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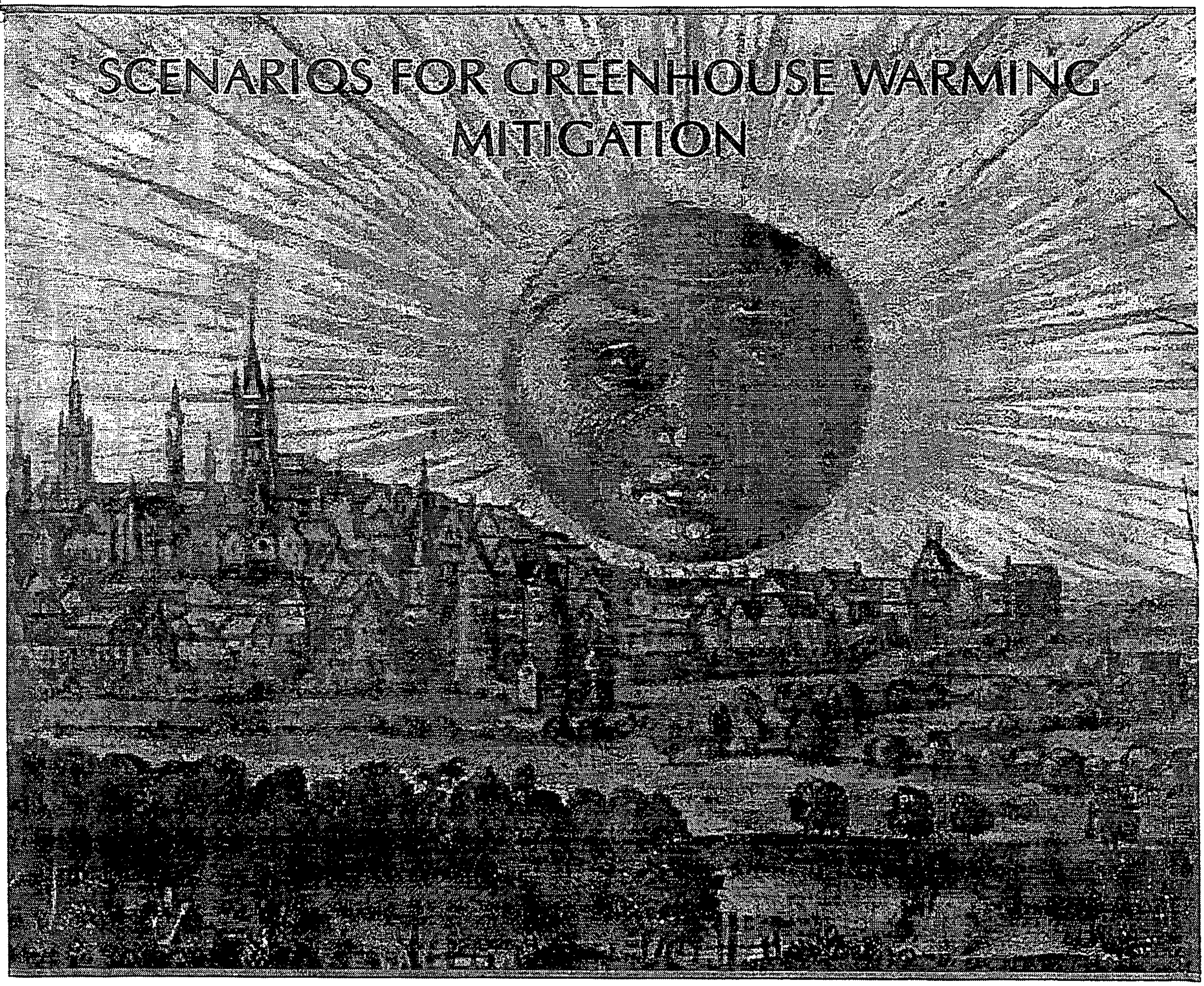
Bent Sørensen

SCENARIOS FOR GREENHOUSE WARMING MITIGATION



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SCENARIOS FOR GREENHOUSE WARMING MITIGATION

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Abstract - Four global scenarios of energy provision are considered, all of which have zero net emissions of greenhouse gases. The scenarios assume the same demand for energy services and a high degree of emphasis on energy efficiency. The supply options are clean fossil fuels, safe nuclear power, centralised or decentralised renewable energy, respectively. The scenarios provide an "existence proof" of greenhouse mitigation options, but otherwise are very different, in terms of energy infrastructure and presumably cost. Detailed estimates of environmental costs and regional setup including trade patterns have not yet been fully carried out, and the results are thus preliminary.

