

energy [r]evolution

A BLUEPRINT FOR SOLVING GLOBAL WARMING



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EREC
EUROPEAN RENEWABLE
ENERGY COUNCIL

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Greenpeace International, European Renewable Energy Council (EREC)

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for further information about the global, regional and national scenarios please visit the energy [r]evolution website: www.energyblueprint.info/

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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 (GHGs), 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. CO₂ 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 CO₂ 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 CO₂ 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, CO₂ 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)
JANUARY 2007

John Coequet
CLIMATE & ENERGY UNIT
GREENPEACE USA

executive summary

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

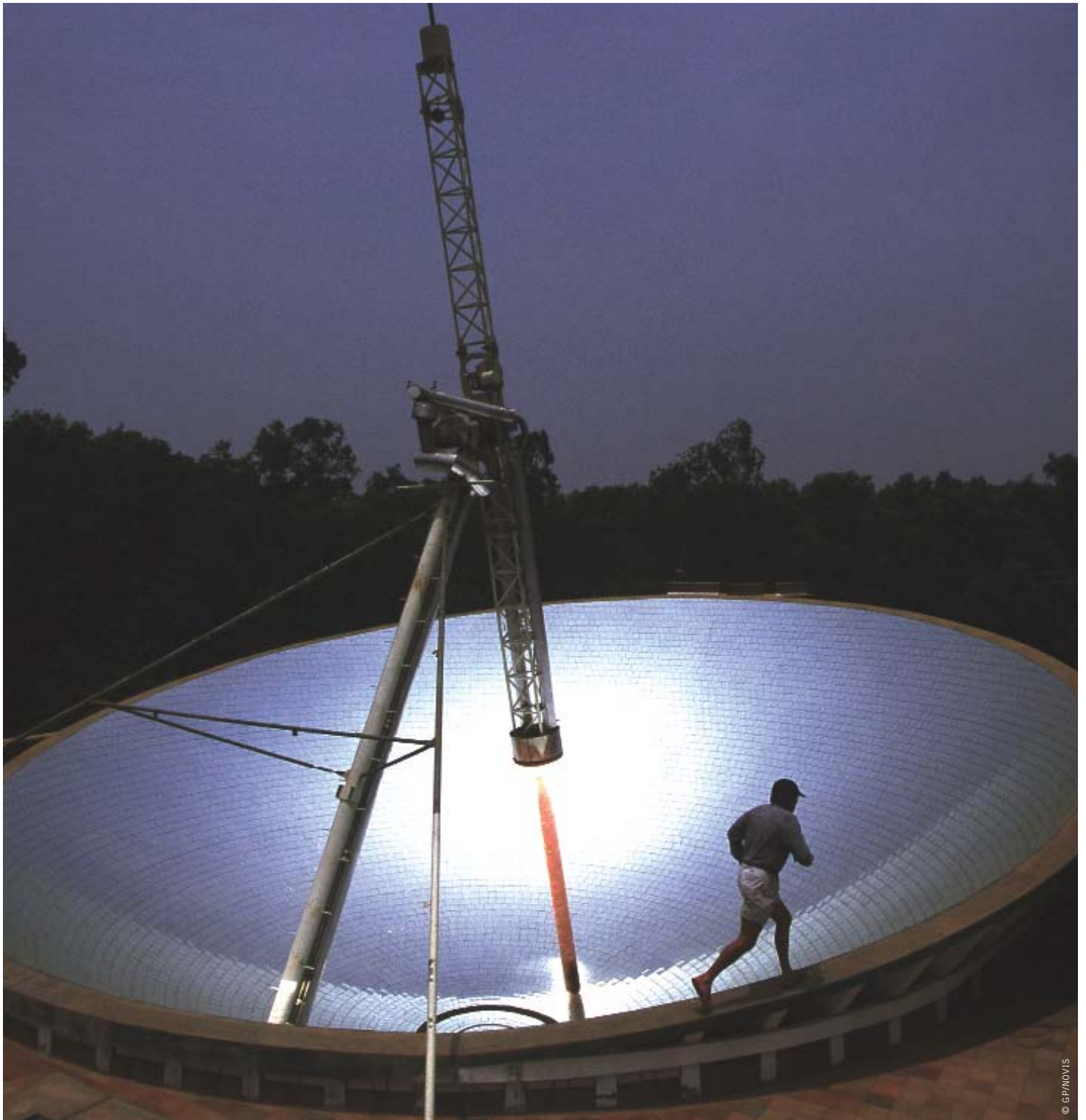


image MAN RUNNING ON THE RIM OF A SOLAR DISH WHICH IS ON TOP OF THE SOLAR KITCHEN AT AUROVILLE, TAMIL NADU, INDIA. THE SOLAR DISH CAPTURES ENOUGH SOLAR ENERGY TO GENERATE HEAT TO COOK FOR 2,000 PEOPLE PER DAY.

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 (CO₂) 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.

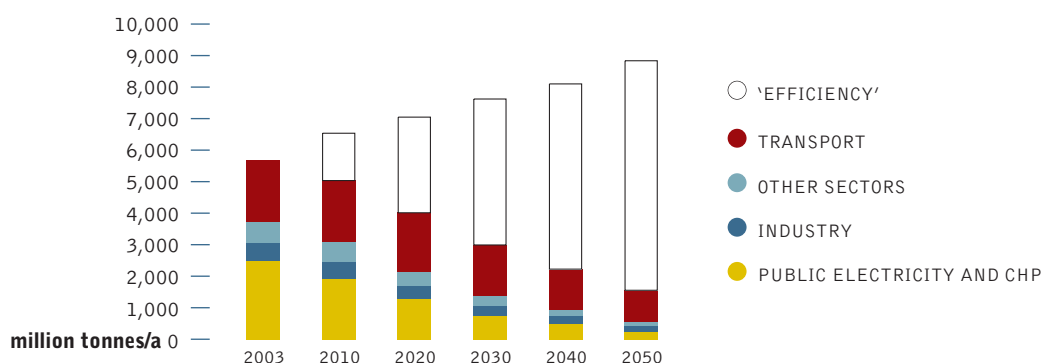
Spurred by oil-price volatility and the war in Iraq, the issue of energy security is now at the top of the energy policy agenda. One reason for price increases is that supplies of all fossil fuels - oil, gas, and coal - are becoming scarcer and more expensive to produce. The days of cheap oil and gas 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 energy 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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.

climate protection

"IF WE DO NOT TAKE URGENT AND IMMEDIATE ACTION TO STOP GLOBAL WARMING, THE DAMAGE COULD BECOME IRREVERSIBLE."

