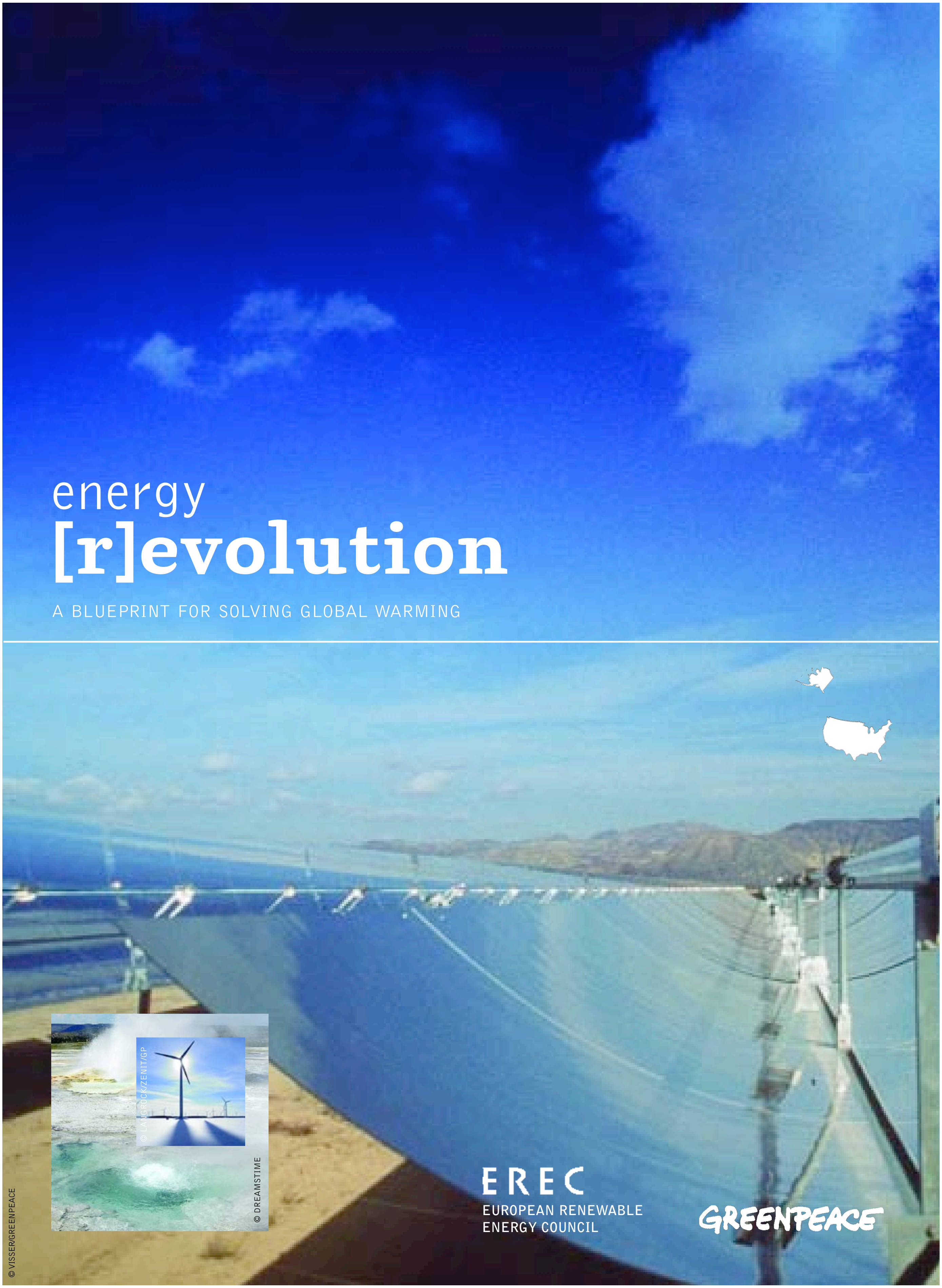
energy [r]evolution

A BLUEPRINT FOR SOLVING GLOBAL WARMING



EREC
EUROPEAN RENEWABLE ENERGY COUNCIL

GREENPEACE

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energy [r]evolution

Greenpeace International, European Renewable Energy Council (EREC)

date January 2007

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cover image CONCENTRATING SOLAR POWER (CSP) AT A SOLAR FARM IN DAGGETT, CALIFORNIA, USA.
image A SMALL ICE BERG WHICH FLOATS IN THE BAY IN FRONT OF THE THE GREENLANDIC TOWN OF NARSAAQ, SOUTH WEST GREENLAND.

foreword

There is now growing awareness on the imperatives for a global energy future which marks a distinct departure from past trends and patterns of energy production and use. These imperatives emerge as much from the need to ensure energy security, as they do from the urgency of controlling local pollution from combustion of different fuels and, of course, the growing challenge of climate change, which requires reduction in emissions of greenhouse gases (GHSs), particularly carbon dioxide.

This publication provides stimulating analysis on future scenarios of energy use, which focus on a range of technologies that are expected to emerge in the coming years and decades. There is now universal recognition of the fact that new technologies and much greater use of some that already exist provide the most hopeful prospects for mitigation of emissions of GHGs. It is for this reason that the International Energy Agency, which in the past pursued an approach based on a single time path of energy demand and supply, has now developed alternative scenarios that incorporate future technological changes. In the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as well, technology is included as a crosscutting theme in recognition of the fact that an assessment of technological options would be important both for mitigation as well as adaptation measures for tackling climate change.

The scientific evidence on the need for urgent action on the problem of climate change has now become stronger and convincing. Future solutions would lie in the use of existing renewable energy technologies, greater efforts at energy efficiency and the dissemination of decentralized energy technologies and options. This particular publication provides much analysis and well-researched material to stimulate thinking on options that could be adopted in these areas. It is expected that readers who are knowledgeable in the field as well as those who are seeking an understanding of the subjects covered in the ensuing pages would greatly benefit from reading this publication.

Dr. R. K. Pachauri
CHAIRMAN INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
JANUARY 2007

introduction

"THE WORLD CANNOT AFFORD TO STICK TO THE CONVENTIONAL ENERGY DEVELOPMENT PATH, RELYING ON FOSSIL FUELS, NUCLEAR, AND OTHER OUTDATED TECHNOLOGIES. ENERGY EFFICIENCY IMPROVEMENTS AND RENEWABLE ENERGY MUST PLAY LEADING ROLES IN THE WORLD'S ENERGY FUTURE."

image TEST WINDMILL N90 2500, BUILT BY THE GERMAN COMPANY NORDEX, IN THE HARBOUR OF ROSTOCK. THIS WINDMILL PRODUCES 2,5 MEGA WATT AND IS TESTED UNDER OFFSHORE CONDITIONS. AT LEAST 10 FACILITIES OF THIS TYPE WILL BE ERECTED 20 KM OFF THE ISLAND DARSS IN THE BALTIC SEA BY 2007. TWO TECHNICIANS WORKING INSIDE THE TURBINE.

The good news first. Renewable energy, combined with energy efficiency, can meet half of the world's energy needs by 2050. This new report, "Energy [R]evolution: A Blueprint for Solving Global Warming," shows that it is not only economically feasible, but also economically desirable, to cut U.S. CO_2 emissions by almost 75% within the next 43 years. These reductions can be achieved without nuclear power, and while virtually ending U.S. dependence on coal. Contrary to popular opinion, a massive uptake of renewable energy and efficiency improvements alone can solve our global warming problem. All that is missing is the right policy support from the President and Congress.

The bad news is that time is running out. The overwhelming consensus of scientific opinion is that the global climate is changing and that this change is caused in large part by human activities; if left unchecked, it will have disastrous consequences for Earth's ecosystems and societies. Furthermore, there is solid scientific evidence that we must act now. This is reflected in the conclusions of the Intergovernmental Panel on Climate Change (IPCC), a collaborative effort involving more than 1,000 scientists. Its next report, due for release early this year, is expected to make the case for urgent action even stronger.

In the United States there is a groundswell of activity at the local and state levels. Many mayors, governors, and public and business leaders are doing their part to address climate change. But they can only do so much; action is needed at the federal level. Now is the time for a national, science-based cap on greenhouse gas emissions.

image FIRST GEOTHERMAL POWER STATION IN GERMANY PRODUCING ELECTRICITY. WORKER IN THE FILTRATION ROOM.

It's time for a national plan to address global warming. Such a plan will create jobs, improve the security of America's energy supply, and protect Americans from volatile energy prices. It will restore America's moral leadership on the critical international issue of climate change. And real action in the United States will inspire confidence as the rest of the world negotiates future global commitments to address climate change.

In addition to global warming, other energy-related challenges have become extremely pressing. Worldwide energy demand is growing at a staggering rate. Over-reliance on energy imports from a few, often politically unstable, countries, and volatile oil and gas prices, have together pushed energy security to the top of the political agenda, while threatening to inflict a massive drain on the global economy. But while there is a broad consensus that we need to change the way we produce and consume energy, there is still disagreement about what changes are needed and how they should be achieved.

the energy scenario

The European Renewable Energy Council (EREC) and Greenpeace International commissioned this report from the Department of Systems Analysis and Technology Assessment (Institute of Technical Thermodynamics) at the German Aerospace Centre (DLR). The Worldwatch Institute was hired to serve as a technical consultant for the U.S. and North American portions of the report. The report presents a scenario for how the United States can reduce CO_2 emissions dramatically and secure an affordable energy supply on the basis of steady worldwide economic development through the year 2050. Both of these important aims can be achieved simultaneously. The scenario relies primarily on improvements in energy efficiency and deployment of renewable energy to achieve these goals. The future potential for renewable energy sources has been assessed with input from all sectors of the renewable energy industry, and forms the basis of the Energy [R]evolution Scenario.

the potential for renewable energy

Renewable energy technologies such as wind turbines, solar photovoltaic panels, biomass power plants, solar thermal collectors, and biofuels are rapidly becoming mainstream. The global market for renewable energy is growing dramatically; global investment in 2006 reached US$38 billion, 26% higher than the previous year.