SCENARIOS FOR GREENHOUSE WARMING MITIGATION

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Abstract - Four global scenarios of energy provision are considered, all of which have zero net emissions of greenhouse gases. The scenarios assume the same demand for energy services and a high degree of emphasis on energy efficiency. The supply options are clean fossil fuels, safe nuclear power, centralised or decentralised renewable energy, respectively. The scenarios provide an "existence proof" of greenhouse mitigation options, but otherwise are very different, in terms of energy infrastructure and presumably cost. Detailed estimates of environmental costs and regional setup including trade patterns have not yet been fully carried out, and the results are thus preliminary.

1. INTRODUCTION

The IPCC Working Group 2 has broadly identified options for mitigation of the greenhouse warming associated with extrapolating the current energy supply structure [1], but it also deplores the absence of well thought-out global scenarios that combine the individual options into a credible picture of the overall future energy supply. The present contribution is a presentation of an ongoing project aimed at supplying such detailed scenarios, and it gives preliminary results for the main characteristics of four key scenarios, each of which is extreme in using basically only one type of energy supply. Actual energy policies may of course select any mix of the base scenarios. However, these are useful in discussing the characteristics as well as the impacts of any combination.

2. BASIC ASSUMPTIONS AND DEMAND MODEL

The scenario year is 2050, in order to allow for a complete replacement of all equipment (except some buildings) with the best technology available. This implies a uniform assumption of high conversion efficiencies, right to the final conversion of energy into the service or product demanded, for all the scenarios. Table 1 gives the assumptions regarding population and end-use energy demand. The population estimates are from the World Bank [2] and the 2050 values correspond to the assumptions of high welfare and economic activity. The end-use energy estimates are the minimum amounts of energy, that could deliver the service actually demanded, using the best method and conversion equipment known today. The goal, which in 2050 has not been achieved in all regions, is based on a basic and derived needs analysis made previously [3]. It assumes that the Earth will continue to be populated by a mixture of audacious and concerned citizens. The audacious citizens are risk takers, who want to implement new ideas quickly and not to deal with negative impacts until they show. The concerned citizens worry about the environment and possible side effects of human activities, so they want to move very cautiously ahead. The scenario growth in demand satisfaction between 1990 and 2050 is seen to be 2-3 times higher than the corresponding growth between 1930 and 1990, which indicates that very challenging assumptions regarding future economic and social development have been invoked. The regional distribution of energy supply will only appear after the energy system analysis has been carried out, but it is already clear, that it will be substantially different from the IPCC and WEC scenarios [1], due to the analysis made of the detailed composition of the energy use at the end-user (a feature that is deplorably missing from most current international statistics).

Figure 1 gives the 1990 energy supply and conversion structure in condensed form. Out of the 10 TWy/y primary energy, about 77% is delivered to the final user. This is reduced to about 50% taking into account some obvious losses in end-use conversion [4,5], but further down to 10%, when the above definition of energy service is used. It is thus clear, that the most significant area for improvement is in the processes taking place at the end-user. Significantly better design of end-use supply systems and better technical efficiencies of end-use equipment is thus a common assumption for all the scenarios. At unchanged demand, this alone would reduce the necessary energy supply by about a factor of four, but it will have to be folded with activity increase and alterations in the system setup, between now and 2050.

3. THE CLEAN FOSSIL (CF) SCENARIO

The clean fossil fuel scenario assumes that by 2050, fossil energy will be used without emission of carbon dioxide. Either the fuel has been transformed into hydrogen or CO_2 is captured and removed from the flue gases.