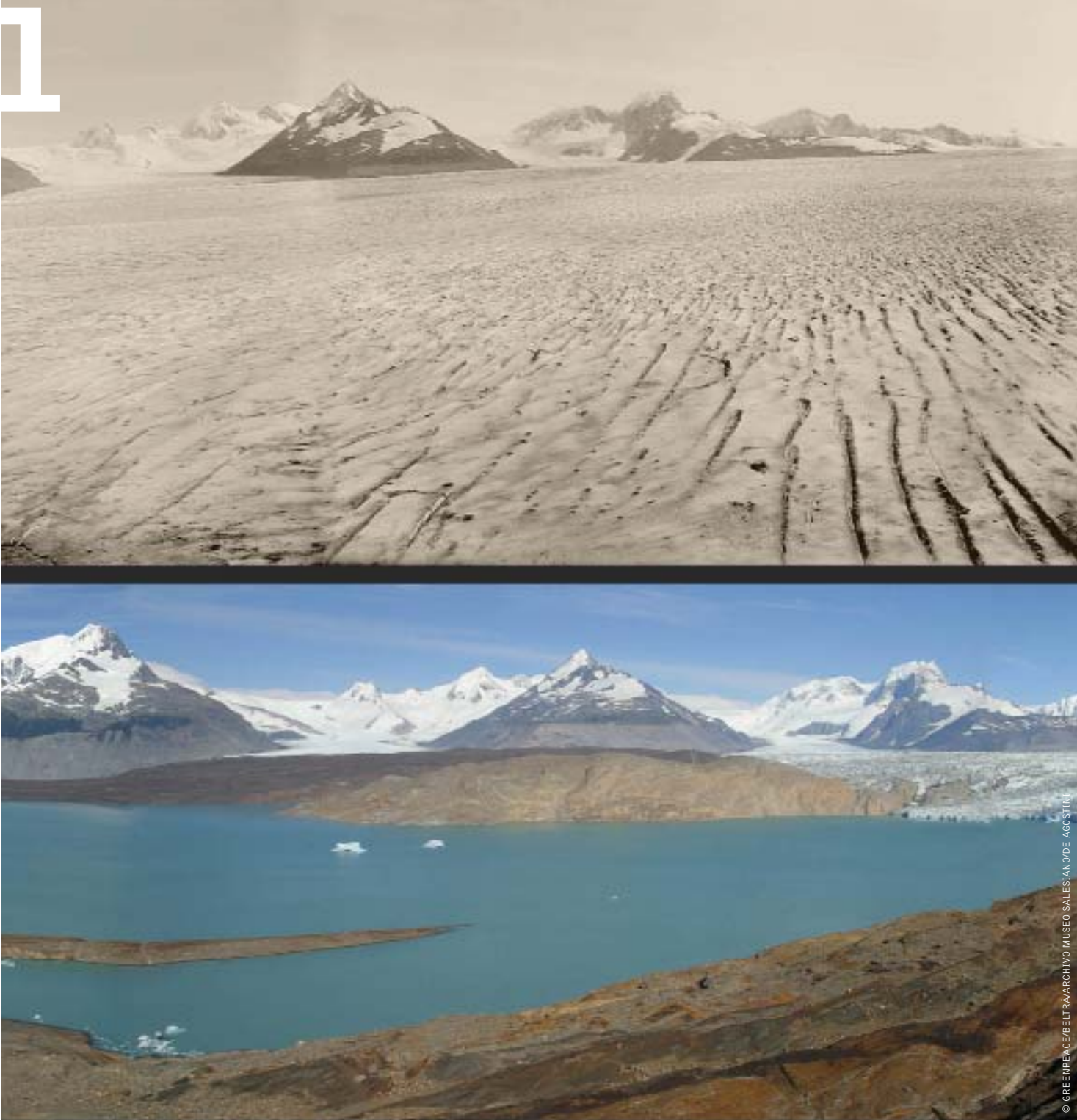


image 1 and 2. ORIGINAL PHOTOGRAPH TAKEN IN 1928 OF THE UPSALA GLACIER, PATAGONIA, ARGENTINA COMPARED WITH THE RECEEDING GLACIER TODAY.

© GREENPEACE/ELTRA/ARCHIVO MUSEO SALESIANO/DE AGOSTINI

the greenhouse effect and climate change

The greenhouse effect is the process by which the atmosphere traps some of the sun's energy, warming the earth and moderating our climate. A human-driven increase in 'greenhouse gases' is increasing this effect artificially, raising global temperatures and disrupting our climate. These greenhouse gases include carbon dioxide, produced by burning fossil fuels and through deforestation, methane, released from agriculture, animals and landfill sites, and nitrous oxide, resulting from agricultural production plus a variety of industrial chemicals.