The time window available for making the transition from fossil fuels to renewable energy is relatively short. Today, energy companies have plans to build well over 100 coal-burning power plants across the United States; if those plants are built, it will be impossible to reduce CO_2 emissions in time to avoid dangerous climate impacts. But it is not too late yet.

We can solve global warming, save money, and improve air and water quality without compromising our quality of life. Strict technical standards are the only reliable way to ensure that only the most efficient transportation systems, industrial equipment, buildings, heating and cooling systems, and appliances will be produced and sold. Consumers should have the opportunity to buy products that minimise both their energy bills and their impact on the global climate.

from vision to reality

This report shows that business as usual is a recipe for climate chaos. If the world continues on its current course, CO_2 emissions will almost double by 2050, with catastrophic consequences for the natural environment, the global economy, and human society as a whole. We have the opportunity now to change that course, but the window is narrow and closing quickly.

The policy choices of the coming years will determine the world's environmental and economic situation for many decades to come. The world cannot afford to stick to the conventional energy development path, relying on fossil fuels, nuclear, and other outdated technologies. Energy efficiency improvements and renewable energy must play leading roles in the world's energy future.

For the sake of a sound environment, political stability, and thriving economies, now is the time to commit to a truly secure and sustainable energy future - a future built on clean technologies, economic development, millions of new jobs, and a liveable environment.

Arthouros Zervos
EUROPEAN RENEWABLE
ENERGY COUNCIL (EREC)

John Coequyt
CLIMATE & ENERGY UNIT
GREENPEACE USA

JANUARY 2007

executive summary

"THE RESERVES OF RENEWABLE ENERGY THAT ARE TECHNICALLY ACCESSIBLE GLOBALLY ARE LARGE ENOUGH TO PROVIDE ABOUT SIX TIMES MORE POWER THAN THE WORLD CURRENTLY CONSUMES - FOREVER."

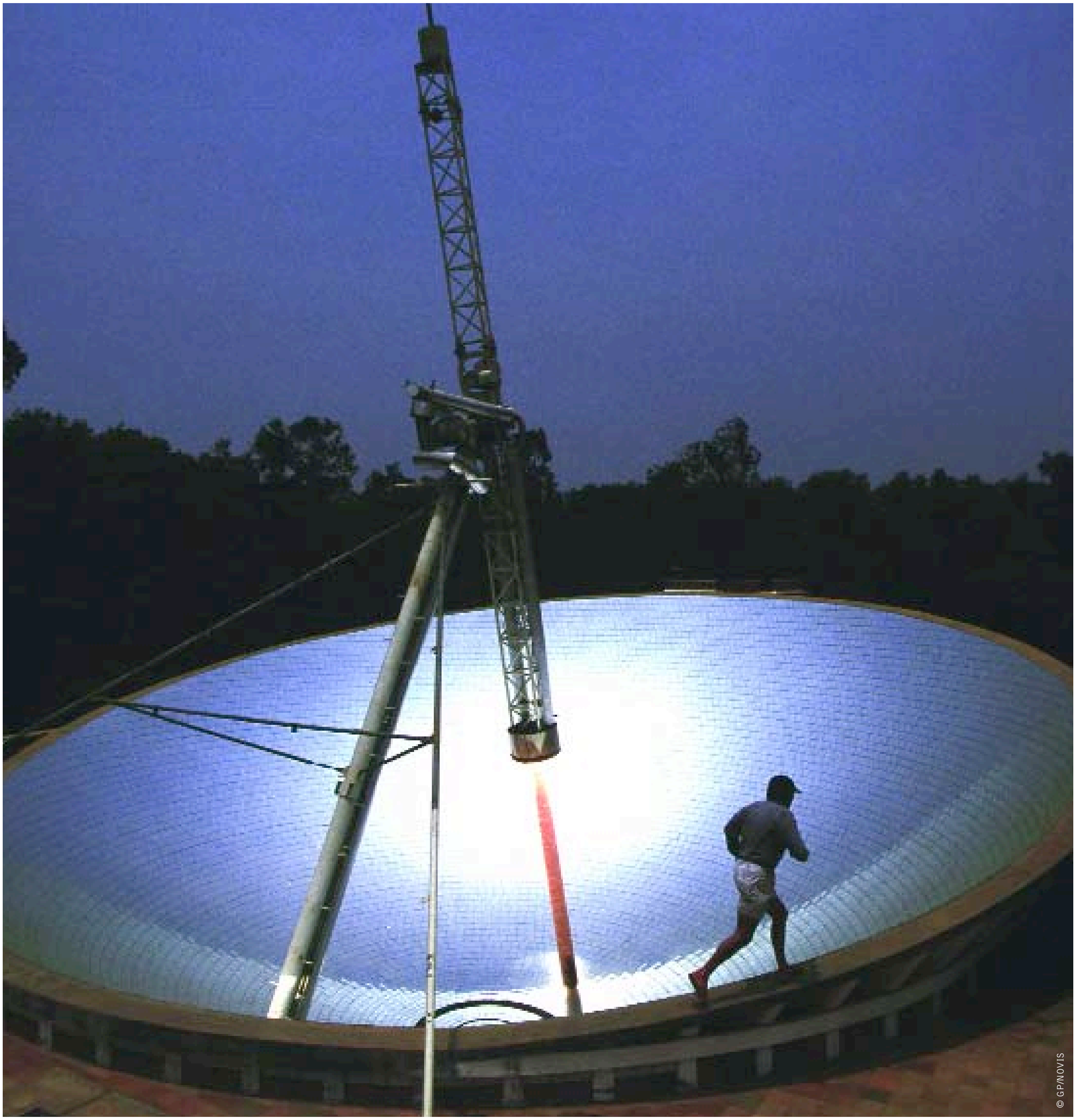


image MAN RUNNING ON THE RIM OF A SOLAR DISH WHICH IS ON TOP OF THE SOLAR KITCHEN AT AUROVILLE, TAMIL NADU, INDIA. THE SOLAR DISH CAPTURES ENOUGH SOLAR ENERGY TO GENERATE HEAT TO COOK FOR 2,000 PEOPLE PER DAY.

image ENERGY PLANT NEAR REYKJAVIK, ENERGY IS PRODUCED FROM THE GEOTHERMAL ACTIVITY. NORTH WEST OF ICELAND.

the energy [r]evolution

The climate change imperative demands nothing short of an Energy Revolution. At the core of this revolution will be a change in the way that energy is produced, distributed, and consumed. The good news is that America is blessed with some of the best renewable energy resources in the world and after initial success with energy efficiency following the oil crisis in the 70s, there is still enormous potential for improvement in the United States.

This report shows that we have a choice: we can cut carbon dioxide (CO_2) emissions in the United States nearly 75% by 2050 without relying on dangerous nuclear power or expensive new coal technologies. With rapid deployment of energy efficiency and renewable energy we can stop global warming.

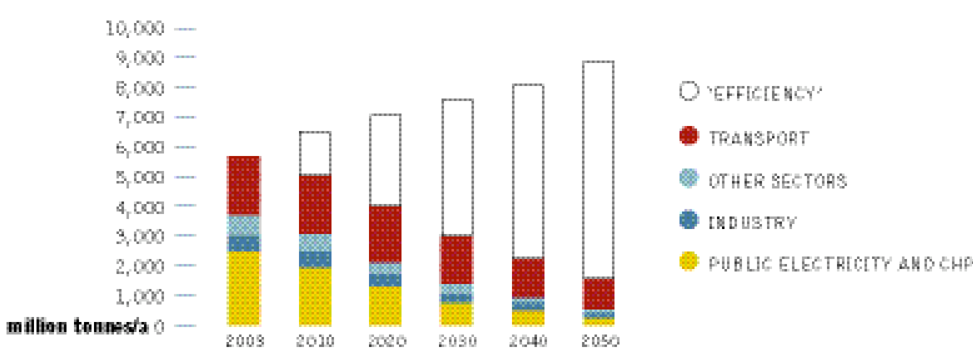
Spurred by oil-price volatility and the war in Iraq, the issue of energy security is now at the top of the energy policy agenda. One reason for price increases is that supplies of all fossil fuels - oil, gas, and coal - are becoming scarcer and more expensive to produce. The days of cheap oil and gas are coming to an end. At the same time green energy is booming business in America, and this growth has to continue if we are going to stop global warming. Renewable energy technologies can deliver the energy we need, as this report shows, but only with consistent support based on an understanding that solving global warming is our top energy priority.

The solution to our future energy needs lies in greater use of renewable energy sources for both heat and power. Nuclear power is not the solution. There are multiple threats to people and the environment from its operations. These include the risks and environmental damage from uranium mining, processing, and transport the risk of nuclear weapons proliferation; the unsolved problem of nuclear waste; and the potential hazard of a serious accident. In addition, uranium, the fuel for nuclear power, is a finite resource. By contrast, the reserves of renewable energy that are technically accessible globally are large enough to provide many times more power than the world currently consumes - forever.

