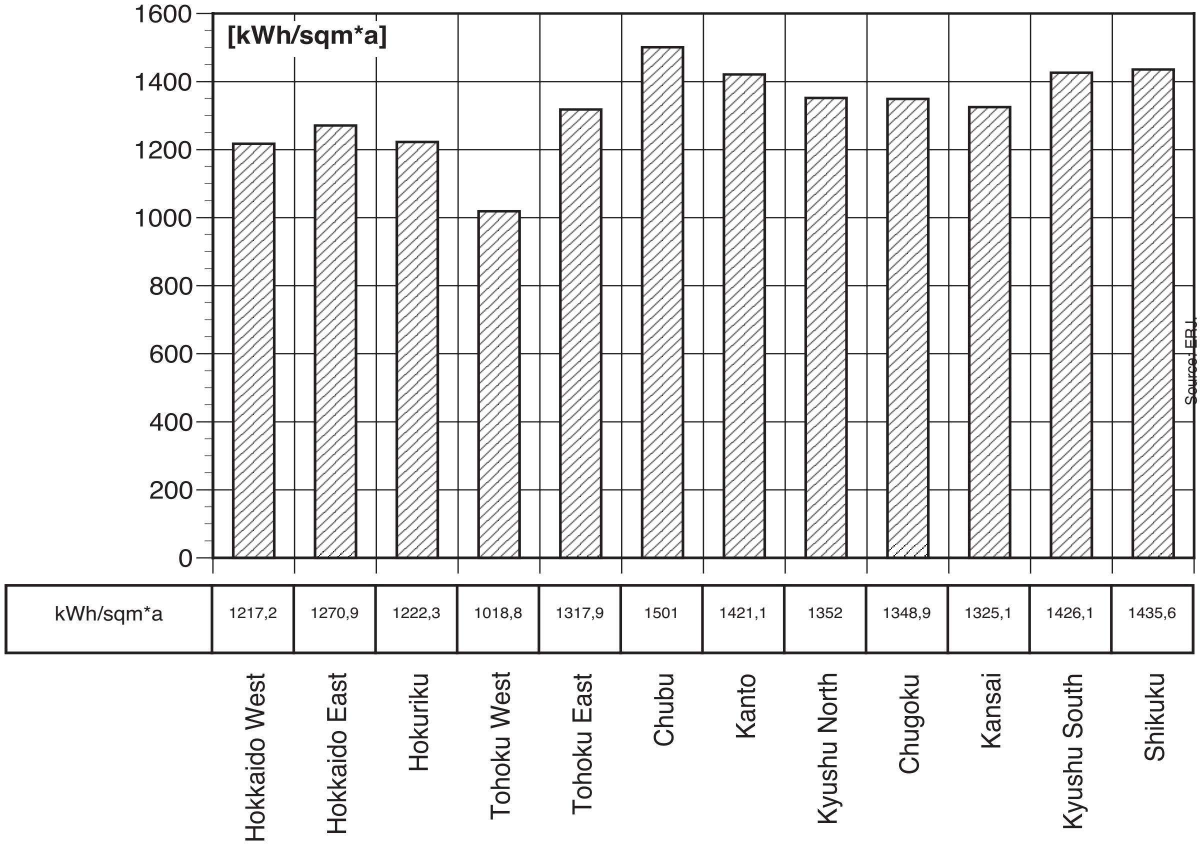
Solar energy can be used to produce electricity using photovoltaics and heat by using solar-thermal collectors. Just considering the residential sector alone, according to our research approximately 880 km^2 of the total roof area is suitable for installing systems that use solar energy. Scenario One includes approximately 400 km^2 (about 45% of the area mentioned above) of photovoltaic generators. This is equivalent to an average surface area of 3.2 m^2 per capita. The peak power of the installed photovoltaic systems amounts to about 60,800 MW; in 1999 approximately 200 MW of photovoltaic systems were installed in Japan. If the suitable area in the commercial and industrial sectors is also considered, 31% of the total available area in Japan was used for the installation of photovoltaic systems in Scenario One [66]. The installation of photovoltaic systems was set according the available areas (depending on the population density described above) and

65. The available roof-area in Europe varies from about 7 m^2 to 9 m^2 per capita, depending on population density. Within Germany a range from approximately 5 m^2/cap to about 9 m^2/cap roof area is available. The German average is about 8 m^2/cap. Source: Lehmann, H. et al. (2003).

66. This is equivalent to about ten percent of the commercial and industrial sectors, 170 km^2 in the commercial and 260 km^2 in the industrial sectors.

the solar radiation data that was gained from 66 weather stations in Japan. The initial installation of photovoltaic systems, i.e. the installation that was chosen before any optimisation process was done, was set to 50 % of the suitable area in the residential sector. During optimisation, sites with high solar radiation were preferred for installation, but it was considered that enough free area had to be set aside for the installation of solar-thermal systems.

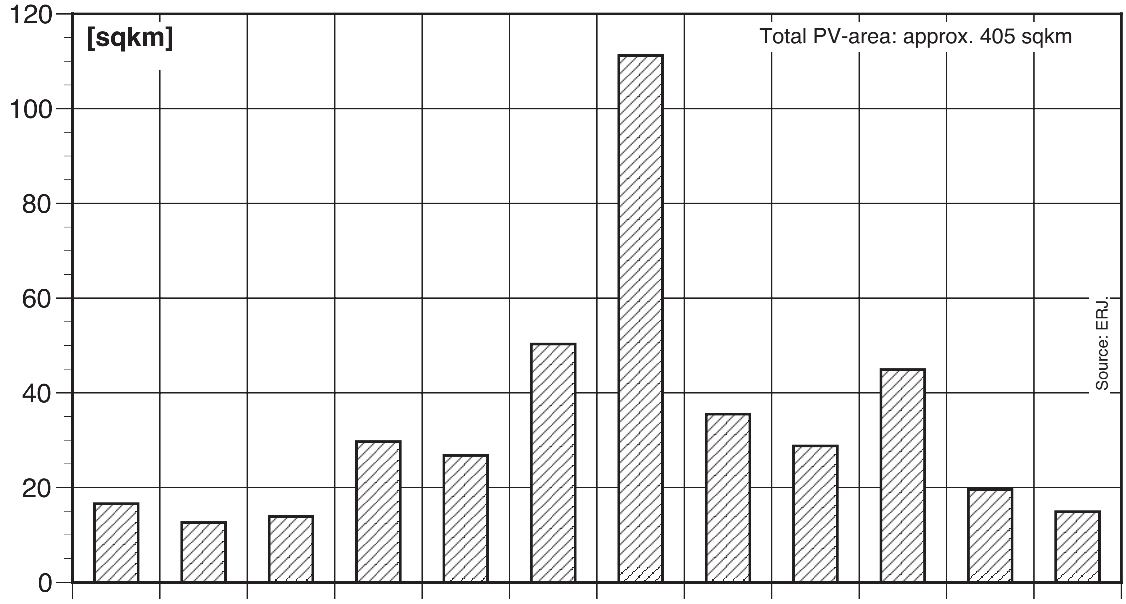
Some of the regions with good solar radiation are densely populated, e.g. Kanto and Kansai. This led to the situation that the optimum installation of photovoltaic systems and solar collectors regarding regional self-sufficiency and reliability would have exceeded the available area in the residential sector. In those regions the optimum installation of photovoltaic systems was maintained by also using suitable areas in the commercial and industrial sectors, such as roof areas of railway stations, commercial or industrial buildings. In addition, installation in remote areas was decreased, even if they were ideal, as not decreasing the installation would have led to significant regional surpluses due to the low demand in such sparsely populated regions, plus necessitating electricity transport over far greater distances. Fine-tuning of the installation was further optimised as a result of simulation runs in order to achieve an installation that best supported the whole supply system while minimising surpluses.



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
kWh/sqm*a	1217,2	1270,9	1222,3	1018,8	1317,9	1501	1421,1	1352	1348,9	1325,1	1426,1	1435,6

Figure 22 : Solar radiation in the different regions of ERJ Supply Model Scenario One as average values for the year 1999 (in kWh per m^2)

The photovoltaic area installed in Scenario One reflects the variation of population distribution in Japan. The per-capita installed area in the most populated regions (such as Kanto and Kansai, which have together approximately 67 million inhabitants) is significantly lower compared to most other regions. Only in Kyushu south, which is a less populated and remote region, is the amount of PV area similar to Kanto and Kansai.



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
sqkm	16,6	12,6	13,9	29,7	26,8	50,3	111,2	35,5	28,8	44,9	19,6	14,9
sqm/cap	5,8	4,4	5,1	5,4	4,9	3,9	2,4	5,3	3,7	2,1	2,4	3,6

Figure 23 : Installed area of solar cells in the different regions of Scenario One

The area of installed photovoltaic systems was not exclusively distributed amongst the available areas in the different sectors (residential, commercial and industrial). But as mentioned above, it was assumed that a fraction of the suitable area in the commercial and industrial sectors is used in densely populated regions with good solar radiation. Taking all the suitable areas together it is quite clear that the installation of photovoltaic systems can be more than doubled. This still does not include façade areas, areas on railway stations or parking places or even noise barriers along-side motorways that are well suited for the installation of photovoltaic systems.

One good example of integrated installation of photovoltaic systems is the headquarters of Kyocera in Japan. The roof and southern side of the building is equipped with a 214 kW photovoltaic plant, which saves at least 45,000 litres of fuel oil per year and in combination with a cogeneration plant makes the building self-sufficient in energy.

Source: Kyocera Corporation.
Figure 24 : The Kyocera Headquarters, which is self sufficient in energy.

The approach of installing solar-thermal collectors was different than with photovoltaic systems. Solar-thermal systems were installed with regard to district heating networks and consumer self-sufficiency. As described above, it is not possible to distribute heat in nationwide networks. The installation for each region was set to three square meters per capita. The actual installation varies according to the local building density. Less area for the installation of solar-thermal systems is available in locations with a high building density. Furthermore, some buildings might receive no solar radiation, making the installation of solar-thermal systems on these buildings useless. Under such conditions the heat supply is more focused on cogeneration and supported by the installed solar collectors. On the other hand, locations with a low building density offer a more suitable area for solar-thermal systems, so substantially increasing the potential for solar heat production; in this case the actual installation can exceed the average of three square meters by far. Here the heat supply is primary based on solar energy, while cogeneration is used to support the solar-thermal systems. All the heat-producing systems are combined in district heating networks with medium- to long-term heat storages.

Solar-thermal systems are used in the industrial and commercial sectors to support other heat producing technologies. In these sectors ten percent of the suitable areas (approximately 1,714 km^2 in the commercial and approximately 2,569 km^2 in the industrial sector) were used for installation, which is a quite conservative approach, especially with regard to flat roofs, which are in the majority in the industrial and commercial sectors.

The total area of solar-thermal collectors in all ERJ Supply Models is about 806 km^2, of which approximately 378 km^2 is on top of residential buildings (around 43% of the suitable area), about 170 km^2 is on commercial buildings and roughly 260 km^2 is on industrial areas; this is about ten percent of the available area in the commercial (approximately 1,700 km^2) and industrial (approximately 2,600 km^2) sectors.