Hydrogen can be produced from natural gas using the chemical reaction energy to form the steam required, or from coal by the water-to-gas shift reaction [6,7]. Flue gas cleaning lower the efficiency of power plants, but is technically feasible [8]. The captured CO_2 would subsequently be stored in abandoned natural gas fields or other types of natural or artificial caverns [1]. The total energy system is shown in Figure 2. The hydrogen is used directly as a fuel in industry, or in fuel cell plants producing electricity and if feasible also heat, to be distributed by appropriate power and district heating lines. Half the transportation sector is run on electric vehicles (with batteries if not on tracks), the other half on hydrogen, using small size fuel cells for increased efficiency. Heat pumps are used to provide low-temperature heat, in addition to the district heating. Oil is only used as a feedstock for non-energy purposes, and the chief source of energy is coal. For natural gas the currently identified resources will only last to around 2030 at the rate of usage assumed, and although additional resources may be turned into commercial reserves, this scenario has to be considered transitional. However, a shift towards only relying on coal would prolong the transitional periods to several hundred years.

Table 1. Population (million) and end-use energy (W/cap), the 2050 values used in all scenarios

	Pop.			energy			
Region	1930	1990	2050	1930	1990	2050	goal
USA, Canada	132	265	310	800	900	1100	1100
W Europe, Jap., Astr.	362	545	610	700	900	1100	1100
E Europe, former Soviet, Middle East	240	530	880	200	380	800	1200
Latin America, SE Asia	660	1860	4000	100	115	700	1000
China, rest of Asia	442	1190	2000	60	60	700	1100
Africa	152	610	2000	60	40	200	900
World (average energy)	2000	5000	9800	251	248	644	1026

4. THE SAFE NUCLEAR (SN) SCENARIO

The safe nuclear scenario addresses the main objections to current nuclear power technologies: proliferation issues, large nuclear accidents and long-term storage of waste. To avoid proliferation of fissile material such as plutonium, spent fuel from reactors would be recycled to an accelerator breeder rather than being reprocessed [9]. One thereby reduces the fuel input by a factor of three, while also avoiding at least part of the proliferation problem. The reactors themselves can be made more safe in two ways. One is to reduce the size so much that core melt accidents almost certainly can be contained. This involves maximum unit sizes of 50-100 MW. The other method is to make the conventional light water reactor inherently safe, by enclosing the reactor core of a pressurized water reactor (PWR) within a vessel of boronated water, that will flood the core if pressure is lost, as there is no barrier between the core and the pool of water, that in the absence of pressure in the primary system will shut the reactor down and continue to remove heat from the core by natural circulation. It is calculated that in an accident situation, replenishing of cooling fluid can be done at weekly intervals (in contrast to hours or less for current light water reactor designs) [10]. Finally, as regards nuclear waste, the most long-lived components could be removed by transmutation. At present, the only scheme for doing this would involve a liquid metal breeder reactor [11], which does not fulfill the demand for inherent safety. For this reason, the transmutation step is just indicated in the energy system diagram shown in Figure 3, but not actually used. On the other hand, breeders seem to be required in any scenario of this kind, due to the resource aspect. Even with the factor 3 accelerator breeding, presently identified resources would at the scenario usage rate become depleted in 9 years, and only the true breeding at over a factor 60 will make this scenario sustainable for even the lifetime of the equipment involved.