Renewable energy technologies vary widely in their technical and economic maturity, but there is a range of technologies that offer increasingly attractive options. These include wind, biomass, solar, geothermal, ocean, and hydroelectric power. Their common feature is that they produce little or no greenhouse gases, and rely on virtually inexhaustible natural sources for their "fuel." Some of these technologies are already competitive, and their economics will continue to improve as they develop technically. The price of fossil fuels, on the other hand, continues to rise.

At the same time there is enormous potential for reducing our energy consumption, while providing the same level of energy services. This study details a series of energy efficiency measures that together can substantially reduce demand in industry, homes, business, and transportation.

figure 1: usa: carbon dioxide emissions can be reduced by nearly three-quarters.



The challenges posed by global warming are great and they require new ways of thinking about energy. At the core of the Energy [R]evolution will be a change in the way that energy is produced, distributed, and consumed. The five key principles behind this shift are:

1. respecting the natural limits of the environment,
2. implementing renewable solutions, especially through decentralized energy systems,
3. phasing out dirty, unsustainable energy sources,
4. decoupling economic growth from the consumption of fossil fuels, and
5. creating greater equity in the use of resources.

Two contrasting scenarios are outlined in this report, the Reference Scenario and the Energy [R]evolution Scenario. The Reference Scenario is based on the Reference Scenario published by the International Energy Agency (IEA) in World Energy Outlook 2004, and extrapolated forward from 2030. In its report the IEA suggests that global CO_2 emissions will almost double as energy demand grows and most of that demand is met with coal, gas, and oil.

The first goal of the Energy [R]evolution Scenario is to cut global carbon dioxide emissions in half by mid-century. The second objective is to achieve these reductions while phasing out nuclear energy. This report shows how the United States can achieve these goals. It outlines how the U.S. can more fully exploit the large potential for reducing energy demand through energy efficiency, to ensure we are using our energy resources wisely. At the same time, cost-effective renewable energy sources are accessed for heat, electricity generation, and the production of biofuels.

the Energy [R]evolution Scenario describes a development pathway to transform the present situation into a safe, sustainable energy supply. the key findings of the scenario are as follows:

- The electricity sector can pioneer renewable energy development. By 2050, nearly 80% of electricity can be produced from renewable energy sources. In the Energy [R]evolution Scenario 34% is generated by wind, 18% by solar, 14% by hydro, and 9% biomass. There is a smaller amount of ocean energy and geothermal power, as well as nearly 20% fossil generation, 85% of which is natural gas.
- Under our Energy [R]evolution Scenario total carbon dioxide emissions are reduced 72% without resorting to an increase in dangerous nuclear power or new coal technologies.
- In the heat supply sector, the contribution of renewables will grow to more than 60% by 2050. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar, and geothermal technologies.
- America's oil use can be cut over 50% by 2050 with much more efficient cars and trucks potentially including new plug-in hybrids, use of biofuels, and greater reliance on electricity for public transportation.

We have a long way to go. Today in America less than 10% of electricity is generated renewably, while the contribution of renewables to heat supply is only 8%. More than 95% of America's primary energy supply still comes from fossil fuels and CO_2 emissions are projected to increase by more than 50% under the Reference Scenario.

The United States faces a significant increase in expenditure on electricity supply under the Reference Scenario. The undiminished growth in demand for electricity, increase in fossil fuel prices, and cost of CO_2 emissions will all result in North America's electricity supply costs rising from $290 billion per year to $750 billion per year in 2050. The Energy [R]evolution Scenario, on the other hand, not only meets global CO_2 reduction targets but also helps to stabilize energy costs and thus relieves the economic pressure on society. Increasing energy efficiency and shifting energy supply to renewable energy resources reduces the net long-term costs for electricity supply by 40% compared to the Reference Scenario. In other words, following stringent environmental targets in the energy sector makes not only good environmental sense, but good economic sense, as well.

to make the energy [r]evolution real and to avoid dangerous climate change, greenpeace recommends that the United States:

- phase out of all subsidies for fossil fuels and nuclear energy,
- set legally binding targets for renewable energy,
- provide defined and stable returns for renewable energy investors,
- guarantee priority access to the grid, and
- institute strong efficiency standards for all appliances, buildings, and vehicles.

United States energy [r]evolution scenario

"AN INCREASE IN ECONOMIC ACTIVITY AND A GROWING POPULATION DOES NOT NECESSARILY HAVE TO RESULT IN AN EQUIVALENT INCREASE IN ENERGY DEMAND."

5

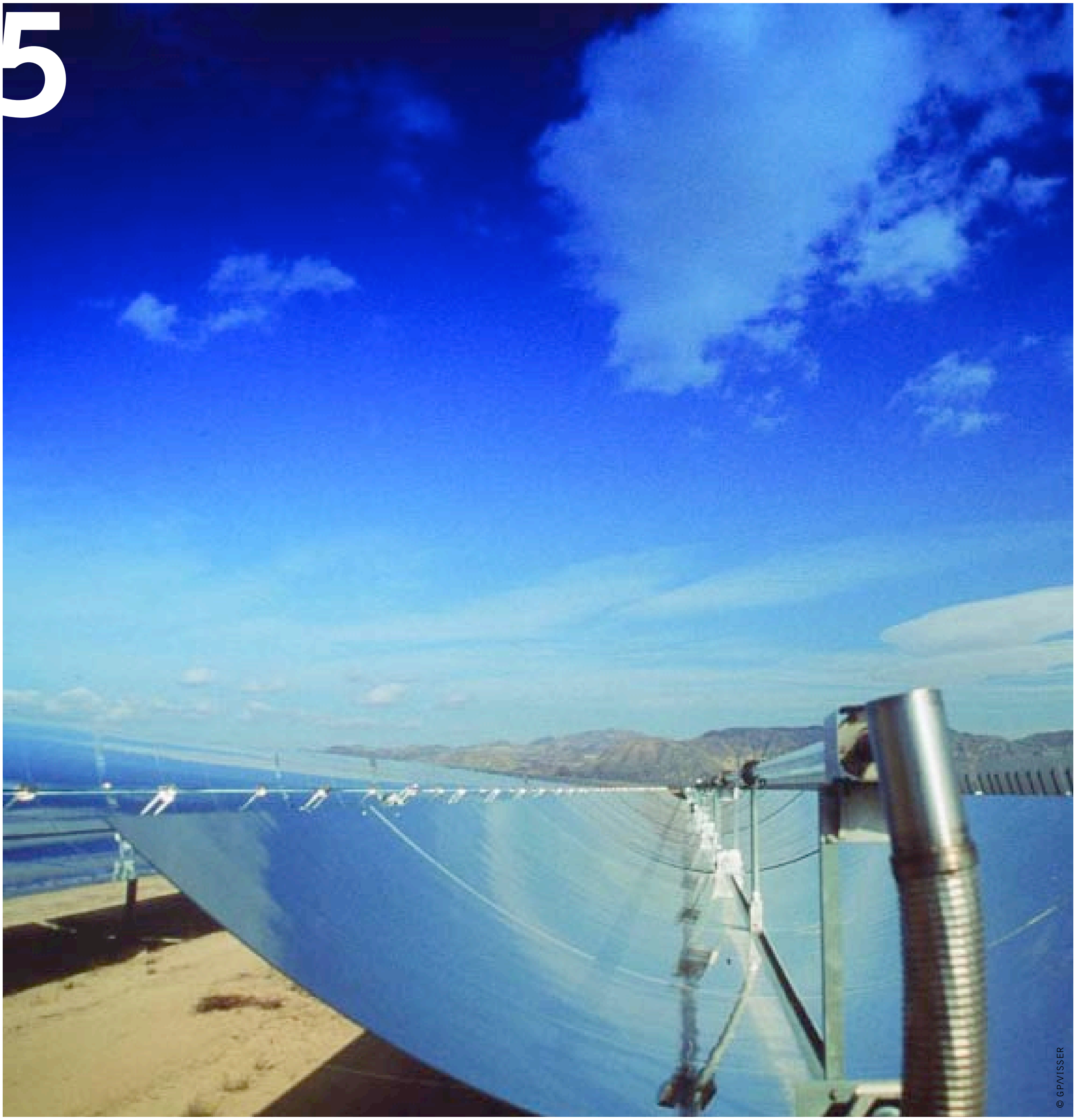


image CONCENTRATING SOLAR POWER (CSP) AT A SOLAR FARM IN DAGGETT, CALIFORNIA, USA.

the development of future global energy demand is determined by three key factors:

- Population development: the number of people consuming energy or using energy services.
- Economic development, for which Gross Domestic Product (GDP) is the most commonly used indicator. In general, an increase in GDP triggers an increase in energy demand.
- Energy intensity: how much energy is required to produce a unit of GDP.