Figure 25 : High efficiency solar thermal vacuum collector systems;
Source : Paradigma, Ritter Energie und Umwelttechnik, Karlsbad, Germany

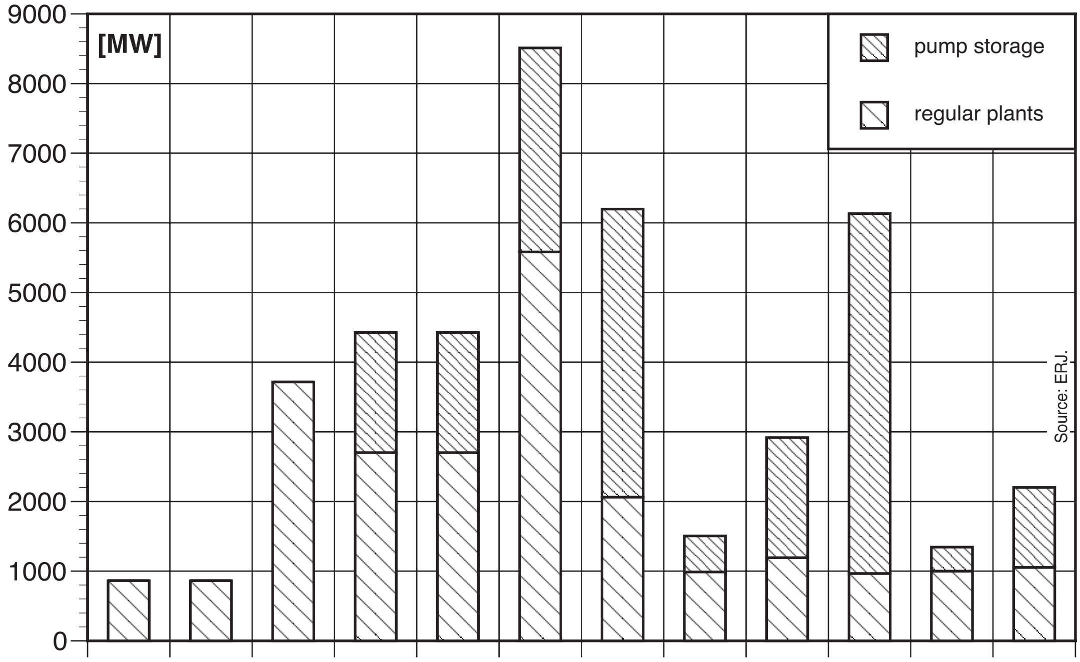
5.2.2) Hydropower:

The energy potential of hydropower depends on precipitation, mass flow rates, velocity and pressure. Hydropower depends on sites where natural conditions are conducive to energy production using water, that is high precipitation and a large mass flow rate or a large drop in altitude.

The utilisation of hydropower is, however, problematic. Large hydropower storage involves a massive destruction of existing ecosystems. Therefore, in all the ERJ Supply Models hydropower was restricted to existing plants. The only measure that was taken into account was the modernisation of plants, resulting in an energy increase of ten precent.

The installed capacity of hydropower plants in the ERJ Supply Models is about 24,000 MW. Another 19,400 MW comes from pumped storage plants, which are used for covering peak loads, i.e. during times when demand exceeds production of electricity by other sources. Pump storages are recharged during times when electrical production exceeds demand (see also the section on Fast Reacting Power Plants).

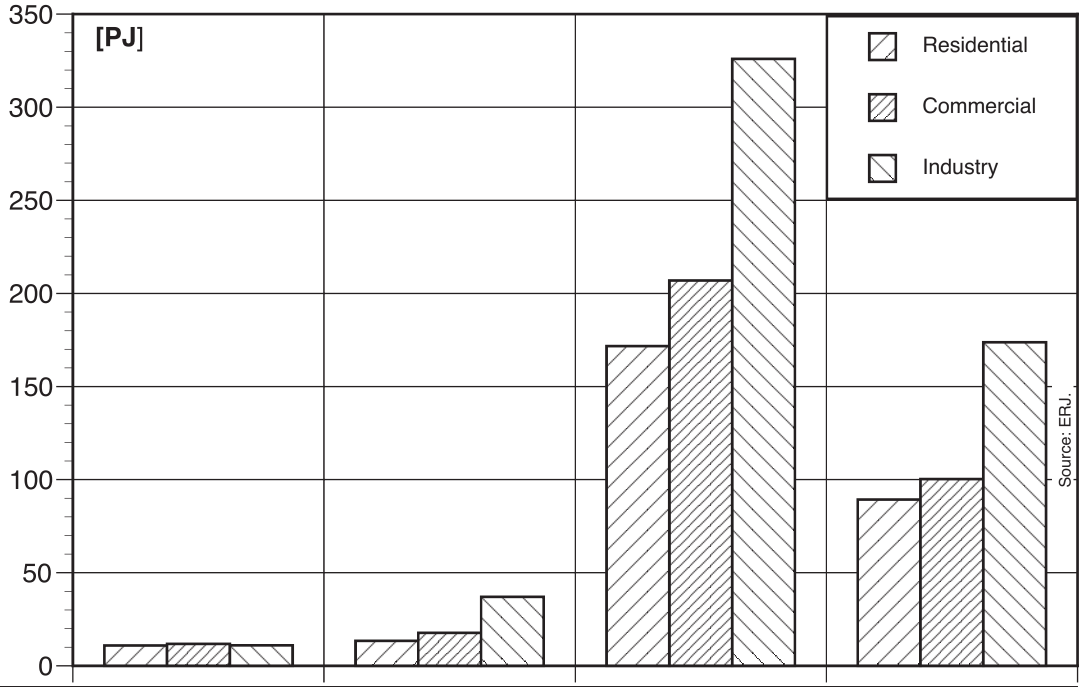
Although Chubu is the smallest region, the highest share of hydropower is located here (5,538 MW, which is about 25 % of the total hydropower). This reflects the good natural conditions this region offers for hydropower generation. This is similar to Hokuriku (northern neighbour to Chubu), which is the second-best region for hydropower. The lowest regional installation of hydropower is located in the two regions of Hokkaido with 862 MW each.



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
regular plants	862	862	3716	2702	2702	5583	2064	989	1194	966	1000	1054
pump storage	0	0	0	1723	1723	2928	4134	517	1723	5168	345	1148

Figure 26 : Installed hydropower in the different regions of the ERJ Supply Model

The highest amount of pumped storage plants is installed in Kanto with 4,143 MW and Kansai with 5,168 MW, representing the most populated regions in Japan (see Figure , "Note: These values were calculated, based on estimations of statistical data." below). Kanto and Kansai are also the most industrialised regions in Japan. As a result the electricity demand in these regions is high and supply's reliability is more critical than in other regions. Any shortfalls in electrical supply would affect Japan's industrial centres as well as about half of Japan's population. Therefore these regions especially need reserve capacities to guarantee the reliability of the electrical supply system. There are no pumped storage plants in Hokkaido and Hokuriku as these regions are less populated and not comparable to Kanto or Kansai in terms of industrialisation; altogether Hokkaido and Hokuriku have approximately 8.4 million inhabitants.



	Hokkaido West	Hokuriku	Kanto	Kansai
Residential	10.91	13.39	171.72	89.3
Commercial	11.81	17.67	206.95	100.28
Industry	11.04	37.06	326.02	173.74

Note: These values were calculated, based on estimations of statistical data.

Figure 27 : Yearly electricity demand in the residential, commercial and industrial sectors of different regions in the ERJ Supply Model

5.2.3) Wind Energy

The energy provided by wind is determined by wind speed and so is defined by climate and geographical conditions. The proportion of the energy usable by wind turbines obviously depends on the number of wind turbines that can be installed. To keep the total installation of wind turbines on an acceptable scale, factors like the use of land, alteration of landscape and nature protection areas have to be considered. In general, sites close to the coast are most suitable for wind energy due to their exposed nature.

Several factors were considered regarding the installation of wind turbines. In order to determine the available area, the land area of each region, including population density were factored. For offshore installation, the maximum distance from the coastline was set to 30 km. Furthermore the choice of sites was made according to weather data that was derived from 153 weather stations.

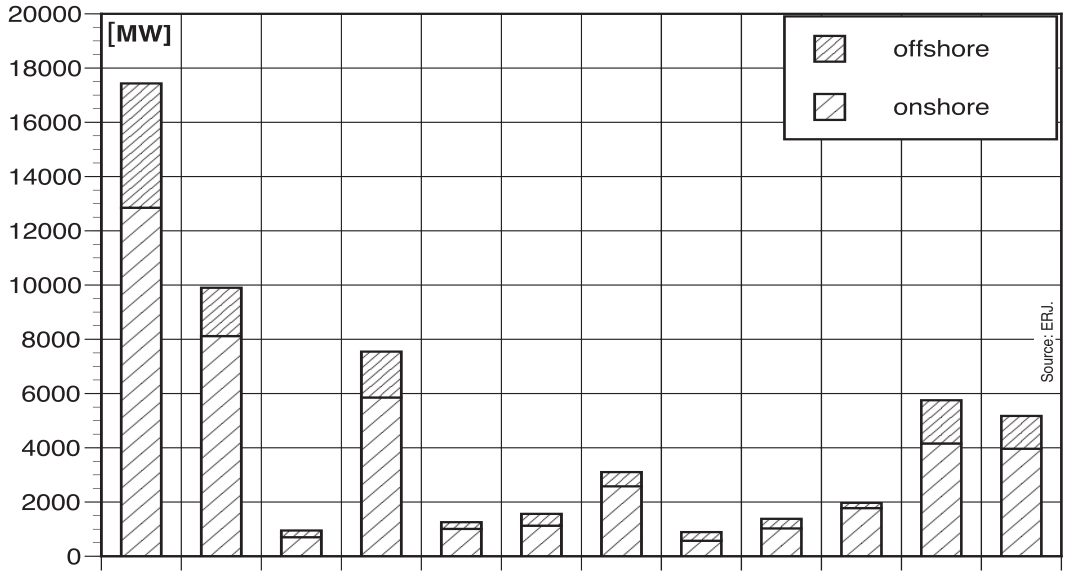
Three different types of wind turbines were chosen for installation in Scenario One:

- 1.8 MW plant with 108.6m-hub height and 82m-rotor diameter (not considered for off-shore installation)
- 2.5 MW plant with 80m-hub height and 72m-rotor diameter
- 3 MW plant with 90m hub height and 80m rotor diameter

The algorithm used to find the optimum mix comprised of weather data, available areas and the different types of wind turbines to minimise the number of plants that are needed to achieve the required electrical output.

To keep the installation to an acceptable scale, the upper limits for the installation density were set according to the specific boundary conditions of each region (e.g. land area, population and length of the coastline). The maximum density for local installation was set to 0.5 plants per km^2 for onshore installation and 0.15 plants/km^2 for offshore installation. The installation in ERJ does not reach these limits in any of the regions. In reality wind turbines are not equally distributed over the available area. Some single wind turbines are installed at very good locations, but in general wind turbines are combined in wind parks, where the installation densities vary according to the type of plant that is used for installation. The size of wind parks is set to 25 wind turbines for onshore wind parks and 50 plants for offshore wind parks.

The area required by a single wind turbine determines the installation density in a wind park. The related values were chosen as follows. For onshore wind turbines it was assumed that the distance between the wind turbines that form a wind park must be at least five times the rotor diameter and ten times the rotor diameter for offshore installation, and thus about 7.5 to ten plants per km^2 are installed in onshore wind parks and about 2 to 2.5 plants/ km^2 offshore. This means that the distance between the wind parks is at least more than five km onshore and 13 km offshore. The nature of these limitations is more theoretical, because in the model the maximum installation density, which is in Kyushu south, reaches a value of 0.139 units/km^2 as a regional average. As a result the distance between wind parks in Kyushu South is more than 11 km on average. At minimum installation density (0.01 plants/km^2 in Kyushu north) the distance is approximately 45 km. For offshore installations the distance ranges from about 17km to 70km (installation densities from 0.009 to 0.106 plants/km^2).