5. THE DECENTRALISED RENEWABLE ENERGY (DRE) SCENARIO

The renewable energy scenario depicted in Figure 4 is similar to one constructed earlier for Denmark [12] and under construction for the European Union [13]. It uses the currently available low-temperature solar thermal, wind and biogas technologies, as well as anticipated photovoltaic technology that is similar to the current one, but affordable for large-scale power production. As in the fossil scenario, fuel cell technology is assumed to be available, as well as technology for producing hydrogen from biomass (gasification plus shift reaction as for coal) [14]. For the non-electrified part of the transportation sector, liquid biofuels such as methanol are introduced [6,15], in order to minimize the change from current gasoline use. The large share of bioenergy ensures that there is backup for the variable renewable energy sources (solar radiation and wind), notably through active storage of either primary biomass or of biogas and hydrogen in caverns, in combination with the flexibility offered by use of reversible fuel cells instead of conventional power stations. This allows surplus wind and solar cell produced electricity to be converted to a storable fuel, whereas in the transportation sector, the liquid biofuels play this role. In the heating sector, some of the solar heat is stored in (communal size) heat stores connected to district heating lines. However, district heating only makes sense in regions with fairly high heat use density, so in other regions, a backup for the solar panels is provided by biogas and by having heat pumps available.

6. THE CENTRALISED RENEWABLE ENERGY (CRE) SCENARIO

The amount of biomass used in the DRE scenario is large (almost as large as in the IPCC high-biomass scenario [1]) and it requires partly an integrated food and energy production (using residues for biogas and returning fertilizer), partly a biomass to hydrogen and methanol path that may require dedicated bioenergy growth (wood plantations etc.). Only in some parts of the world is this possible, and generally, one has to ensure not only a sustainable energy production, but also a sustainable food production. This involves a number of issues, such as ecological farming (without pesticides) and altered animal and vegetable production ratios [12]. Only the detailed analysis of DRE scenarios will determine, if such sustainability is possible. It is therefore explored here, if a scenario with considerably less biomass use would be feasible. The methanol production is removed and the biomass gasification reduced. The additional energy is obtained from photovoltaics. The decentralized potential on building roofs and facades is considered exploited already in the DRE scenario, so the additional solar cell installations are assumed to be central plants located on infertile lands (deserts etc.). The price for this arrangement is considerable intercontinental power transmission, but losses are still smaller than in the liquid biofuel production. A detailed analysis is needed in order to ensure that the storage capacity in this scenario is sufficient. A positive feature is that the solar electricity production is likely to be higher and more stable in the mostly equatorial desert areas considered, and that the increased power production per unit collector area may pay for the additional structure and transmission equipment.

7. COST ESTIMATES

In the fossil scenario, decarbonization of fuels is estimated to increase costs less than 50%, whereas removal from flue gases is somewhat more expensive. The cost of CO_2 deposition is little known, but probably affordable for natural gas wells. Totally, the energy cost may rise to 2-3 times the present one, which may match the externality cost of greenhouse warming damages [16]. For the nuclear scenario, entirely new techniques are brought in at unknown or high cost [11]. Adding the uncertainty of the breeder reactor that seems to be required for this scenario, the preliminary conclusion would be that it is not a viable option for introduction before 2050. The renewable energy scenarios incorporate wind and biogas systems with costs only slightly higher than current system costs, and also photovoltaic panels, for which considerable (but envisaged) cost reductions have to become realised. These scenarios also include increased use of energy storage or demand management, at a corresponding cost. For the decentralised scenario, the cost of biofuels has to be considered (currently about twice the present energy price [15]), while for the centralised one, the cost of long-distance power transmission is crucial and probably requires new technologies of lower cost than current ones. The detailed cost and externality estimates will have to be performed in order to complete this discussion.

8. CONCLUSIONS

As the scenarios presented here are preliminary and the detailed region by region analysis still has to be done, one should be careful in attaching too much importance to the evaluation of the scenarios. It does appear that the nuclear scenario will have serious problems and probably is not realisable within the 60 year time period considered. Also the centralized renewable energy scenario depends on unproven technology advances (in transmission technology), or will become very expensive. Only the clean fossil and decentralized renewable scenarios seem to be technically feasible and at costs than may be within the range of "fair market" estimates based on present energy prices (minus subsidies and taxes) but plus externality costs, of which the very uncertain greenhouse warming costs are the most significant (estimated at over 0.1 ecu/kWh [16], mostly due to the effects of extreme events on developing countries).