Both the Reference and energy [r]evolution scenarios are based on the same projections of population and economic development. The future development of energy intensity, however, differs between the two, taking into account the measures to increase energy efficiency under the energy [r]evolution scenario.

projection of population development

Following the IEA's Reference Scenario, which uses United Nations population development projections, the population of America will increase from 300 million people now to 420 million in 2050. This continuing growth will put additional pressure on energy resources and the environment.

projection of energy intensity

An increase in economic activity and a growing population does not necessarily have to result in an equivalent increase in energy demand. There is still a large potential for exploiting energy efficiency measures. Under the Reference Scenario, we assume that energy intensity will be reduced by 1.3% per year, leading to a reduction in final energy demand per unit of GDP of about 45% between 2003 and 2050. Under the energy [r]evolution scenario, it is assumed that active policy and technical support for energy efficiency measures will lead to an even higher reduction in energy intensity of 70%.

development of global energy demand

Combining the projections on population development, GDP growth and energy intensity results in future development pathways for energy demand in America. These are shown in Figure 17 for both the Reference and the energy [r]evolution scenarios. Under the Reference Scenario, total energy demand increases by almost 50% from the current 95,000 PJ/a to 143,000 PJ/a in 2050. In the energy [r]evolution scenario, a decrease is expected to 56,000 PJ/a by 2050, half of the projected consumption under the Reference Scenario.

An accelerated increase in energy efficiency, which is a crucial prerequisite for achieving a sufficiently large share of renewable sources in energy supply, will be beneficial not only for the environment but from an economic point of view. Taking into account the full life cycle, in most cases the implementation of energy efficiency measures saves money compared to increasing energy supply. A dedicated energy efficiency strategy therefore helps to compensate in part for the additional costs required during the market introduction phase of renewable energy sources.

Under the energy [r]evolution scenario, electricity demand is expected to decrease. With the exploitation of efficiency measures, an increase can be avoided despite continuing economic growth, leading to electricity demand of around 3,600 TWh/a in 2050. Compared to the Reference Scenario, efficiency measures avoid the generation of about 3,200 TWh/a. This reduction in energy demand can be achieved in particular by introducing highly efficient electronic devices using the best available technology in all demand sectors. Introduction of passive solar design in both residential and commercial buildings will help to curb the growing demand for active air-conditioning.

figure 15: **usa: population development projection**

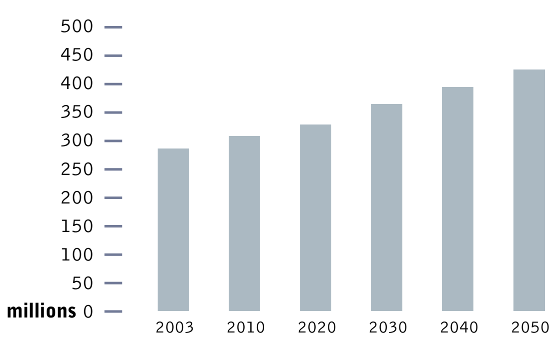


figure 16: **usa: projection of energy intensity under the reference and energy [r]evolution scenarios**

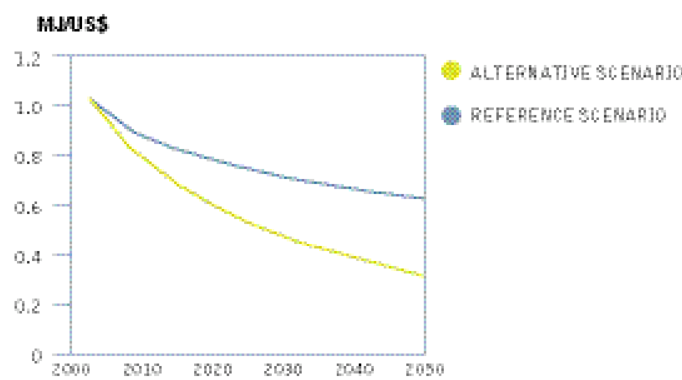


image NEW CONTROL PANEL WITH STATIC ENERGY METRES.

Efficiency gains in the heat supply sector are even larger. Under the energy [r]evolution scenario, final demand for heat supply will experience a steep decline (see Figure 17). Compared to the Reference Scenario, consumption equivalent to 87,500 PJ/a is avoided through efficiency gains by 2050. As a result of energy-related renovation of the existing stock of residential buildings, as well as the introduction of low energy standards and 'passive houses' for new buildings, enjoyment of the same comfort and energy services will be accompanied by a much lower future energy demand.

In the transport sector, which is not analysed in detail in the present study, it is assumed under the energy [r]evolution scenario that energy demand will decrease by 10% to 27,000 PJ/a by 2050, saving half of the demand expected under the Reference Scenario. This reduction can be achieved by the introduction of highly efficient vehicles, by shifting the transport of goods from road to rail and by changes in mobility-related behaviour patterns.

figure 17: usa: projection of energy demand by sector in the reference and energy [r]evolution scenarios

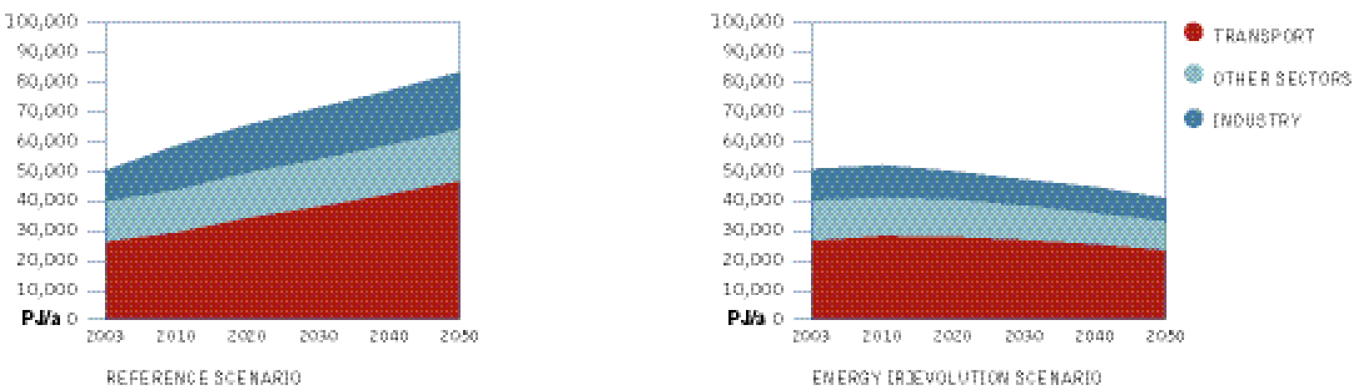


figure 18: usa: development of energy demand for electricity by demand sectors

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO; OTHER SECTORS = SERVICES, HOUSEHOLDS)

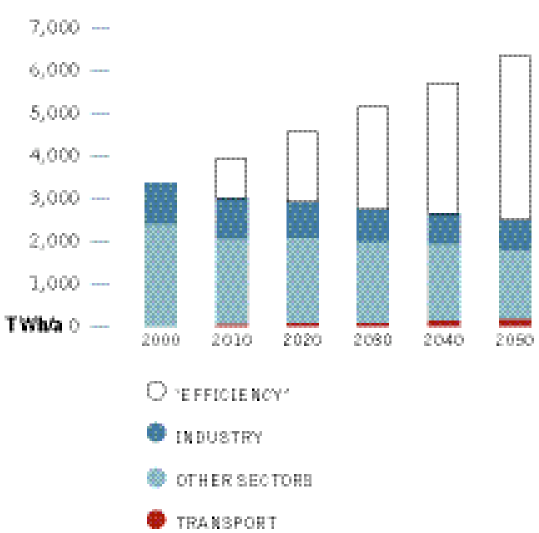
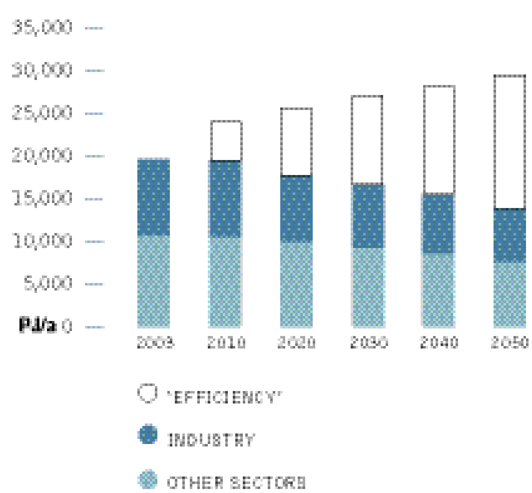


figure 19: usa: development of energy demand for heat supply

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



electricity generation

The development of the electricity supply sector is characterised by a dynamically growing renewable energy market and an increasing share of renewable electricity. This will compensate for the phasing out of nuclear energy and reduce the number of fossil fuel-fired power plants required for grid stabilisation. By 2050 nearly 80% of the electricity produced in the United States will come from renewable energy sources. 'New' renewables - mainly wind, solar thermal energy and PV - will contribute most of electricity generation. The following strategy paves the way for a future renewable energy supply:

- The phasing out of nuclear energy and rising electricity demand will be met initially by bringing into operation new highly efficient gas-fired combined-cycle power plants, plus an increasing capacity of wind turbines and biomass. In the long term, wind will be the most important single source of electricity generation.
- Solar energy, hydro and biomass will make substantial contributions to electricity generation. In particular, as non-fluctuating renewable energy sources, hydro, biomass and solar thermal, combined with efficient heat storage, will be important elements in the overall generation mix.
- The installed capacity of renewable energy technologies will grow from the current 107 GW to 888 GW in 2050. Increasing renewable capacity by a factor of eight within the next 43 years requires political support and well-designed policy instruments, however. There will be a considerable demand for investment in new production capacity over the next 20 years. As investment cycles in the power sector are long, decisions on restructuring America's energy supply system need to be taken now.