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
onshore	12848	8116	703	5850	1010	1127	2576	572	1028	1778	4156	3962
units/sqkm	0,135	0,114	0,042	0,091	0,016	0,024	0,022	0,011	0,017	0,031	0,139	0,093
offshore	4583	1785	250	1693	245	437	526	320	355	191	1598	1211
units/sqkm	0,106	0,054	0,014	0,053	0,013	0,036	0,019	0,011	0,009	0,009	0,09	0,038

Figure 28 : Installed wind power in the different regions of Scenario One

In total, 27,029 wind turbines are installed in Scenario One, with 5096 offshore and 21,933 onshore. The total electric power is about 57,000 MW, which is less than five times more than was installed in Germany by March of 2003<67>. To get an impression of Japan's wind power potential compared to Germany's, the length of Japan's coastline is about 29,000 km, whereas the German coastline is approximately 1,000 km.

The potential offered by wind energy is immense. Its potential globally even exceeds the estimated world electricity demand in 2020 by more than a factor of two. The Greenpeace study "Wind Force 12" showed that 12% of the world's electricity demand could be covered by wind energy by the year 2020<68>.

67. Bundesverband Windenergie e.V. (2002).

5.2.4) Geothermal Energy

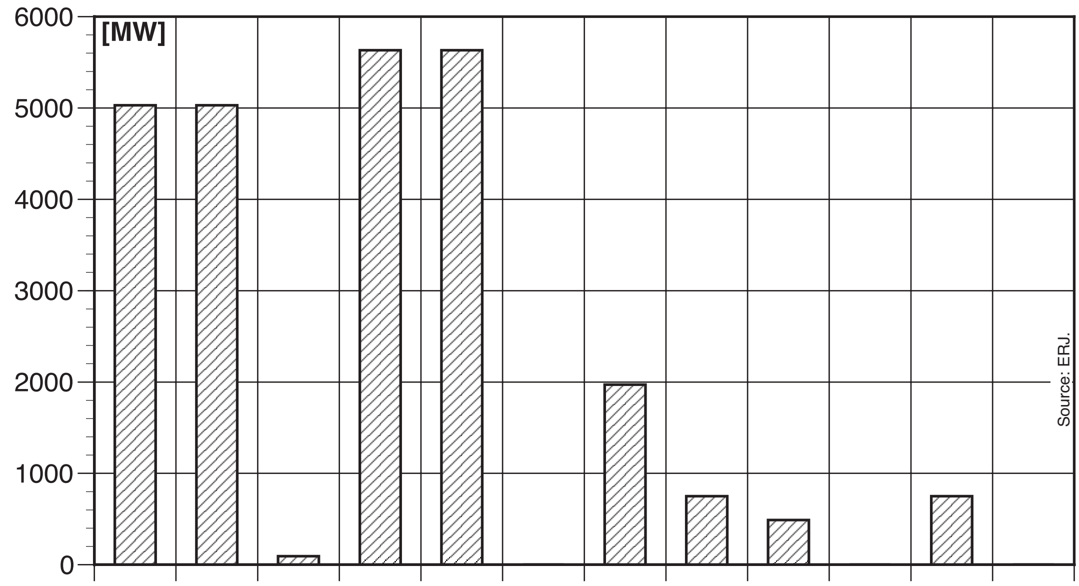
Geothermal energy utilises heat from the earth's core. Temperatures rise by about 3°C per 100m as you descend from the surface of the earth. In some locations, in so-called geothermal anomalies, high temperatures can be found relatively close to the earth's surface. These heat sources are easy to exploit and can be used for the production of heat and electricity. The utilisation of geothermal energy requires a power plant to be built close to the geothermal source. This restricts exploitation to sources that are outside national parks and that can be used with minimal impact on the ecosystem.

According to the Institute for Energy and Total Engineering[69], Japan's geothermal sources located outside of national parks offer the potential for installing power plants with approximately 76,200 MW of electrical power. Scenario One contains about 22,900 MW of geothermal power plants (about 25% of the potential) for the production of electricity; in 2000 the installed capacity was approximately 550 MW[70]. The degree of utilisation in Scenario One is equivalent to approximately 7,000 full load hours a year, which is quite conservative, compared to nuclear power plants (with approximately 7,500 full load hours a year[71]).

As the distribution shows (Figure 29, "Installed geothermal power plants in the different regions of Scenario One"), geothermal energy production is concentrated to Hokkaido and Tohoku, with more than 5,000 MW each. Much less is installed in Kanto (approximately 2,000 MW), which is due to the densely populated and industrialised structure of Kanto. Only smaller installations are located in the other regions. This regional distribution is not mandatory and might be altered.

The use of heat pumps, which can utilise near-surface or deep geothermal heat, despite the fact that there is a very big potential, is not considered for the heat supply in the ERJ Supply Models.

68. EWEA (2002).
69. NEDO (1989).
70. Lund, J. (2000).
71. Akademie für Technikfolgenabschätzung in Baden-Württemberg (1999).



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu Sout	Shikuku
rated output	5029	5029	93	5633	5633	0	1971	751	490	0	751	0

Figure 29 : Installed geothermal power plants in the different regions of Scenario One

5.2.5) Fuels from Renewable Sources

The oil economy, for so long the provider of apparently cheap fuels, will need to be replaced with renewable fuels. So what are our options for renewable fuels that can be supplied in great enough quantities? The main players here are bio fuels and hydrogen. Fuels from renewable sources can be produced from biomass (such as biogas in the form of methane) or hydrogen from the electrolysis of water (using renewable energy sources). It is important to note that biomass has to be produced under the rules of sustainability as described below.

Biomass

Although no biomass is included in all the ERJ Models, it is clear that it will play an important role in a future energy system. Biomass can be burned to produce electricity and heat in combined heat and power plants; it can be used to produce bio fuels (e.g. biogas) for vehicles. In addition, biomass can be stored and transported. Note: biomass mentioned below does not include energy recovery from waste incineration. The following describes the requirements for a sustainable biomass supply:

- Positive Energy Balance[72]

The net energy produced by the biomass cycle (that is released solar energy) must be greater than the energy used in its germination-to-generation lifecycle. That is, when all the energy from other sources used to produce, process and transport the biomass is aggregated, this must be less than the amount of energy that is derived from the combustion of the biomass. Only the energy derived above and beyond this threshold may be considered renewable.

- Carbon Neutral

The net (carbon) greenhouse gas emission of the biomass cycle used must be zero or negative. That is, the carbon, and carbon equivalent of nitrous oxides, methane and other greenhouse gases released to the atmosphere by the full germination-to-generation cycle must be less than, or equal to, the carbon absorbed or fixed by the biomass itself – including carbon removed or fixed within the soil, sequestration by forest or live crop, greenhouse gases emitted though land use change or net depletion, and greenhouse gases released due to transportation and production of fertilisers and pesticides.

- Biodiversity Impacts

Biomass production involves production over significant land areas, and this requires careful consideration of potential for biodiversity impacts. Biomass productions must aim to maintain and restore indigenous biodiversity, taking particular account of rare, threatened and endangered species and ecosystems, complement biodiversity conservation strategies, entail no conversion of natural ecosystems, and be guided by the results of environmental impact assessments and ongoing monitoring.

- GMO free

The biomass plants, or enzymes used in the processing of the biomass must not include genetically modified plants or other organisms. This includes agricultural and forestry residues as well as purpose grown 'energy crops' and their conversion to other energy forms.

72. Many organic waste streams or residues do not meet the positive energy balance and carbon neutral criteria defined above. However it is useful to recognise that residues which were not designed to be energy sources may be useful sources of energy, which are otherwise wasted. In this case it may be appropriate to recognise that the extra energy/carbon, which has been spent in the processing has been expended for its primary purpose, not its waste value. Provided this energy has been expended for the primary purpose of the material, then it may be appropriate to neglect the energy balance and carbon balance prior to the time of processing when the waste stream is created.

- Sustainable Plantation/Agriculture

The processes for producing the biomass must be sustainable with respect to water, nutrient and mineral balances within the soil. Biomass production must be constrained to existing agricultural croplands and the restoration of degraded or abandoned land. The production process must also be socially sustainable and therefore responsible in terms of its social impacts. Specific criteria for land-use sustainability are contained within Greenpeace plantations policy documents (see http://archive.greenpeace.org/~forests/).

- Toxicity

The biomass conversion processes and its secondary effects (i.e. any non bio-organic substances processed along with the biomass) should not cause:

- Additional toxic matter – solid, liquid or gaseous
- Net increase in the toxicity of the matter
- A net increase of the impact of toxic materials with respect to the environment i.e. improved containment relative of the toxic matter, comparative to the input material
- External emissions that are not related to the carbon combustion process. Emission of pollutants that are related to the basic carbon combustion process such as nitro-oxidents and sulpher-oxidents (NOX and SOX) should be equal to best available technology levels

It seem that Japan has a substantial potential for sustainable produced biomass, but no accurate assessment of its scale is available.

Hydrogen

The issues of hydrogen production and infrastructure are discussed in more detail in Scenario One below. Hydrogen can be produced by a number of processes. The most sustainable process for the production of hydrogen is the electrolysis of water, which is energy intensive[73]. Electricity used for hydrogen production must come from renewable sources. A number of other processes are currently used for hydrogen production. A common method using steam reformation of natural gas, accounts for a large percentage of world production. Natural gas is a fossil fuel, which is a finite resource. This process also produces carbon dioxide and is therefore unsustainable.

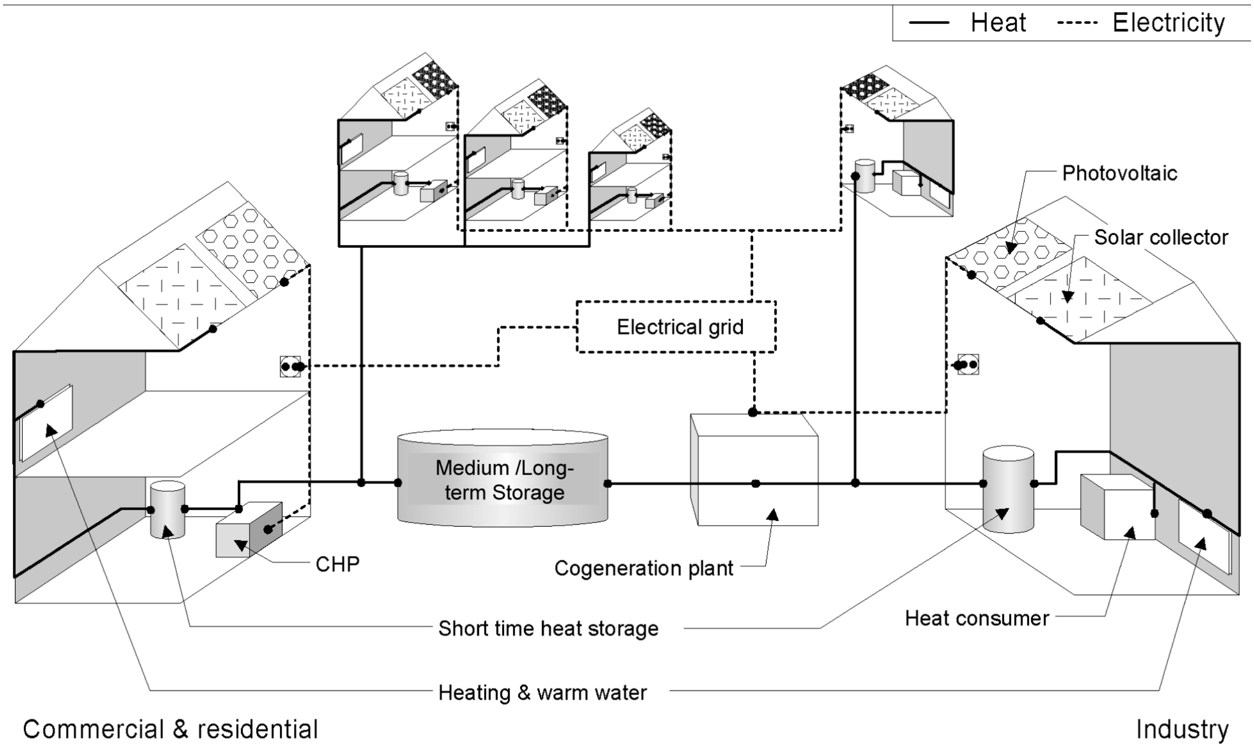
Hydrogen can be used as a fuel for vehicles and for the production of electricity and/or heat. Hydrogen is used in cogeneration plants for generating electricity and heat in the ERJ Supply Models. Fast Reacting Power Plants (FRPP) are also used solely to produce electricity. In the ERJ Supply Models, fuel consumption and production are shown as the hydrogen equivalent in order

73. Hydrogen produced from the steam reformation of natural gas is not sustainable.

to easily calculate the amount of hydrogen required. The simulation determines the installation capacity of fuel-consuming plants in the electrical system. Surpluses in the electrical supply system are used for the production of hydrogen. The domestic production of hydrogen can be increased by the additional use of renewable sources, such as photovoltaic systems, wind turbines and solar power plants installed in remote areas used solely for producing hydrogen.