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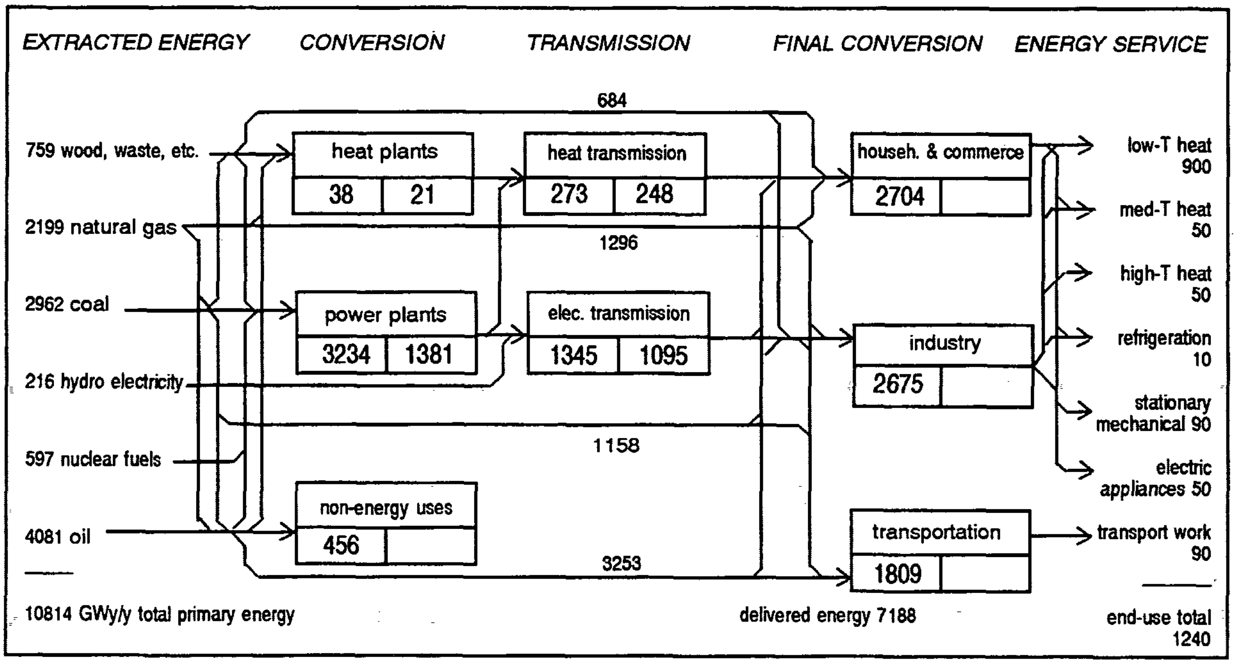

Figure 1. The 1990 global energy system (GWy/y).