To achieve an economically attractive growth in renewable energy sources, a balanced and timely mobilisation of all technologies is of great importance. This mobilisation depends on technical potentials, cost reduction and technological maturity. Figure 22 shows the comparative evolution of the different renewable technologies over time. Up to 2010, hydro power and biomass will remain the main contributors to the growing market share. After 2020, the growing use of wind will take over the lead, complemented by electricity from photovoltaics and solar thermal power plants.

This scenario is only one possible renewable future. Relative growth rates should not be taken for a Greenpeace endorsement of one technology over another, but instead reflect the current understanding of resource potential and somewhat conservative assumptions about expected technological development. There are several renewable resources and technologies that could provide a much larger source of energy in the future than projected here. Geothermal power plants, for example, could ultimately provide far more energy than is reflected in our scenario if recent evaluations by the U.S. Department of Energy's National Renewable Energy Laboratory hold up. Similarly, ocean energy and solar thermal power, both of which have tremendous resource potential, could turn out to be more attractive than is currently understood. Therefore, the scenario presented here may be quite conservative, given the sheer size of the renewable resource base and the opportunity for technology advancement and cost reductions during the study period.

figure 20: usa: development of the electricity supply structure under the reference scenario

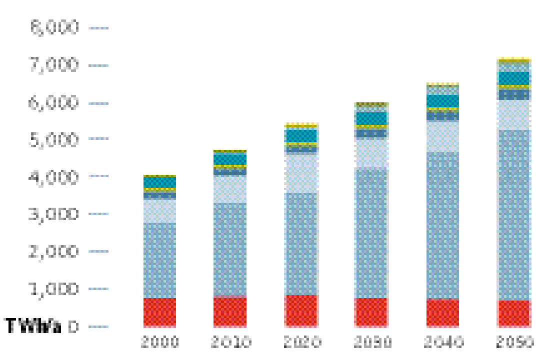


figure 21: usa: development of the electricity supply structure under the energy [r]evolution scenario

'EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO

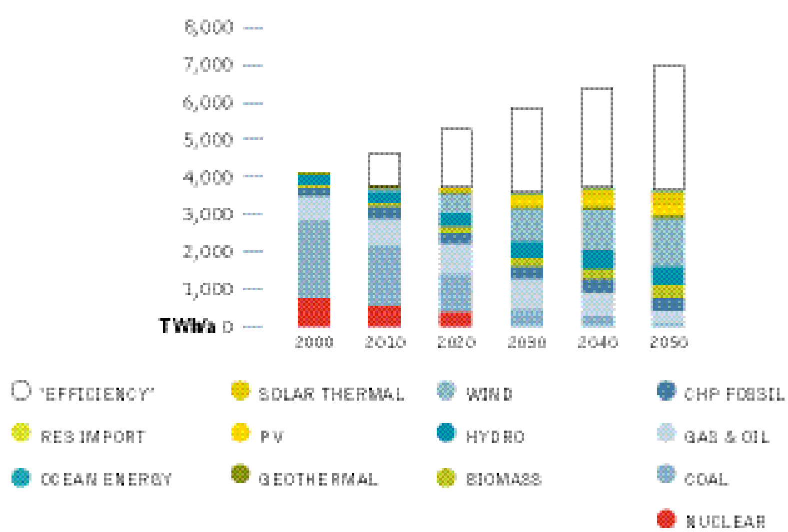


image PHOTOVOLTAIC (SOLAR) PANEL ON TOBI ISLAND, BELAU ISLANDS, PACIFIC. THESE PANELS PRODUCE ALL THE ELECTRICITY USED ON TOBI ISLAND.

figure 22: usa: growth of renewable electricity generation under the energy [r]evolution scenario

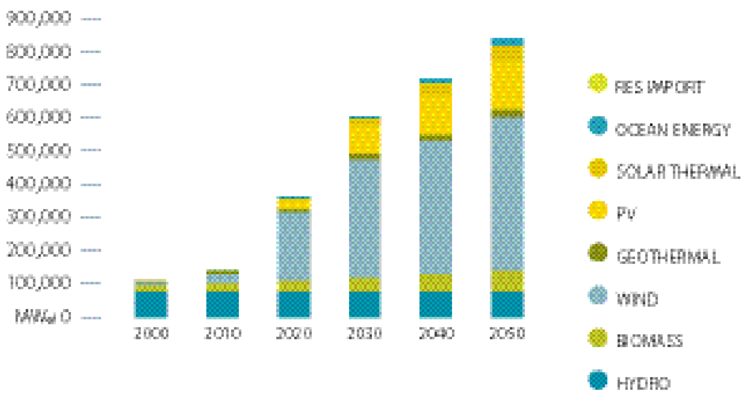


table 7: usa: projection of renewable electricity generation capacity under the energy [r]evolution scenario

IN TWh/a

	2003	2010	2020	2030	2040	2050
Hydro	279	320	375	435	475	510
Biomass	78	109	157	213	281	341
Wind	11	63	502	877	1,063	1,220
Geothermal	15	31	47	76	96	114
PV	0	3	48	167	229	285
Concentrating Solar Power	1	6	38	150	262	366
Ocean energy	0	2	7	12	20	33
Total	**383**	**534**	**1,174**	**1,930**	**2,426**	**2,868**

heat supply

Development of renewables in the heat supply sector raises different issues. Today, renewables provide 8% of primary energy demand for heat supply, the main contribution coming from the use of biomass. The lack of district heating networks is a severe structural barrier to the large-scale utilisation of geothermal and solar thermal energy. Past experience shows that it is easier to implement effective support instruments in the grid-connected electricity sector than in the heat market, with its multitude of different actors. Dedicated support instruments are required to ensure a dynamic development.

- Energy efficiency measures can decrease the current demand for heat supply by 30%.
- The increasing contribution of decentralised combined heat and power production in a shrinking heat market will lead to a CHP share of nearly 20% in 2050.
- For direct heating, solar collectors, biomass/biogas as well as geothermal energy will increasingly replace fossil fuel-fired systems.
- A shift from coal and oil to natural gas in the remaining conventional applications will lead to a further reduction of CO_2 emissions.

figure 23: usa: development of heat supply under the reference scenario

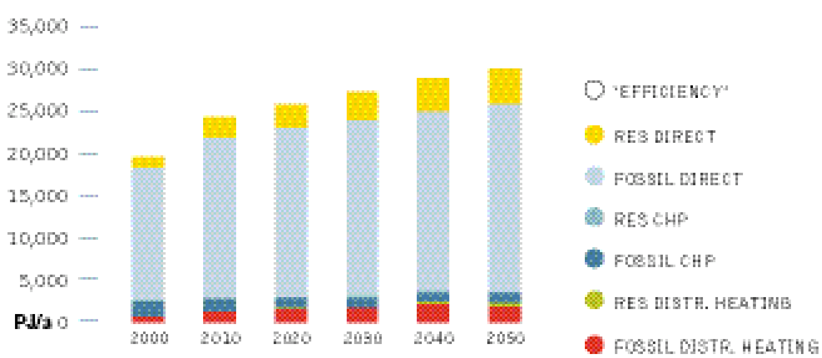
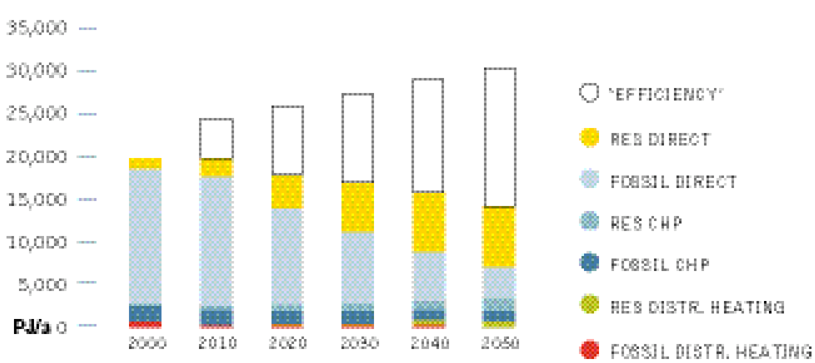


figure 24: usa: development of heat supply under the energy [r]evolution scenario

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



primary energy consumption

Taking into account the assumptions discussed above, the resulting primary energy consumption in America under the energy [r]evolution scenario is shown in Figure 26. Compared to the Reference Scenario, overall energy demand will be reduced by over 60% in 2050. Half of the remaining demand will be covered by renewable energy sources. Note that because of the 'efficiency method' used for the calculation of primary energy consumption, which postulates that the amount of electricity generation from hydro, wind, solar and geothermal energy equals the primary energy consumption, the share of renewables seems to be lower than their actual importance as energy suppliers.

development of CO_2 emissions

Whilst emissions of CO_2 in the United States will increase by over 50% under the Reference Scenario, under the energy [r]evolution scenario they will decrease from 5,600 million tons in 2003 to 1,550 m/t in 2050. Annual per capita emissions will drop from 19.2 t to 3.7 t. In spite of the phasing out of nuclear energy and increasing demand, CO_2 emissions will decrease in the electricity sector. In the long run efficiency gains and the increased use of biofuels will even reduce emissions in the transport sector. Transport will take over as the largest source of CO_2 emissions in the Unites Sates, with a share of 62% in 2050.

figure 25: usa: development of primary energy consumption under the reference scenario