5.2.6) Cogeneration Plants

Cogeneration plants use fuels from renewable sources to simultaneously produce heat and power with high efficiency. The mode of operation can be adjusted to supply demand, either mostly for heat or for power. Surpluses can contribute to the public supply, whether heat or electricity, or be stored for use on demand as in the case of heat.

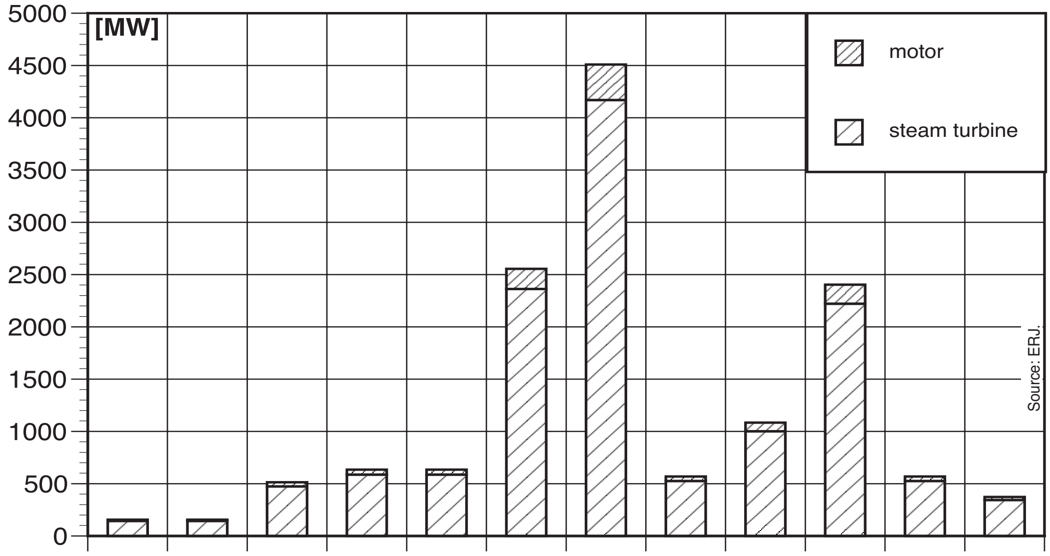


Source: ISUSI
Figure 30 : The use of cogeneration plants in the ERJ Supply Models (storage and solar systems are also shown)

The ERJ Supply Models use cogeneration plants in the industrial, commercial and residential sectors. Smaller systems installed in commercial and residential sector make use of motors or fuel cells. Larger systems are installed in the industrial sector. These systems utilise steam turbines if the heat output has to be at high temperatures, or motors for the production of low temperature heat and electricity.

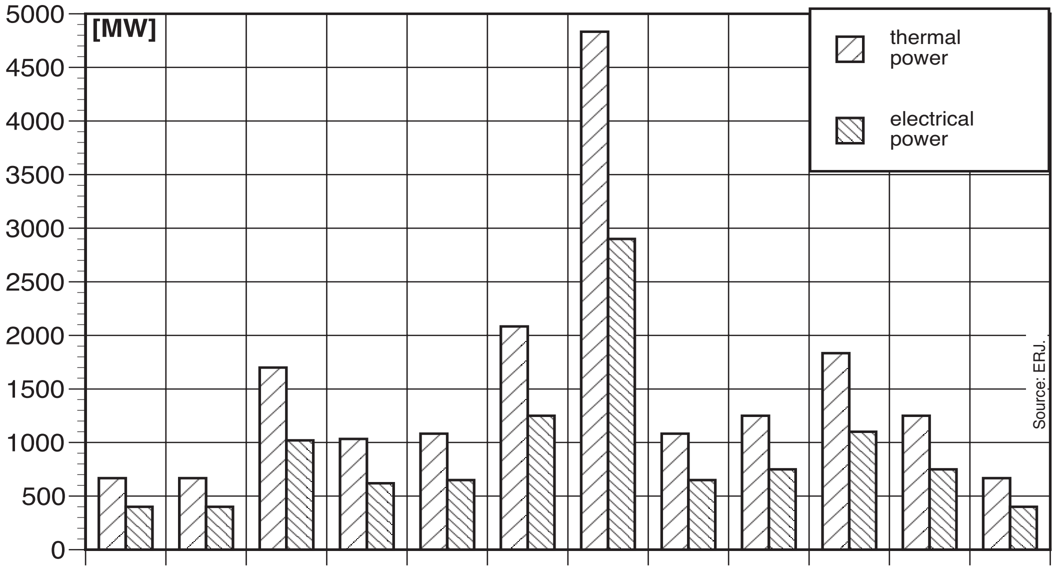
The installed capacity of cogeneration plants in industry in the Scenario One is 22,900 MW electrical power. In 1999, the total installed capacity of cogeneration plants in Japanese industry was approximately 4,000 MW.

The most densely populated regions are the most industrialised regions. The distribution shows the connection between energy demand in the industrial sector and population distribution. The highest amount of industrial cogeneration is installed in Kanto, followed by Chubu and Kansai. Although Chubu is less populated than Kansai it is more industrialised. The reason is that Chubu is the region next to Kanto, which is the industrial centre in Japan.



	Hokkaido West	Hokkaido East	Hokuriku	Tokoku West	Tokoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikiku
steam turbine	143	143	474	587	587	2363	4170	525	1001	2222	525	344
motor	12	12	39	48	48	192	339	44	83	182	44	29

Figure 31 : Electrical power of industrial cogeneration in the different regions of Scenario One



	Hokkaido West	Hokkaido East	Hokuriku	Tokoku West	Tokoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikiku
thermal power	667	667	1700	1033	1083	2083	4833	1083	1250	1833	1250	667
electrical power	400	400	1020	620	650	1250	2900	650	750	1100	750	400

Figure 32 : Electrical and thermal power of cogeneration in the residential and commercial sectors in the different regions of Japan in Scenario One

Cogeneration plants in the residential and commercial sectors are used in combination with solar-thermal systems. On locations with good conditions for solar heat production (enough available area, high solar irradiation) solar collectors are the primary source in heat supply. If the available area and/or the solar irradiation is not sufficient, cogeneration takes over the primary task in heat supply, while solar-thermal systems are used to support them. The scale of installation was chosen in order to guarantee a sufficient heat supply even during times with low solar irradiation and as a back-up for days or periods with unusual low outside temperatures.

The total installed electrical power in the commercial and residential sectors in Scenario One is nearly 11,000 MW; the installed capacity in Japan in 1999 was about 1,000 MW[74].

74. EDMC (2001).

5.2.7) Solar-thermal Power Plants

Solar-thermal power plants produce heat from the solar irradiation that then is converted into electricity using conventional power plant technologies. Because of the high temperatures, necessary for electricity generation in a conventional process, the solar irradiation is concentrated by parabolic solar collectors (so called ‘Solar Farm‘ concept) or gets focused on a cental absorber by a field of mirrors (‘´Solartower‘ concept).

Nine plants of the ‘Solar Farm‘ type have been built near Kramer Junction in Mojave desert, California, from 1984 to 1991.

Source: XXX.

Figure 33 : The Kramer Junction “SEGS” solar-thermal power plants

The total generation capacity of these plants is 345 MW. About 75% of the electricity is produced from solar heat, while the rest is supplied by conventional co-firing.

The first generation of “Solar Farm” power plants uses thermo-oil as heat transfer medium (to transport heat from the parabolic collector field to the heat circulation of the power generating part of the plant). Recent developments aim for the direct production if steam within the parabolic collectors, using water as heat transfer meduim, thus eliminating the need for potentially ground contanimating fluids.

While the ‘Solar Farm‘ concept has proved to be ready for the market, the ‘Solar Tower‘ concept is still in test stage, promising good performance especially for single big units.[75]

Solar-thermal power plants were used in scenarios Five and Six with different amounts for the installed capacities. Scenario Five contained about 600 square kilometers of solar-thermal power plants and it was 370 sqkm were installed in scenario Six.

5.2.8) Fast Reacting Power Plants

Any electrical supply system is exposed to the risk that a proportion of electricity production suddenly fails. This might happen due to malfunction of a power plant or sudden decrease in electricity production of fluctuating sources. This might lead to the situation that demand exceeds production. Fast Reacting Power Plants can be used in this case to increase electricity production to the level needed. The ERJ Supply Models utilise pumped storage plants and hydrogen power plants to perform this task due to their rapid response time.

The installed capacity of hydrogen power plants utilised in all the ERJ Supply Models is 3,000 MW. As the simulation showed, this power is sufficient to support the pump storage plants in all critical conditions that might occur in the course of the year 1999; this is the year that was simulated. The simulation included the introduction of summertime, which was helpful in minimising the installation capacities of Fast Reacting Power Plants (see the chapter „Simulating the Dynamics of ERJ“ on page 92 for details).

5.3) Installed Technologies in Scenario One of the ERJ Supply Model

The ERJ Supply Models utilise photovoltaic panels, hydropower, wind power and geothermal sources for the direct production of electricity. Surpluses in the electrical supply system are converted into hydrogen that can be used as a fuel for different types of plants (cogeneration, power plants for electricity generation and furnaces for producing heat). Solar power plants are not considered in the Scenario One, but are considered as an option for an additional production of hydrogen (see section on scenarios for further information).

Regarding heat supply solar collectors are the only technology that is used for direct heat production from renewable sources. Cogeneration plants and furnaces, which need fuels for operation, are used to support the solar heat supply. All heat suppliers are combined in district heating networks with short- to long-term heat storage.

75. German Aerospace Centre (DLR) operates a solar testing facility in south Spain – the so-called Plataforma Solar de Almeria -, for hot testing both concepts and further development of solar themal power plant technology.

Fuels in the ERJ Supply Models are always calculated as the heating value of hydrogen, because, as we can now say, this will be the leading fuel in a future sustainable energy supply system. Bio fuels can also be derived from biomass. But there are uncertainties about the amount of domestic biomass that could be produced under the restrictions that have to be made to maintain the rules of sustainability. For this reason the use of biomass was not considered in this study. Nevertheless one has to be aware that biomass will contribute to energy supply.

The following Table 17, "Overview of the electrical supply in Scenario One" provides an overview of the supply of electricity in Scenario One.