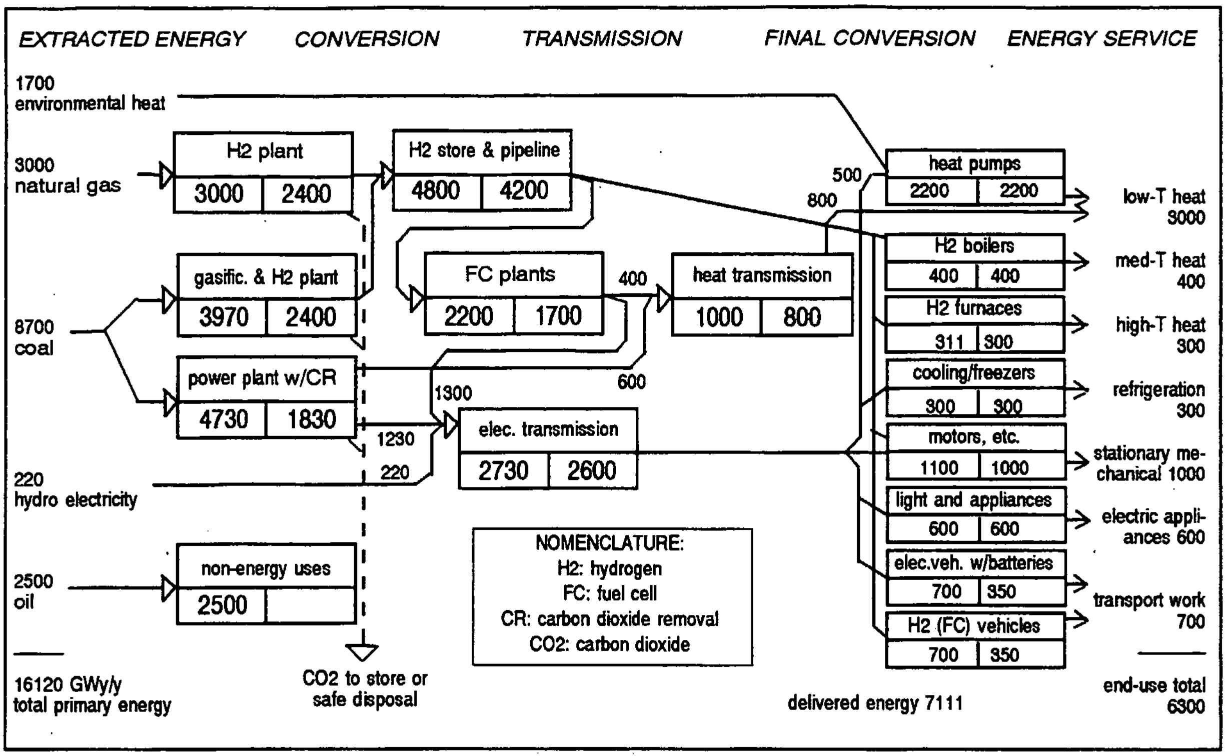

Figure 2. A 2050 clean fossil energy scenario (GWy/y).