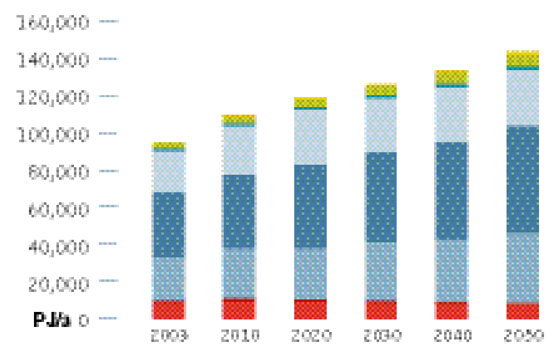


figure 26: usa: development of primary energy consumption under the energy [r]evolution scenario

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)

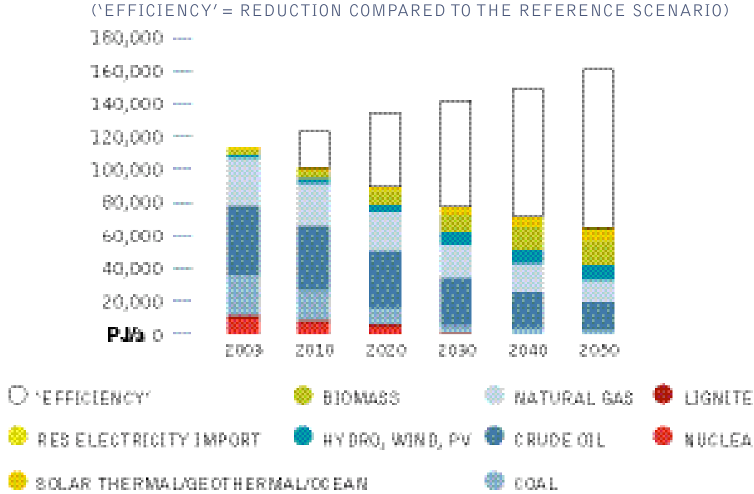
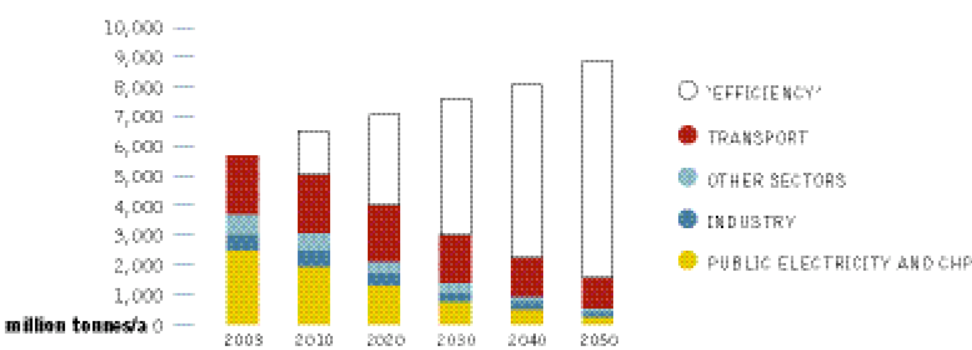


figure 27: usa: development of co_2 emissions by sector under the energy [r]evolution scenario

('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



future costs of electricity generation

Figure 28 shows that the introduction of renewable technologies under the energy [r]evolution scenario will still be competitive with the costs of electricity generation in the Reference Scenario, partly because of the additional CO_2 emission costs that will be imposed on power generation from 2010 onwards. From 2020 the cost difference will increase from about 0.4 cents/kWh up to 1.8 cents/kWh in 2050. Note that any increase in fossil fuel prices beyond the projection given in Table 3 will reduce the gap between the two scenarios.

Due to growing demand, we face a significant increase in society's expenditure on electricity supply. Under the Reference Scenario, the unchecked growth in demand, the increase in fossil fuel prices and the cost of CO_2 emissions result in total electricity supply costs for North America rising from today's $290 billion per year to more than $750 bn in 2050. Figure 29 shows that the energy [r]evolution scenario not only complies with global CO_2 reduction targets but also helps to stabilise energy costs and relieve the economic pressure on society. Increasing energy efficiency and shifting energy supply to renewables leads to long term costs for electricity supply that are 40% lower than in the Reference Scenario. It becomes clear that pursuing stringent environmental targets in the energy sector also pays off in terms of economics.

figure 28: usa: development of electricity generation costs under the two scenarios

(CO₂ EMISSION COSTS IMPOSED FROM 2010 IN INDUSTRIALISED REGIONS, FROM 2020 IN ALL REGIONS, WITH INCREASE FROM 15 $/T$_{CO_2}$ IN 2010 TO 50 $/T$_{CO_2}$ IN 2050)

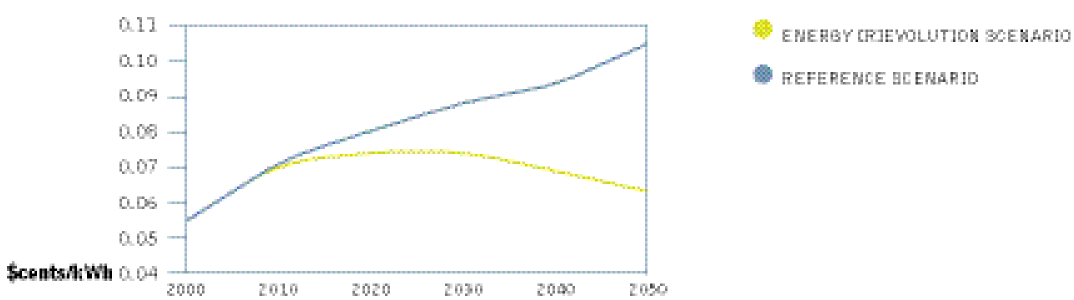
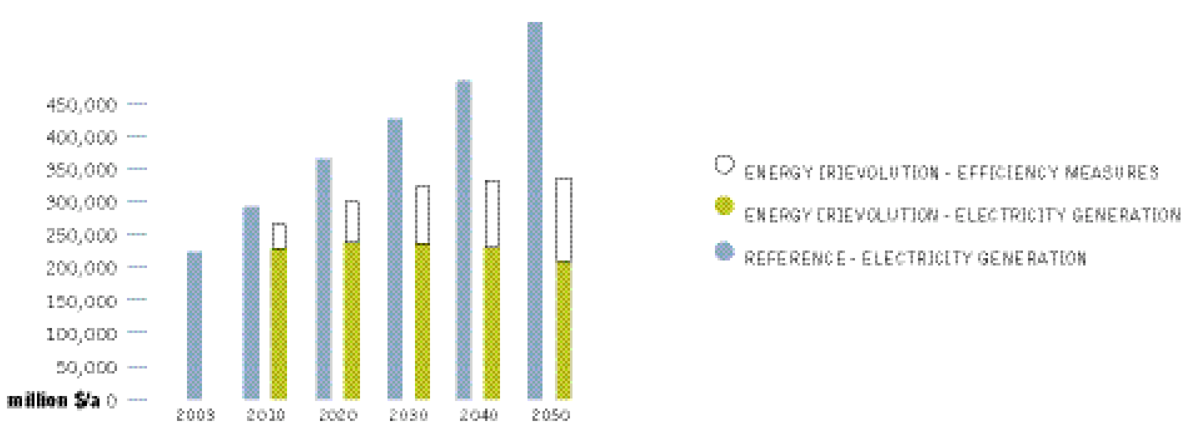


figure 29: usa: development of total electricity supply costs



reference scenario

table 15: electricity generation

TWh/a

	2003	2010	2020	2030	2040	2050
Power plants	**3,777**	**4,443**	**5,109**	**5,684**	**6,190**	**6,840**
Coal	1,923	2,302	2,660	3,316	3,827	4,469
Lignite	98	206	119	130	133	135
Gas	518	605	915	790	783	787
Oil	114	98	92	53	35	30
Nuclear	788	833	850	792	745	700
Biomass	31	35	39	52	57	64
Hydro	279	309	312	324	329	332
Wind	11	33	90	180	220	245
PV	0	1	2	4	8	13
Geothermal	15	19	22	26	29	32
Solar thermal power plants	1	3	8	17	25	33
Ocean energy	0	0	0	0	0	0
Combined heat & power production	**270**	**283**	**306**	**330**	**349**	**355**
Coal	42	42	40	44	51	56
Lignite	0	0	0	0	0	0
Gas	164	173	192	205	212	208
Oil	16	16	15	15	14	14
Biomass	47	51	58	63	69	73
Geothermal	0	1	1	2	3	4
CHP by producer						
Main acitivity producers	116	126	139	158	172	176
Autoproducers	154	157	167	172	177	179
Total generation	**4,047**	**4,726**	**5,416**	**6,013**	**6,539**	**7,195**
Fossil	2,875	3,442	4,033	4,552	5,054	5,699
Coal	1,965	2,344	2,700	3,360	3,878	4,525
Lignite	96	206	119	130	133	135
Gas	682	778	1,107	995	995	995
Oil	130	114	107	68	49	44
Nuclear	788	833	850	792	745	700
Renewables	**383**	**451**	**532**	**669**	**740**	**796**
Hydro	279	309	312	324	329	332
Wind	11	33	90	180	220	245
PV	0	1	2	4	8	13
Biomass	78	86	97	115	126	137
Geothermal	15	20	23	28	32	36
Solar thermal	1	3	8	17	25	33
Ocean energy	0	0	0	0	0	0
Import	30.4	37.0	42.0	48.0	53.0	58.0
Import RES	4.6	5.6	6.3	7.2	8.0	8.7
Export	24.0	29.0	33.0	37.0	41.0	45.0
Distribution losses	284.6	321.0	344.0	361.0	345.0	352.0
Own consumption electricity	293.1	33.0	354.0	372.0	356.0	362.0
Final energy consumption (electricity)	**3475**	**4,083**	**4,727**	**5,291**	**5,850**	**6,494**
Fluctuating RES (PV, Wind, Ocean)	12	37	100	201	253	291
Share of fluctuating RES	0.3%	0.8%	1.8%	3.3%	3.9%	4.0%
RES share	**9.5%**	**9.5%**	**9.8%**	**11.1%**	**11.3%**	**11.1%**