Technology	**Installed capacity in MW**	**% of capacity**	**Elec. Production in GWh**	**Elec. Production in PJ**	**% of production**
PV	60,750	28.4%	82,167	296	11.5%
Total area installed: 405 km^2					
Specific area installed: 3.2 m^2/cap.					
Wind energy	56,917	26.6%	16,4361	592	23.1%
Number of plants onshore: 21,933					
Power onshore: 43,725 MW					
Number of plants offshore: 5,096					
Power offshore: 13,192 MW					
Hydropower	23,694	11.1%	125,611	452	17.6%
Geothermal energy	25,381	11.8%	180,500	650	25.3%
Cogeneration in industry	14,150	6.6%	121,306	437	17.0%
Power, steam turbines: 13,080 MW					
Power, motors: 1,070 MW					
Cogeneration in commercial and residential sector	10,890	5.1%	38,694	139	5.4%
Pumped storage power plants*	19,408	9.1%	-1,853	-7	-0.3%
Storage capacity: 1.2 PJ					
Fast reacting hydrogen power plants	3,000	1.4%	1,278	5	0.2%
Total	214,189	100.0%	712,064	2,563	100.0%

* Electricity demand for storage charge: 5,910 GWh, electrical output: 4,057 GWh
By comparison the installation data for 1999: PV 205 MW, Wind power 83 MW, Hydropower (including pump storage) 45,860 MW, Geothermal power 547 (in 2000), Cogeneration 4,973 MW, Nuclear 45,248 MW, Thermal power plants 161,869 MW. Source: Handbook of Energy & Economic Statistics in Japan, The Energy Conservation Centre, Japan; 2001.

Source: ERJ.

Table 17 : Overview of the electrical supply in Scenario One

Table 17, "Overview of the electrical supply in Scenario One" shows geothermal energy and wind power as the largest producers in the electrical supply system. Second and third positions are taken by hydropower and industrial cogeneration, which are at comparable levels. Although photovoltaic systems are in first position in terms of the installed capacity, the contribution to electrical supply is only about 12%. As mentioned above, the value of the installed capacity represents the peak power under optimal conditions. Therefore most of the time the electrical output of photovoltaic systems is much lower than the peak power.

The combination of renewable energy technologies used in the Scenario One can produce all the required electricity according to the ERJ Demand Model. The perceived shortcomings of some renewable sources, in terms of fluctuating energy production of solar and wind energy can be fully compensated by a well-chosen mixture of renewable energy technologies and an intelligent control and exchange structure. Security of supply, often unjustly cited by critics, is as reliable as with any conventional system. Please refer to the chapter on the simulation for time-dependent results.

The electrical production from domestic renewable sources amounts to about 1,983 PJ if fuel-consuming plants are not included. This is a share of about 94% compared to the electrical demand of approximately 2,100 PJ. Taking fuel-consuming plants into account, the electrical production of Scenario One is 2,559 PJ (about 122% of demand).

Technology	**Installed capacity in MW**	**% of capacity**	**Production in GWh**	**Production in PJ**	**% of production**
Solar collectors	338,745	76.9%	497,056	1,789	40.9%
Total area installed: 806 km^2					
549 km^2 in commercial and residential					
257 km^2 in industry					
Cogeneration in industry:	23,583	5.4%	202,178	728	16.6%
Steam turbines: 21,800 MW					
Motors: 1,783 MW					
Heating plants (high temp. Heat)*	60,148	13.7%	451,111	1,624	37.1%
Cogeneration in commercial and residential sector	18,150	4.1%	64,489	232	5.3%
Total	440,626	100.0%	1,214,834	4,373	100.0%

* calculated with 7,500 h/a (full load hours per year)

Source: ERJ.

Table 18 : Overview of the heat supply in Scenario One

The two main providers of heat are solar-thermal systems and heating plants. Solar-thermal systems lead by far regarding installed capacities, but this value only represents the peak power under optimal conditions, which is comparable to photovoltaic systems. Cogeneration systems produce about a fifth of the heat produced.

Regarding total installed capacities for the different regions, Kanto, Kansai and Chubu produce the greatest amount. This is because they are the most populated regions in Japan. About 64% of Japan's population is concentrated in these regions; 36% of the population live in Kanto alone. The least amount of thermal power is installed in Hokkaido, which is the least populated region in Japan. Concerning the importance of technologies in heat production solar-thermal systems lead by far, followed by industrial cogeneration with steam turbines and cogeneration in the residential and commercial sectors.

The combination of solar collectors and cogeneration plants utilised in the ERJ Supply Model can cover the demand for low temperature heat in the industrial sector as well as in the commercial and residential sectors. The gross heat production of solar-thermal systems in the commercial and residential sectors is about 1,450 PJ, which slightly exceeds heat demand (103% of heat demand). This is not sufficient to fulfil heat demand due to the losses that occur in storage and transport of heat. Another 232 PJ of heat is therefore produced using small cogeneration systems. The resulting total heat production amounts to 1,680 PJ, which is 119% of the heat demand. The share of solar produced low temperature heat in the industrial sector is about 92% (production: 342 PJ, demand: 372 PJ).

About 30% (673 PJ) of industrial demand for high temperature heat (2,419 PJ) can be produced by the utilisation of steam turbines in industrial cogeneration. The remaining 1,746 PJ of high temperature heat has to be covered by fuels from renewable sources, whether imported or from domestic sources.

Technology	**Fuel demand in PJ**
Cogeneration	1,920
Heating plants (high temp. heat, eta =0,88)	1,984
Transport	1,176
Hydrogen from electrical supply	-371
Total	4,709

Source: ERJ.

Table 19 : Overview of fuel demand and production

Fuels are needed in Scenario One for operating cogeneration plants in the industrial, commercial and residential sectors and for vehicles in transport. The fuel consumption resulting from heat and electricity production of cogeneration plants is 1,920 PJ. Of this about 370 PJ of hydrogen is produced by the supply system itself, leaving a demand of 1,550 PJ to be supplied from other sources. In addition, about 1,980 PJ is required for the production of high temperature heat in the industrial sector and 1,180 PJ is needed for transport.

Altogether, about 4,700 PJ of hydrogen equivalent fuel remains to be found from other regional or external sources. This is not necessarily the amount that has to be imported, as additional hydrogen can be produced by the increased use of domestic renewable sources, such as wind power, photovoltaic systems or solar power plants.

5.4) The ERJ Supply Model Scenarios

Japan is a heavily industrialised, highly populated and also relatively small island. The ERJ Demand Model reduced the energy demand by about 50%, Scenario One then provided an electricity and heat supplying system covering over 50% of Japan's needs from regional sources[76]. The amount of energy that had to be covered by imports of hydrogen or biomass in this scenario amounted to about 4,700 PJ of energy. A number of scenarios (reported later in this chapter) were then developed in order to consider reducing the import percentage, ranging from increasing the amount of renewable sources, whilst still including imports, raising the efficiency levels of renewables, up to measures to reduce demand and supply in order to achieve a 100% regional supply with no imports. An overview of the scenarios can be seen in Figure 34, and detailed figures appendix.

Three scenarios (Two, Four and Six) show the effect of a decrease in the Japanese population from 127 million in 1999 to 100 million in 2050. It must be noted that a linear interpolation of demand reduction is adopted for the sake of simplicity. A demographic shift would entail an older population with smaller households and a reduced workforce, among other things. The effect would mean per capita reductions in some areas, but increases in others, making prediction extremely complex. There is also no precedent in history with which to compare the effects of such a shift.

It should be noted that although 4,700 PJ of energy imported in Scenario One is a huge amount of energy compared with the ERJ Demand, it is significantly lower than the total Japanese primary energy supplied in 1999 (about 20% of the supply in 1999). This stood at 22,971 PJ, mostly from fossil fuels or nuclear power, 80% of which was imported in the form of oil, coal and gas. Consider this in terms of oil imports: The amount of oil imported in 1999 is enormous compared to the 4,700 PJ that needs to be produced or imported in the ERJ Model. This amounted to nearly 12,000 PJ, or over 50% of Japan's primary energy supply in 1999, nearly three times the amount of energy that the ERJ Model needs to import or produce from other domestic sources in Scenario One. The table below shows the amount of energy supplied in Japan in 1999 in its various forms, expressed in Petajoules, 80% of which was imported.

76. The fuel for transport issue is assessed in the discussion of hydrogen imports.

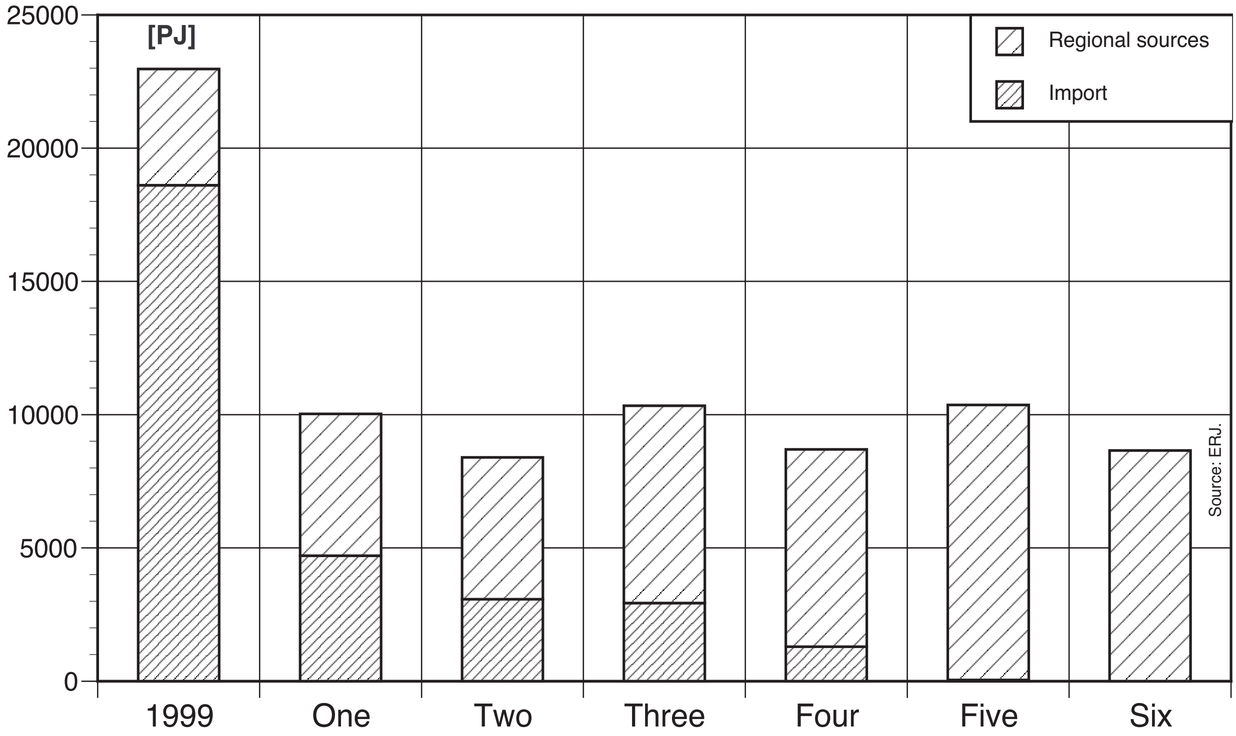


Figure 34 : Overview of the ERJ Scenarios showing primary energy supply and the share of domestic production

Energy source	Coal	Oil	Gas	Hydro	Nuclear	New energy	Primary energy supply
Energy in PJ	3,991	11,942	2,920	832	2,983	303	22,971

Source: EDMC (2001).

Table 20 : Primary energy supply to Japan in 1999[77]

As already stated, the 4,700 PJ of energy will be covered by hydrogen or biofuels. We therefore investigated a number of scenarios in order to consider the possible options, ranging from importing all the hydrogen to complete production in Japan. The Scenarios range from a 47% import share in Scenario One, to no imports in Scenarios Five and Six.

Sources of hydrogen from domestic renewables primarily include wind and solar photovoltaic, and geothermal sources. The ERJ Research Team excluded increased large-scale hydropower provision in Japan due to the environmental impact of such plants, although clearly there is much scope for small-scale hydropower, including along rivers. Such small-scale hydropower is viable, but more research is required into the potential for Japan. Sustainably produced biomass also

77. EDMC (1999).

holds enormous potential for substituting a part of the import share, but the amount available was unknown at the time of publication of this study. Other renewable sources such as tidal power were not considered due to the level of development and their as yet unknown potential.