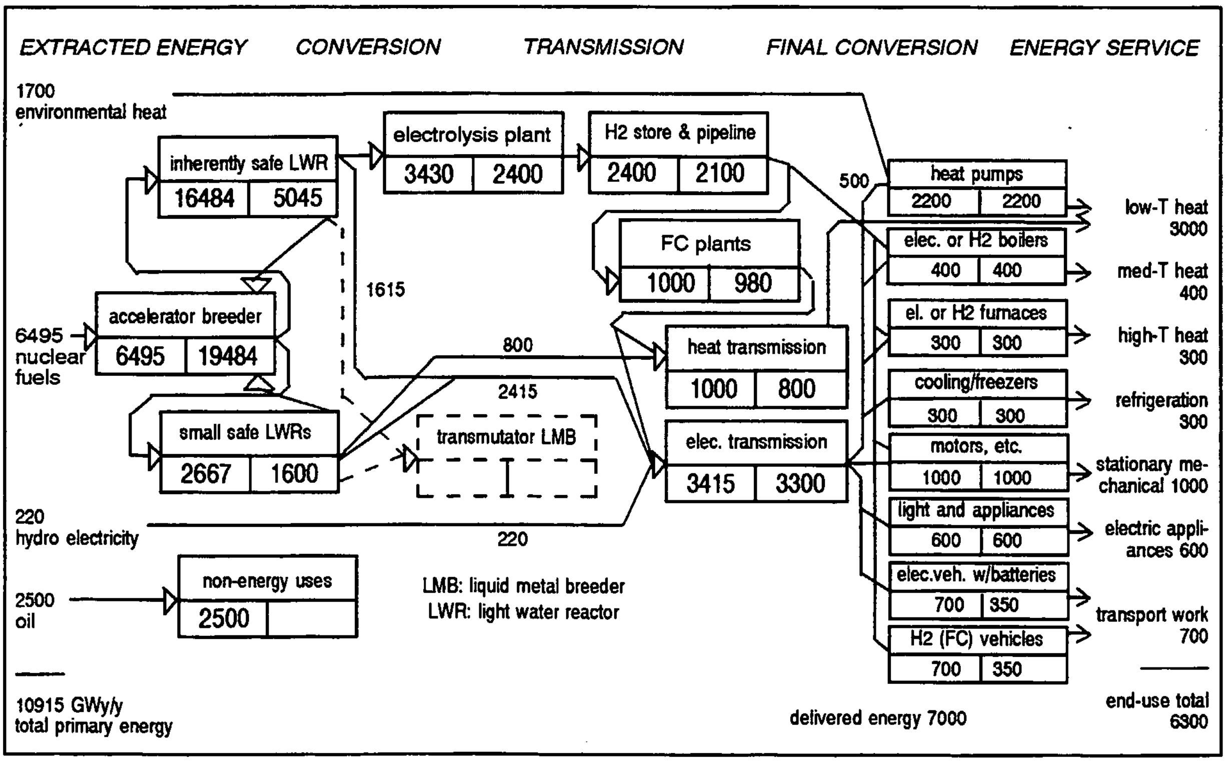

Figure 3. A 2050 safe nuclear energy scenario (GWy/y).

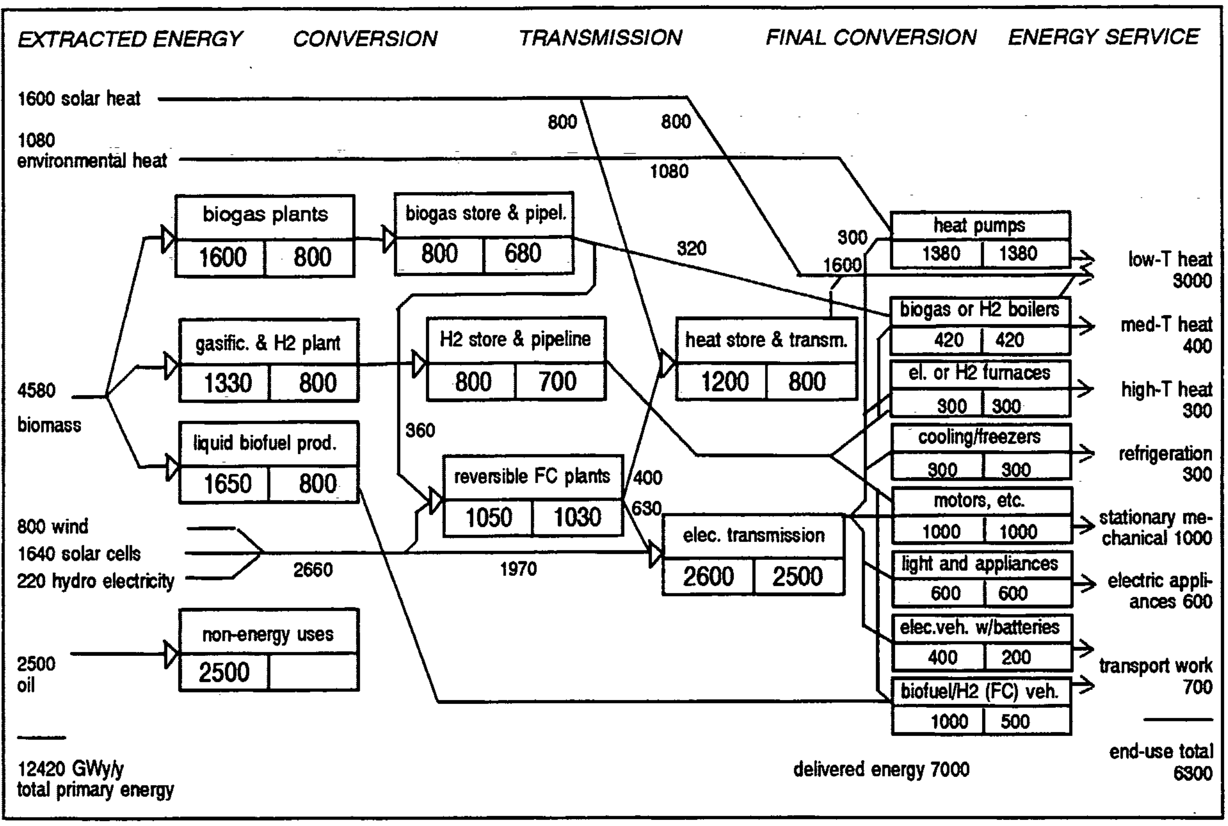

Figure 4. A 2050 decentralized renewable energy scenario (GWy/y).