table 16: installed capacity

GW

	2003	2010	2020	2030	2040	2050
Power plants	**733**	**831**	**964**	**1,020**	**1,096**	**1,214**
Coal	275	332	389	491	589	715
Lignite	13.0	27.6	16.2	18.0	18.7	19.3
Gas	185.0	198.2	267.9	209.2	189.2	174.9
Oil	64.5	54.5	49.9	28.0	18.5	15.9
Nuclear	103.0	107.2	107.0	97.5	91.7	86.2
Biomass	4.3	4.9	5.5	7.4	8.1	9.1
Hydro	81	87	85	85	84	83
Wind	5.1	15.0	36.7	73.5	83.7	93.2
PV	0.0	0.3	1.1	2.1	3.9	6.7
Geothermal	3.0	3.8	4.4	5.2	5.8	6.4
Solar thermal power plants	0.2	0.7	1.1	2.4	3.4	4.4
Ocean energy	0.0	0.0	0.0	0.0	0.0	0.0
Combined heat & power production	**84**	**82**	**85**	**87**	**90**	**92**
Coal	18	19	17	18	20	23
Lignite	0	0	0	0	0	0
Gas	48	47	50	53	53	52
Oil	4	4	3	3	3	3
Biomass	14	13	14	13	14	14
Geothermal	0	0	0	0	1	1
CHP by producer						
Main activity producers	44	46	47	50	55	56
Autoproducers	40	36	37	36	36	36
Total generation≈	**817**	**914**	**1,048**	**1,107**	**1,187**	**1,306**
Fossil	607	681	793	820	891	1,002
Coal	292	351	406	509	609	738
Lignite	13	28	16	18	19	19
Gas	233.2	244.7	318.1	261.7	242.2	226.6
Oil	68.7	58.1	53.2	31.1	21.4	18.7
Nuclear	103.0	107.2	107.0	97.5	91.7	86.2
Renewables	**107**	**125**	**148**	**190**	**204**	**218**
Hydro	81	87	85	85	84	83
Wind	5	15	37	73	84	93
PV	0	0	1	2	4	7
Biomass	18.3	18.3	19.4	20.6	21.7	23.2
Geothermal	3	4	5	6	6	7
Solar thermal	0	1	1	2	3	4
Ocean energy	0	0	0	0	0	0
Fluctuating RES (PV, Wind, Ocean)	5.4	16.0	39.0	78.0	91.0	104.2
Share of fluctuating RES	0.7%	1.8%	3.7%	7.0%	7.7%	8.0%
RES share	**13.1%**	**13.7%**	**14.1%**	**17.1%**	**17.2%**	**16.7%**

table 17: primary energy demand

PJ/A

	2003	2010	2020	2030	2040	2050
Total	**94,757**	**109,158**	**118,831**	**126,374**	**133,269**	**143,313**
Fossil	**81,942**	**94,623**	**103,250**	**110,240**	**116,664**	**126,311**
Hard coal	23,778	26,922	27,938	31,291	33,554	37,501
Lignite	1,038	2,077	1,119	1,140	1,088	1,080
Natural gas	22,626	26,209	29,573	29,268	29,681	30,571
Crude oil	34,500	39,416	44,620	48,541	52,340	57,159
Nuclear	**8,594**	**9,087**	**9,273**	**8,640**	**8,127**	**7,636**
Renewables	**4,221**	**5,448**	**6,308**	**7,494**	**8,478**	**9,365**
Hydro	1,003	1,112	**1,123**	1,166	1,184	1,195
Wind	41	119	324	648	792	882
Solar	56	70	115	178	247	322
Biomass	2,767	3,725	4,288	5,002	5,743	6,452
Geothermal	355	421	458	499	512	515
Ocean Energy	0	0	0	0	0	0

reference scenario

table 18: heat supply

PJ/A

	2003	2010	2020	2030	2040	2050
District heating plants	**683**	**1,361**	**1,625**	**1,767**	**2,406**	**2,341**
Fossil fuels	678	1,342	1,578	1,669	2,158	1,882
Biomass	141	16	37	80	217	421
Solar collectors	5	1	8	16	29	35
Geothermal	0	1	2	2	2	2
Heat from CHP	**2,118**	**1,683**	**1,478**	**1,373**	**1,320**	**1,292**
Fossil fuels	1,773	1,395	1,198	1,112	1,078	1,050
Biomass	344	282	267	240	215	211
Geothermal	0	6	13	21	27	32
Direct heating[1)]	**16,818**	**21,119**	**22,700**	**24,028**	**25,089**	**26,415**
Fossil fuels	15,527	18,892	19,912	20,726	21,274	22,205
Biomass	1,198	2,140	2,681	3,177	3,672	1,042
Solar collectors	54	56	71	87	102	121
Geothermal	39	31	36	39	41	47
Total heat supply[1)]	**19,618**	**24,163**	**25,803**	**27,168**	**28,815**	**20,048**
Fossil fuels	17,978	21,629	22,688	23,507	24,510	25,137
Biomass	1,547	2,438	2,985	3,497	4,104	4,674
Solar collectors	54	58	79	103	130	156
Geothermal	39	38	50	61	71	81
RES share (including RES electricity)	**8.4%**	**10.5%**	**12.1%**	**13,5%**	**14,9%**	**16,3%**

1) heat from electricity (direct and from electric heat pumps) not included; covered in the model under 'electric appliances'

table 19: CO_2 emissions

MILL t/a

	2003	2010	2020	2030	2040	2050
Condensation power plants	**2,332**	**2,696**	**2,810**	**3,028**	**3,131**	**3,512**
Coal	1,893.2	2,131.8	2,257.4	2,577.9	2,725.9	3,116.9
Lignite	115.2	230.6	124.2	126.6	120.8	119.9
Gas	242.9	265.9	366.7	288.7	260.9	255.9
Oil	80.9	67.8	62.1	34.9	23.0	19.8
Combined heat & power production	**191**	**160**	**149**	**148**	**154**	**155**
Coal	54	45	38	40	47	52
Lignite	0	0	0	0	0	0
Gas	120	102	102	99	100	96
Oil	17	12	10	9	8	8
CO_2 emissions electricity & steam generation	**2,523**	**2,856**	**2,960**	**3,176**	**3,285**	**3,668**
Coal	1,948	2,177	2,295	2,618	2,773	3,169
Lignite	115	231	124	127	121	120
Gas	363	368	469	388	360	352
Oil & diesel	98	80	72	43	31	27
CO_2 emissions by sector	**5,577**	**6,435**	**6,935**	**7,481**	**7,947**	**8,674**
% of 2000 emissions	100%	115%	124%	134%	143%	156%
Industry	531	720	732	748	766	811
Other sectors	647	652	667	676	675	675
Transport	1,08	2,137	2,471	2,762	3,048	3,378
Electricity & steam generation	2,416	2,779	2,893	3,116	3,229	3,614
District heating	75	148	172	179	228	196
Population (Mill.)	291	309	336	364	392	420
CO_2 emissions per capita (t/capita)	**19.2**	**20.8**	**20.6**	**20.6**	**20.3**	**20.7**

alternative scenario

table 20: heat supply

PJ/A

	2003	2010	2020	2030	2040	2050
District heating plants	**683**	**262**	**387**	**478**	**750**	**700**
Fossil fuels	678	225	249	196	169	35
Biomass	5	24	66	124	233	245
Solar collectors	0	12	43	91	203	245
Geothermal	0	2	29	67	146	175
Heat from CHP	**2,118**	**2,181**	**2,161**	**2,252**	**2,383**	**2,575**
Fossil fuels	1773	1,763	1,536	1,388	1,271	1,216
Biomass	344	387	545	693	798	922
Geothermal	0	32	80	171	314	437
Direct heating[1)]	**16,818**	**17,100**	**15,206**	**13,972**	**12,473**	**10,694**
Fossil fuels	15,527	15,037	11,271	8,230	5,546	3,730
Biomass	1,198	1,664	2,914	4,148	4,787	4,625
Solar collectors	54	282	676	1,059	1,363	1,470
Geothermal	39	118	345	535	778	869
Total heat supply[1)]	**19,618**	**19,543**	**17,753**	**16,702**	**15,606**	**13,969**
Fossil fuels	17,978	17,024	13,057	9,814	6,986	4,981
Biomass	1,547	2,074	3,525	4,965	5,817	5,792
Solar collectors	54	294	718	1,150	1,566	1,715
Geothermal	39	152	453	773	1,238	1,481
RES share (including RES electricity)	**8.40%**	**12.90%**	**26.50%**	**41.20%**	**55.20%**	**64.30%**
'Efficiency' savings (compared to Ref.)	**0**	**4,620**	**8,050**	**10,466**	**13,209**	**16,079**