5.4.1) Increasing the Share of Renewables – What is possible?

Solar Photovoltaic

The ERJ Scenario One includes approximately 405km^2 (about 46% of the area mentioned above) of photovoltaic generators. This is equivalent to an average surface area of 3.2m^2 per capita. If the suitable area in the commercial and industrial sectors is also considered, 31% of the total available area in Japan was used for the installation of photovoltaic systems in Scenario One[78]. This is increased to 4.8 m^2 per capita in Scenarios Three, Four and Six, and further increased to a maximum of 6.0 m^2 per capita in Scenario Five, representing about 60% of the total available area[79] in Japan.

Increasing the efficiency of solar cells offers additional potential. The PV systems used in Scenario One are 15% efficient. The other scenarios use efficiency values of up to 18% (BP Solar currently produce mono-crystalline cells with an efficiency of 18%). The maximum efficiency reached in the laboratory is 24.7% for silicon-based mono-crystalline solar cells of the wafer type. Past experience shows that the maximum efficiency reached in the laboratory will be found within the commercial arena after approximately ten years[80]. A further development of the Institute for Solar Energy Research (Institute für Solarenergieforschung, ISFH) in Hameln, Germany is the MINP solar cell, with which a standard solar cell - with p-n junction - having an MSI contact, was combined with a structured surface; the efficiency reached was 21.1%. According to ISFH this technology offers the potential for economical mass production.

Solar-thermal

Solar-thermal systems are used in the industrial and commercial sectors to support other heat producing technologies. In these sectors ten percent of the suitable areas (approximately 1,714 km^2 in the commercial and approxmiately 2,569 km^2 in the industrial sector) were used for installa-

78. This is equivalent to about ten percent of the commercial and industrial sectors, 170 km^2 in the commercial and 260 km^2 in the industrial sectors.
79. The total available area is described in the section on energy sources. This area is located on roofs and façades with a southerly orientation.
80. Green, M. (2001)

tion, which is a quite conservative approach, especially with regard to flat roofs, which are in the majority in the industrial and commercial sectors.

The total area of solar-thermal collectors in all ERJ Supply Models is about 800 km^2, thereof approximately 280 km^2 on top of residential buildings (about 30% of the suitable area), about 170 km^2 on commercial buildings, and roughly 260 km^2 on industrial areas; this is about ten percent of the available area in the commercial (approximately 1,700 km^2) and industrial (approximately 2,600 km^2) sectors.

Hydropower

The use of hydropower is not increased in any of the scenarios beyond that used in Scenario One. This amount is ten percent greater than presently supplied in Japan, the increase resulting from the modernisation of plants as described in the section on energy sources.

Wind

In total, 27,029 wind turbines are installed in Scenario One, with 5,096 plants offshore and 21,933 onshore. The total electric power is 56,917 MW, which is less than five times greater than was installed in Germany by the end March 2003[81].

To get an impression of Japan's wind power potential compared to Germany's, the length of Japan's coastline is about 29,000 km, whereas the German coastline is approximately 1,000 km. The potential in Germany has been estimated at about 65,700 MW peak power[82]. This includes sites up to 30km distance from the coast and up to a water depth of 40m. They even mention the possibility of supplying the total electrical demand by offshore wind energy from the North Sea. This requires an installed capacity of about 136 GW. The area required would be 107 km^2. Thirty projects are planned in Germany with a total of 60,000 MW peak power at the request of the Bundesamt für Seeschifffahrt und Hydrographie (BSH) in Hamburg[83]. DEWI forecast an installed capacity of 15GW to 26 GW in 2030.

If Germany is able to produce so much energy from offshore wind parks with such little coastline (around 1000 km), Japan should have no problem with its 29,000 km of coastline.

The world's largest offshore windpark, with a capacity of 160 MW has now been completed at Horns Rev in Denmark. The windpark, consisting of 80 turbines oftwo MW, is capable of produc-

81. Bundesverband Windenergie e.V. (2002).
82. DEWI (2001), Ender, C. (2002), Molly 2001, Rehfeld 2002.
83. Bundesverband Windenergie e.V.(2002).

ing 160 MW in full operation, and is expected to produce approximately 600 million kWh (600 GWh) annually, roughly two percent of the total power consumption in Denmark. The Danish plan is to provide a total capacity of 4,000 MW in Danish waters before 2030.

Photo copyright: Elsam A/S.
Figure 35 : Horns Rev in Denmark

It is difficult to quantify the maximum potential for wind power in Japan. Taking into account the installation density in Scenario One, the upper limit is set to 0.5 plants per km^2 onshore, and 0.15 per km^2 offshore. The highest density onshore is in Kyushu South with 0.39 per km^2, and offshore it is 0.106 per km^2 in Hokkaido West. Taking these values and the average size of wind parks at 25 units per wind park, a distance of over 11km between windparks is seen at Kyushu South. Offshore installation distances range from 7km to 70 km. Tripling onshore installation is therefore not a problem regarding area or wind. The only limitation with offshore plants is in Hokkaido West, which is already well used.

The world potential offered by wind energy is immense. Its potential even exceeds the estimated world electricity demand in 2020 by more than a factor of two. The Greenpeace study "Wind Force 12" showed that 12% of the world's electricity demand could be covered by wind energy by the year 2020[84].

Geothermal

The potential for geothermal energy in Japan is not as great as with wind. According to the Institute for Energy and Total Engineering[85], Japan's geothermal sources located outside of national parks offer the potential for installing power plants with 76,158 MW of electrical power. Scenario One uses just over 22,900 MW of geothermal power plants (about 25% of the potential) for the

84. EWEA (2002).
85. NEDO (1989).

production of electricity. So clearly there is scope for an increase of 75% in theory. Scenarios Three, Four and Six increase the use of geothermal to 35% of the potential and Scenario Five uses 40%. In addition, the degree of utilisation in Scenario One is equivalent to approximately 7,000 full load hours a year. Scenarios Three to Six increase this to 8,100 full load hours.

Further improvements can be achieved by using the Organic Rankin Cycle technology. This technology is already well established[86]. In addition, further improvements can be made through the "Kalina cycle" produced by General Electric & Exergy, which claims it is possible to increase the efficiency of geothermal power production by 50%, using this system[87]. Those plants can reach an overall efficiency of up to 62% according to the manufacturers.

Figure 36 : An ORC power plant[88]; Source :Turboden, Brescia, Italy.

Solar-thermal Plants

Scenarios Five and Six utilise solar-thermal plants for the production of hydrogen. These must be located in southerly areas in Japan and require, 600 km^2 and 410 km^2 respectively. Clearly the

86. Turboden s.r.l., in Brescia, Italy market an ORC plant with a electrical efficiency of 18 %.
87. California Energy Commission (1997).
88. Two geothermal power-plants using the ORC (Organic Rankine Cycle) technology are already in operation in Austria and Germany. The plant in Altheim, Austria from Turboden has a generating capacity of 1.000 kW. After a testing period of two years the plant is in normal operation since September 2002. The German plant in Neustadt-Glewe started operation in November 2003 and has a generating capacity of 210 kW. Sources: [Geothermische Energie 36/37 - Sonderheft Altheim, 10. Jahrgang/Heft 3/4, Juni/September 2002, Magazin of Geothermische Vereinigung e.V., Germany; 2002], [Erdwärme-Kraft GbR, Berlin, Germany; 2003].

maximum potential is restricted to the amount of free area available in the south of Japan. The most southerly islands of Okinawa for example cover 2,267 km^2 .

5.4.2) The Scenarios

Scenario One: Importing Energy in the Form of Hydrogen

As already stated, Japan does not have much available space, so future development will show if a greater proportion of the hydrogen required gets imported from areas where space, costs and radiation conditions are more ideal for hydrogen production. Issues of hydrogen in a future energy system are discussed later in this report. Please refer to table in appendix for detailed information regarding the scenarios.

Scenario Two: Population Change

This is the same as in Scenario One, but the projected decline in the Japanese population from 127 million in 1999 to 100 million by 2050 results in a reduction in energy demand from nearly 7,500 PJ to under 6,000 PJ. The supplies of electricity and heat remain the same, but the supply of fuels from electrical surpluses almost doubles, coupled with a decline in consumption of fuels for heat production. This results in a surplus of fuels and a resulting increase in supply to cover 63% supply of Japan's energy needs with 3,075 PJ of hydrogen to be imported. This is now 13.4% of the import share compared to 1999.

Scenario Three: Offshore Offensive

Energy supply is increased, mostly using offshore wind power, as the name suggests. A number of measures are taken to increase energy supply from domestic sources including:

Photovoltaic: (PV) installation was increased by a factor of 1.5 compared to Scenario One, reaching 4.8m^2 per capita. PV's efficiency was also increased to 18% (compared to 15% in Scenario One). This, coupled with heat supply in industry is still less than the total surface area available in Japan.

Heat supply in industry: The amount of solar collectors in industry was doubled (an additional 257 km^2).

The amount of area required for photovoltaic and solar collectors is still less than the maximum area available in Japan[89].

Wind: The onshore installation of windmills remained unchanged, while the offshore installation is four times the amount of plants, compared to Scenario One. It was assumed that all additionally installed windmills are five MW plants. So the average installed power climbs from 2.6 MW in Scenario One to 4.4 MW in Scenario Two.

Geothermal: The used potential was set to 35% and the amount of full-load hours increased to 8,100 hours per year. Organic Rankin Cycle technology (ORC) is used in all geothermal plants. Efficiency is still 17.7%.

Use of electrical surpluses: The efficiency of hydrogen production was set to 80%.

These measures raise the amount of energy produced from regional sources from 5,321 PJ in Scenario One to 7,403 PJ or 72% of Japan's energy needs. Another 2,932 PJ must then be supplied by imported hydrogen or regionally produced sources. This is under 13% of the 1999 import share.

Figure 37 : Horns Rev in Denmark

89. Please refer to the discussion on maximum installation in Japan for estimates of the maximum installation capacities (section 5.2.1).

Scenario Four: Offshore Offensive combined with Population Reduction

Measures are the same as with Scenario Three with increased energy supply, but the population decline described in Scenario Two is adopted, resulting in an increase in the share of domestic energy supply to 85% and a reduction in imports to 1,294 PJ or 5.6 % of the 1999 import figure.

Scenario Five: Full Supply and Rational Use of Electricity

Electricity not needed to cover the fuel demand of cogeneration and transport is used for heat production, rather than converting surplus electricity to fuels and then heat. A direct conversion to heat is 90% efficient compared to conversion to fuels first and then combustion (with an efficiency of 75% See the discussion on electrical surpluses below). Further measures taken to increase energy supply from domestic sources include:

Photovoltaic: (PV) The area was increased to 6m^2 per capita, with efficiency remaining at 18% An additional 6m^2 per capita was installed on façades of buildings.

Heat Supply in industry: The amount of solar collectors for industrial process heat was tripled (an additional 514 km^2).

Solar-thermal plants: This scenario utilises 600 km^2 of solar-thermal power plants (with an efficiency of 20%).

Wind: Efficiency was assumed to be 30% instead of 25% in Scenario One.

Onshore installation (installed units) was increased by a factor of 2.5. Offshore installation (installed units) was increased by a factor of 4.5. All offshore plants are of the 5MW type.

Geothermal: Increased use of geothermal potential to 40%. ORC is used in all plants with an efficiency increased to 20%.