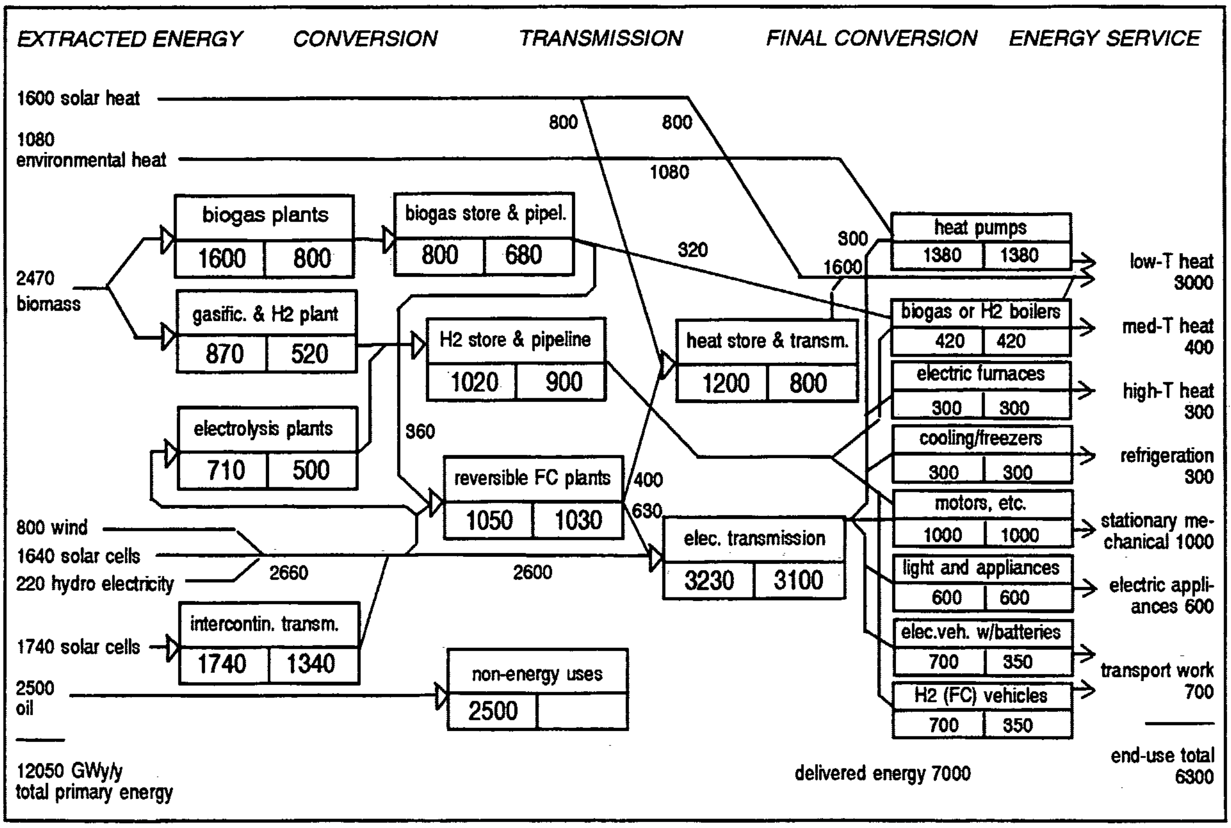

Figure 5. A 2050 centralized renewable energy scenario (GWy/y).

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Vejleder: Viggo Andreasen

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283/94 Grænser for tilfældighed
(en kaotisk talgenerator)

af: Erwin Dan Nielsen og Niels Bo Johansen

284/94 Det er ikke til at se det, hvis man ikke lige ve' det!

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En specialerapport af Peter Hauge Jensen
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Et 3.modul matematik projekt

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an example of using methods developed for the OECD/IEA and the US/EU fuel cycle externality study

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Et matematisk modelprojekt

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