table 21: CO_2 emissions

MILL t/a

	2003	2010	2020	2030	2040	2050
Condensation power plants	**2,332**	**1,821**	**1,186**	**669**	**416**	**178**
Coal	1,893.20	1,394.60	787.6	335.1	207.8	76
Lignite	115.2	92.9	77.3	36	0	0
Gas	242.9	270.7	300.2	285	205.3	101.8
Oil	80.9	62.3	20.9	12.5	2.6	5
Combined heat & power production	**191**	**198**	**182**	**166**	**160**	**155**
Coal	54	43	26	6	4	3
Lignite	0	0	0	0	0	0
Gas	120	140	146	153	153	152
Oil	17	15	10	6	3	8
CO_2 emissions electricity & steam generation	**2,523**	**2,018**	**1,368**	**834**	**576**	**333**
Coal	1,948	1,437	813	341	212	79
Lignite	115	93	77	36	0	0
Gas	363	411	447	439	358	254
Oil & diesel	98	77	31	19	6	0
CO_2 emissions by sector	**5,577**	**4,963**	**3,946**	**2,942**	**2,192**	**1,550**
% of 2000 emissions	100%	89%	71%	53%	39%	28%
Industry	531	523	392	307	238	181
Other sectors	647	586	429	296	194	139
Transport	1,908	1,931	1,834	1,574	1,250	975
Electricity & steam generation	2,416	1,898	1,264	744	493	254
District heating	75	25	27	21	17	2
Population (Mill.)	291	309	336	364	392	420
CO_2 emissions per capita (t/capita)	**19.2**	**16.1**	**11.7**	**8.1**	**5.6**	**3.7**
'Efficiency' savings (compared to REF.)	**0**	**1,427**	**2,989**	**4,539**	**5,755**	**7,124**

alternative scenario

table 21: electricity generation

TWh/a

	2003	2010	2020	2030	2040	2050
Power plants	**3,777**	**3,330**	**3,236**	**3,018**	**3,075**	**2,945**
Coal	1,923	1,506	928	431	292	109
Lignite	98	83	74	37	0	0
Gas	518	616	749	780	616	313
Oil	114	90	31	19	4	0
Diesel	0	0	0	0	0	0
Nuclear	788	568	393	0	0	0
Biomass	31	46	53	53	53	53
Hydro	279	320	375	435	475	510
Wind	11	63	502	877	1,063	1,220
PV	0	3	48	167	229	285
Geothermal	15	27	38	57	61	65
Solar thermal power plants	1	6	38	150	262	366
Ocean energy	0	2	7	12	20	33
Combined heat & power production	**270**	**365**	**434**	**516**	**602**	**674**
Coal	42	42	29	7	4	3
Lignite	0	0	0	0	0	0
Gas	164	239	278	320	330	335
Oil	16	18	14	10	5	0
Biomass	47	63	104	160	228	288
Geothermal	0	4	9	19	35	49
CHP by producer						
Main acitivity producers	116	136	170	204	244	284
Autoproducers	154	229	264	312	358	390
Total generation	**4,047**	**3,695**	**3,670**	**3,534**	**3,677**	**3,628**
Fossil	2,875	2,593	2,103	1,604	1,251	760
Coal	1,965	1,547	957	438	296	112
Lignite	98	83	74	37	0	0
Gas	682	855	1,027	1,100	946	648
Oil	130	108	45	29	9	0
Nuclear	788	568	393	0	0	0
Renewables	**383**	**534**	**7,688**	**1,930**	**2,426**	**2,868**
Hydro	279	320	1,174	435	475	510
Wind	11	63	502	877	1,063	1,220
PV	0	3	48	167	229	285
Biomass	78	109	157	213	281	341
Geothermal	15	31	47	76	96	114
Solar thermal	1	6	38	150	262	366
Ocean energy	0	2	7	12	20	33
Import	30.4	30	30	30	30	30
Import RES	4.6	7.5	12.6	17.1	20.4	23.7
Export	24	24	24	24	24	24
Distribution losses	284.6	255	254	247	243	224
Own consumption electricity	293.1	249	239	217	188	152
Final energy consumption (electricity)	**3,475**	**3,197**	**3,183**	**3,076**	**3,252**	**3,258**
Fluctuating RES (PV, Wind, Ocean)	12	74	596	1,206	1,574	1,904
Share of fluctuating RES	0.30%	2.00%	16.20%	34.10%	42.80%	52.50%
RES share	**9.50%**	**14.50%**	**32.00%**	**54.60%**	**66.00%**	**79.10%**
'Efficiency' savings (compared to REF.)	**0**	**886**	**1,543**	**2,215**	**2,598**	**3,236**

table 22: installed capacity

GW

	2003	2010	2020	2030	2040	2050
Power plants	**733**	**688**	**788**	**893**	**907**	**910**
Coal	275	217	136	64	45	17
Lignite	13	11.1	10.1	5.1	0	0
Gas	185	201.8	219.3	206.5	148.9	69.6
Oil	64.5	50.1	16.8	10.1	2.1	0
Nuclear	103	73.1	49.5	0	0	0
Biomass	4.3	6.4	7.5	7.6	7.6	7.6
Hydro	81	90	102	115	122	128
Wind	5.1	28.6	204.9	358	404.2	463.9
PV	0	1.6	25.9	88.5	119.4	146.2
Geothermal	3	5.4	7.6	11.4	12.2	13
Solar thermal power plants	0.2	1.1	5.4	20.9	35.7	48.8
Ocean energy	0	1	3.5	6	10	16.5
Combined heat & power production	**84**	**101**	**112**	**122**	**135**	**147**
Coal	18	14	9	2	2	1
Lignite	0	0	0	0	0	0
Gas	48	62	71	81	81	82
Oil	4	6	4	2	1	0
Biomass	14	17	25	33	44	55
Geothermal	0	1	2	4	7	10
CHP by producer						
Main acitivity producers	44	48	54	56	63	70
Autoproducers	40	53	58	66	72	77
Total Generation	**817**	**789**	**901**	**1,015**	**1,042**	**1,058**
Fossil	607	563	467	371	280	170
Coal	292	232	145	66	47	19
Lignite	13	11	10	5	0	0
Gas	233	264	291	287	230	151
Oil	69	56	21	13	3	0
Nuclear	103	73	49	0	0	0
Renewables	**107**	**153**	**384**	**644**	**762**	**888**
Hydro	81	90	102	115	122	128
Wind	5	29	205	358	404	464
PV	0	2	26	89	119	146
Biomass	18	23	33	40	51	62
Geothermal	3	6	9	15	19	23
Solar thermal	0	1	5	21	36	49
Ocean energy	0	1	4	6	10	17
Fluctuating RES (PV, Wind, Ocean)	5.4	32.7	239.7	473.4	569.3	675.3
Share of fluctuating RES	0.70%	4.20%	26.60%	46.70%	55.70%	63.80%
RES share	**13.10%**	**19.40%**	**42.70%**	**63.40%**	**73.10%**	**83.90%**

table 24: primary energy demand

PJ/A

	2003	2010	2020	2030	2040	2050
Total	**94,757**	**88,614**	**79,141**	**68,353**	**62,535**	**55,890**
Fossil	**81,942**	**75,646**	**62,661**	**49,601**	**38,774**	**29,353**
Hard coal	23,778	16,994	10,034	4,825	3,380	1,783
Lignite	1,038	837	696	325	0	0
Natural gas	22,626	23,973	22,343	19,948	16,007	12,344
Crude oil	34,500	33,842	29,588	24,503	19,387	15,226
Nuclear	**8,594**	**6,196**	**4,287**	**0**	**0**	**0**
Renewables	**4,221**	**6,772**	**12,192**	**18,752**	**23,761**	**26,537**
Hydro	1,003	1,152	1,350	1,566	1,710	1,836
Wind	41	227	1,807	3,157	3,827	4,392
Solar	56	326	1,028	2,291	3,333	4,058
Biomass	2,767	4,300	6,688	9,672	12,087	13,018
Geothermal	355	768	1,319	2,066	2,804	3,233
Ocean Energy	0	7	25	43	72	119
'Efficiency' savings (compared to Ref.)	**0**	**20,573**	**39,734**	**58,078**	**70,805**	**87,502**

GREENPEACE

Greenpeace is a global organisation that uses non-violent direct action to tackle the most crucial threats to our planet's biodiversity and environment. Greenpeace is a non-profit organisation, present in 40 countries across Europe, the Americas, Asia and the Pacific. It speaks for 2.8 million supporters worldwide, and inspires many millions more to take action every day. To maintain its independence, Greenpeace does not accept donations from governments or corporations but relies on contributions from individual supporters and foundation grants.

Greenpeace has been campaigning against environmental degradation since 1971 when a small boat of volunteers and journalists sailed into Amchitka, an area north of Alaska, where the US Government was conducting underground nuclear tests. This tradition of 'bearing witness' in a non-violent manner continues today, and ships are an important part of all its campaign work.

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EREC

european renewable energy council - [EREC]
EREC is an umbrella organisation of the leading European renewable energy industry, trade and research associations active in the sectors of photovoltaic, wind energy, small hydropower, biomass, geothermal energy and solar thermal:

AEBIOM (European Biomass Association)
EGEC (European Geothermal Energy Council)
EPIA (European Photovoltaic Industry Association)
ESHA (European Small Hydropower Association)
ESTIF (European Solar Thermal Industry Federation)
EUBIA (European Biomass Industry Association)
EWEA (European Wind Energy Association)
EUREC Agency (European Association of Renewable Energy Research Centers)

EREC represents the European renewable energy industry which has an annual €20 billion turnover. It provides jobs to around 300.000 people!

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image ICE FLOES ON THE SNOW COVERED LAKE BAIKAL, RUSSIA, IN THE SUN.