Use of electrical surpluses: The efficiency of hydrogen production was increased to 85%. Only a part of electrical surpluses is used for fuel production (after fuel demand of cogeneration and transport is covered). The remaining electrical surplus is used for direct production of process heat in industry (efficiency 90%) This reduces the need for heating plants. The conversion chain of electricity to heat is more effective (an efficiency of 90%) than the chain of electricity to fuel and then to heat (an efficiency of 75%).

This scenario provides over 10,000 PJ from domestic sources, equivalent to almost 100% of Japan’s needs.

Scenario Six: Full Supply, Rational Use of Electricity and Population Change

Again the projected population decline is employed and combined with Scenario Five. The main differences include:

Photovoltaic: Area: 4.8m^2 per capita (1.5 times of Scenario One, but less than in Scenario Five). No façade mounted PV is included.

Heat supply in industry: The amount of solar collectors in industry was halved compared to Scenario Five.

Solar-thermal plants: Area of 410 km^2.

Wind: The number of onshore windmills is a third greater than in Scenario One, but much less than in Scenario Five. Offshore is just under four times the amount of Scenario One (slightly less than in Scenario Five), using only 5MW plants (this differs from Scenario 3). Efficiency remains at 30%.

Geothermal: Used potential is 35%, with all plants using ORC. Full-load hours: 8,100 hours per year.

Use of electrical surpluses: The efficiency of hydrogen production was set to 85%. Only a part of electrical surpluses gets used for fuel production (fuel demand of cogeneration and transport are covered). The remaining electrical surplus is used for direct production of process heat in industry (efficiency 90%) This reduces the need for heating plants as explained in Scenario Five.

This is a 100% regional supply, producing over 8,500 PJ of energy, with no imported fuels.

5.4.3) Which Scenario offers the Best Solution?

All of the above scenarios are feasible in Japan, both in technical terms and in terms of natural resources, such as wind, solar radiation and geothermal capacity. The decisive factors will be costs, public acceptance and priorities set by national policy in terms of energy security and international commitments. In terms of costs and energy security, a mixture of regional sources including sustainably produced biomass, supplemented by imports of hydrogen represents the best solution to ensure a sustainable supply.

These scenarios provide a number of possible solutions, but these are in no way comprehensive as many variations are possible. The team have attempted to offer a wide spectrum of possibilities, but do not attempt to provide an “ideal” solution.

5.4.4) Domestic Energy Production in the ERJ Scenarios

In Scenario One, the electrical output of photovoltaics, wind power, hydropower and geothermal energy is equivalent to 48% of the total energy production. Solar-thermal collectors produce an additional 14%. Renewable fuels account for about 38% of energy production; this consists of the three percent of energy that is produced by domestic hydrogen production. These results do not consider opportunities of increasing the domestic share of energy production, such as sustainably produced biomass and an extended use of renewable sources for hydrogen production. Scenario One shows that at least 53% of energy can be produced from domestic renewable sources. A number of alternative scenarios for covering the remaining demand are also presented.

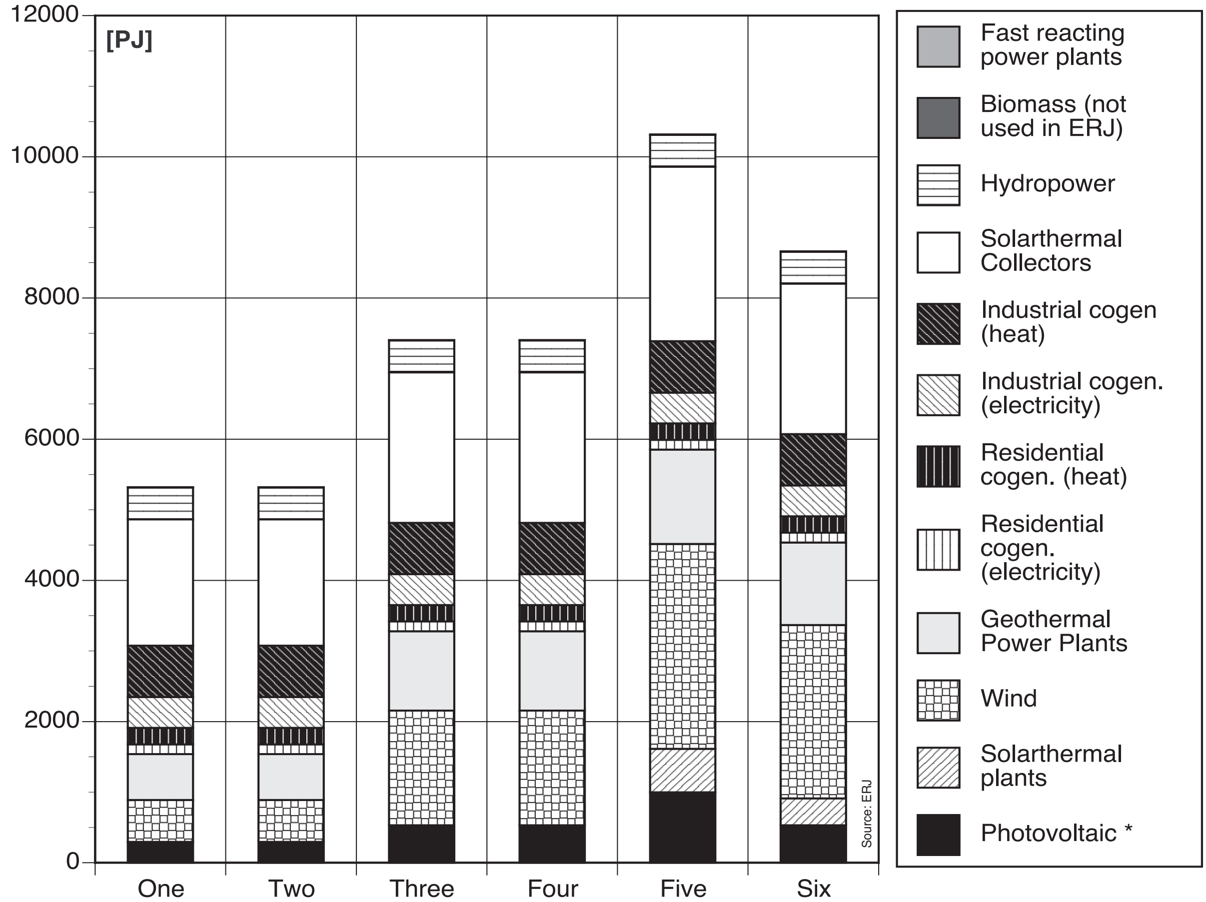


Figure 38 : Domestic energy production in all "Energy-Rich Japan" scenarios. This is the production of electricity and heat in the installed power plants. Biomass is set to zero. Sustainably produced biomass holds enormous potential, but the amount available was unknown at the time of publication of this study

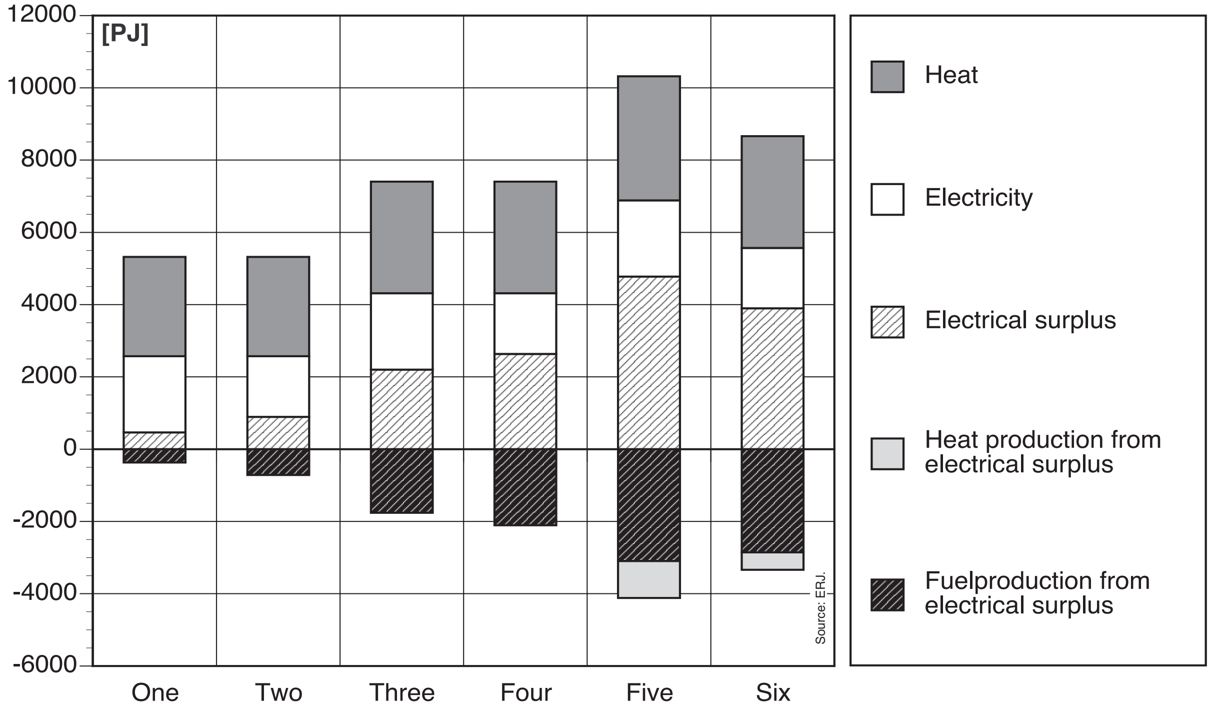


Figure 39 : Domestic electricity and heat production in all six “Energy-Rich Japan” scenarios. Electricity surplus is used for heat and fuel production

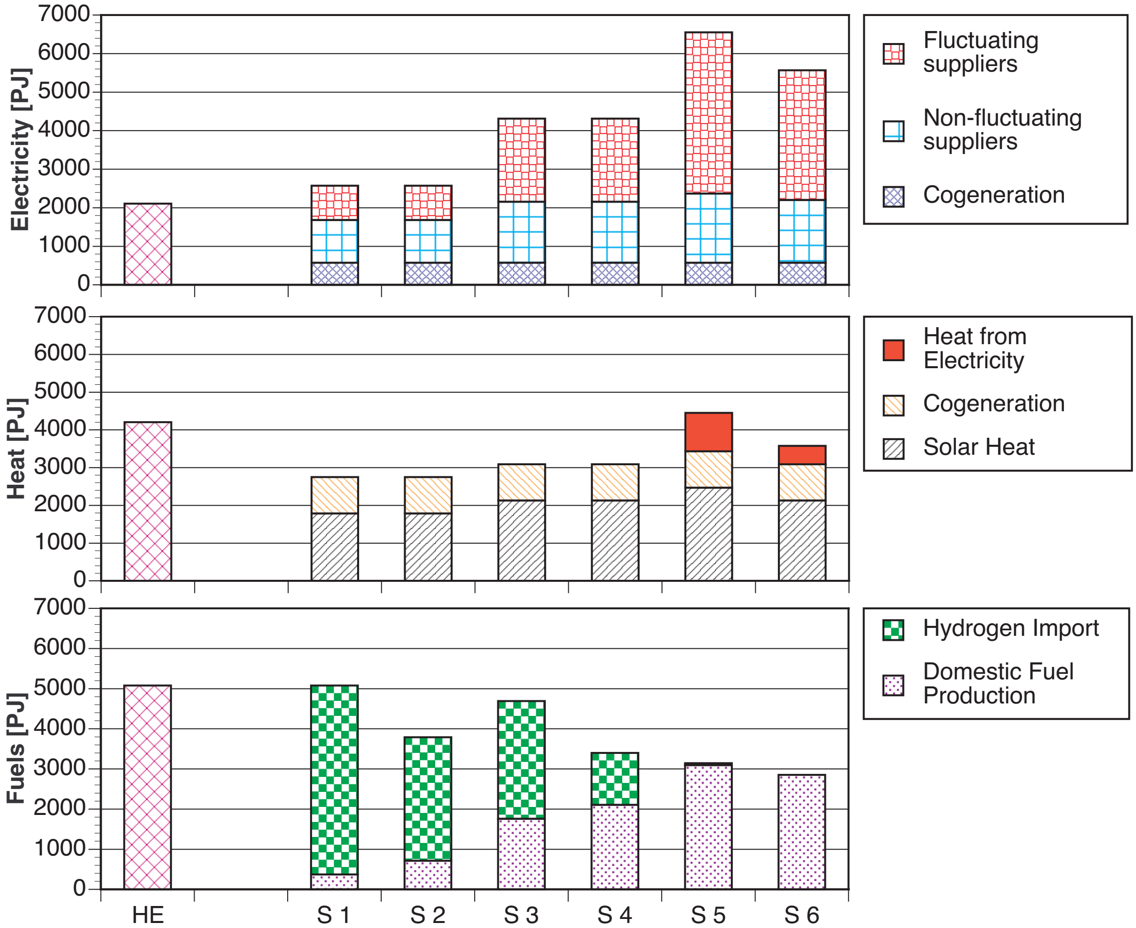


Figure 40 : Electricity, heat and fuel production in all six “Energy-Rich Japan” scenarios. Electricity surplus is used for heat and fuel production

5.4.5) The Use of Hydrogen in a Future Energy System

Importing hydrogen represents no technical barrier in terms of production, the amount that can be produced, the technology or transport, whether by ship or by pipeline[90]. The global potential exists for solar-thermal plants worldwide, mostly in desert areas, to sustainably produce 344x103 PJ of hydrogen per year[91]. The amount required by Japan is only 1.3% of this figure. By comparison, the worldwide primary energy consumption in 1999 was 360x103 PJ. In other words the world's total primary energy consumption is only a little more than could be produced a from solar-thermal plants producing hydrogen. The world wind potential is also enormous with an ability to produce 153x103 PJ of hydrogen.

Photo copyright: Duke Solar Energy, Raleigh, USA.

Figure 41 : Parabolic reflectors producing electricity used for hydrogen production

90. This issue is discussed in detail in the Greenpeace commissioned report: "Hydrogen Production via Electrolysis using Electricity from Renewable Energy Sources in Off-grid Regions" by the Frauenhofer Institute in Germany.
91. DLR (1989).

	Electrical potential (TWh)	Hydrogen production ($x10^3$ PJ)	Japan's $4.5x10^3$ PJ as % of total
Global wind power potential	53,000	153	2.9
Solar-thermal plants in desert regions and wastelands (1.9 million km^2)	119,430	344	1.3

Note: assumed electrolyis efficiency of 80%[92][93].

Source: ISUSI (2003).

Table 21 : Global hydrogen production and Japan’s demand in Scenario One

The issue of creating a hydrogen infrastructure for supplying transport and combined heat and power is a matter for policy decisions and market forces. In the transportation sector we have really only seen research and development in the last 15 years. This makes it difficult to make recommendations or predictions, but many lessons have been learnt from experiences in the last few years with the use of natural gas in vehicles.

A hydrogen infrastructure already exists in parts of the world. For example at Munich airport in Germany, a fully functioning network of hydrogen fuelling buses exists. Two extensive hydrogen networks have been in existence for over 50 years in Germany. One is located in the industrial Ruhr valley and is operated by BOC under contract for Hüls AG. The second is located in Leuna-Bitterfeld-Wolfen and is operated by Linde AG. Both networks include over 50 km of piping and connect local producers and consumers, mostly in the chemical industry.

Icelandic New Energy Ltd. is a joint venture company that was founded to investigate the potential for eventually replacing the use of fossil fuels in Iceland with hydrogen-based fuels. The planned transformation of Iceland into a hydrogen society is divided into five phases, starting with the introduction of fuel-cell driven buses in Reykjavik (2002) and ending in a fully hydrogen based energy supply by between 2030 and 2050[94].

Another important issue is location. One central location for hydrogen production is not ideal due to transportation and security issues, but would benefit from a better price/performance ratio, as larger plants are more competitive. A distributed system of production using a range of renewable energy sources would provide for regional needs, therefore reducing transport costs. This is also a better policy for ensuring supply should one region or energy source fail.

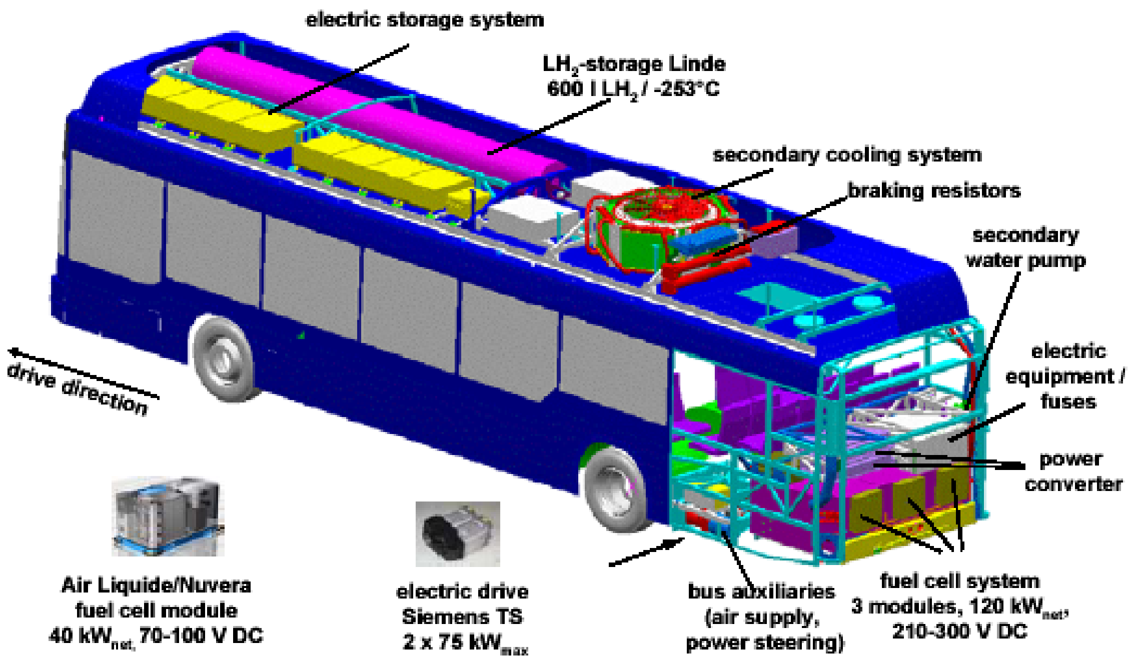
92. German LB-Systemtechnik claims an efficiency of 74-79%, related to the upper heating value of hydrogen. Energy consumption of supporting devices is already included.
93. German Fraunhofer Institut für solare Energiesysteme –ISI- has developed a PEM electrolyser with an efficiency of 85%. (Hydrogen Production via Electrolysis using Electricity from Renewable Energy Sources in Off-grid Regions; 2003).
94. The Company is owned by VistOrka hf, Daimler-Chrysler AG, Norsk Hydro ASA and Shell Hydrogen B.V. Icelandic New Energy Ltd., 2001.

Hydrogen in Transport

In May 2000 MAN presented its first city bus using an emission-free PEM-fuel-cell drive jointly developed by Siemens and Linde in Germany. The fuel-cell system, consisting of four inline connected stacks, produces 120 kW electric power for the drive system and is supplied by hydrogen from 250 bar high pressure storage tanks mounted on the bus roof[95]. The bus was successfully tested as a regular city bus service between Nuremberg, Erlangen and Fürth in Germany October 2000 and April 2001.

A number of cars and buses have been successfully running on both liquid and gaseous hydrogen since 1999 in the Munich International Airport hydrogen project[96]. Refuelling of the cars is fully automated and made safe with the use of advanced robotics, coupled with gas sensors.

On 10th of March 2003, the Japanese Ministry of Infrastructure and Transport gave General Motors the first permission for a car operated with liquid hydrogen to operate on Japanese roads to the GM/OPEL HydroGen3. It also received the first permission for an LH2-vehicle fuel tank from the Japanese High Pressure Gas Safety Institute of Japan.



Source: Karl Viktor Schaller, Christion Gruber (2001) Hydrogen Powered Fuel-Cell Buses Meet Future Transport Challenges. MAN Nutzfahrzeuge AG.

Figure 42 : Schematic diagram of the MAN hydrogen bus

95. Nowadays pressure tanks with 350 bar pressure are state of the art, whereas tanks up to 700 bar are currently under development (Source: LB-Systemtechnik (2003)).
96. The project, run by a consortium called ARGEMUC, consists of 14 German companies along with the free state of Bavaria, which has a 50% stake in the project. Gaseous hydrogen is generated locally by electrolysis and Linde TG supplies liquid hydrogen from Ingolstadt.

On the 11th of March the first Japanese test centre for fuel cell vehicles was officially opened. In the project five car manufacturers, (DaimlerChrysler, General Motors, Honda, Nissan and Toyota) and further companies from the energy industry, have combined in order to test fuel cell vehicles and the fuel infrastructure in everyday use. The Japan Hydrogen & Fuel Cell Demonstration Project[97] (JHFC), promoted by the Japanese government in close co-operation with industry, has the goal of advancing the science and the readiness for the market of this technology. The JHFC mechanism offers long-term conditions for vehicle testing, as both workshops and an information centre are available to users. The first of five hydrogen gas stations for the fuel cell cars opened one day later in Yokohama, Japan. DaimlerChrysler is planning to lease fuel cell vehicles in Japan by the second half of 2003.

The plan is to lease up to ten vehicles in Japan between 2003 and 2004. DaimlerChrysler's Japanese partner Mitsubishi is said to support the project. DaimlerChrysler intends to deliver 60 fuel cell A-class-vehicles in Europe, the USA, and Singapore between 2003 and 2004[98].

Briefly after distribution of the first leasing vehicles with fuel cell drive, Toyota presented a new concept vehicle at the Detroit Motor Show. According to Toyota the vehicle represents only the beginning of a whole set of planned new vehicles. The drive (fuel cell hybrid) is a basis element of a modular structure and is identical in each case and can therefore be easily integrated into further vehicles.

Hydrogen Safety Issues

Hydrogen has been used safely in vast quantities in chemical and metallurgical applications, the food industry and the space program for many years. Hydrogen and fuel cells will soon play an even greater role in meeting our energy needs. Like all fuels, hydrogen can be used safely with appropriate handling and engineering controls.

Similar to the fuels we use today, there are hazards associated with handling and using hydrogen, but industry has shown that hydrogen can be used safely in a wide variety of applications and conditions by employing proper safety controls. Safety considerations associated with handling hydrogen include fire, explosion, and asphyxiation. Hydrogen is the lightest gas known and is very buoyant, which means it quickly dissipates to the surrounding air. It does not spontaneously combust[99]. It is flammable over a wider range of concentrations than either petrol or natural gas, but it dissipates more rapidly than either of these fuels in a spill. Hydrogen gas, like other gases used today, should be used in areas that can be ventilated.

97. JHFC (2003).
98. HyWeb (2002).
99. The ignition point of hydrogen is 570˚C, compared to petrol at 500˚C.

As with all fuels, appropriate measures can be put in place to achieve acceptable levels of safety. With proper handling and controls, hydrogen can be as safe as, or safer than, other fuels that we use today.

Hydrogen has a higher combustion energy per kilogram relative to any other fuel, meaning hydrogen is more efficient on a weight basis than fuels currently used in air or ground transportation. This weight factor makes hydrogen an attractive fuel, although the volume required for the same energy is greater.