Every day we damage our climate by using fossil fuels (oil, coal and gas) for energy and transport. As a result, climate change is already impacting on our lives, and is expected to destroy the livelihoods of many people in the developing world, as well as ecosystems and species, in the coming decades. We therefore need to significantly reduce our greenhouse gas emissions. This makes both environmental and economic sense.

figure 2: the greenhouse effect

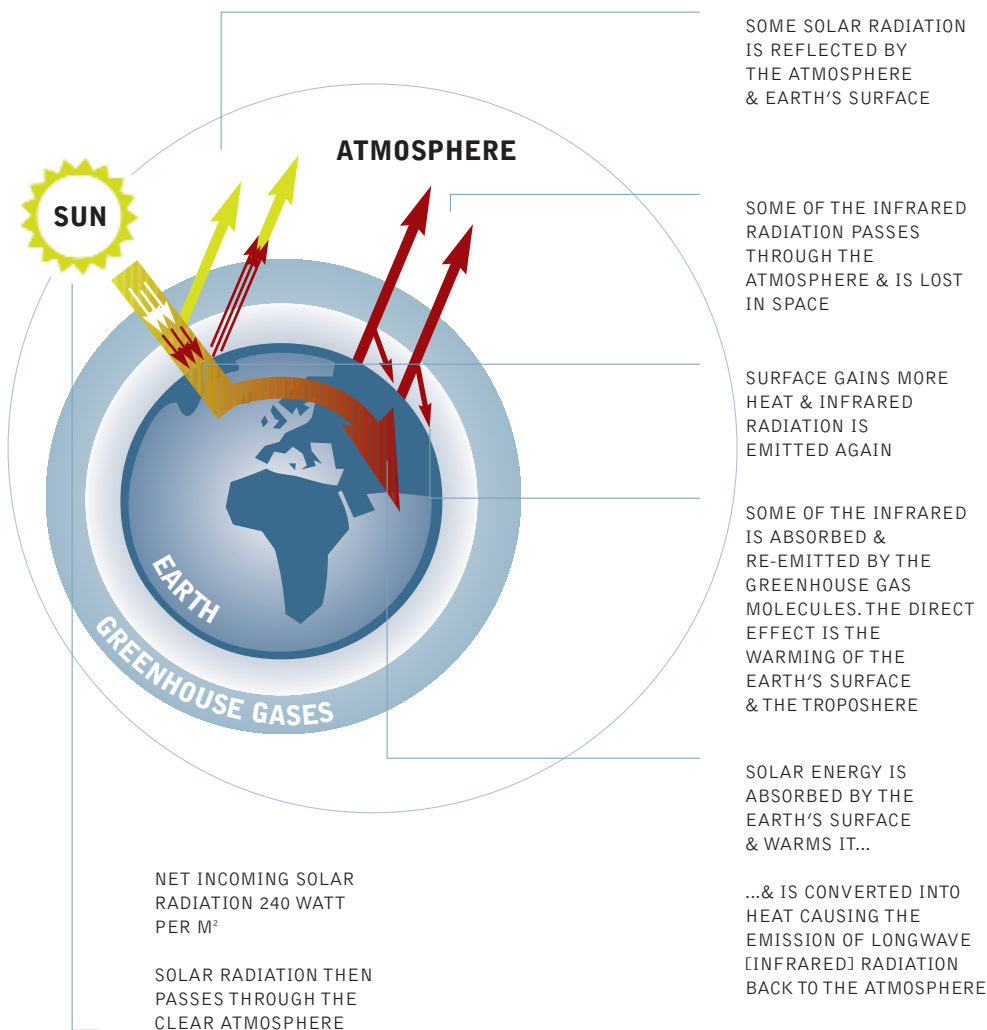


table 1: top 10 warmest years between 1850 and 2005

COMPARED TO MEAN GLOBAL TEMPERATURE 1880-2003

YEAR	GLOBAL TEMPERATURE ANOMALY	RANK
1998, 2005	+0.63°C	1
2003	+0.56°C	2 (tie)
2002	+0.56°C	2 (tie)
2004	+0.54°C	4
2001	+0.51°C	5
1997	+0.47°C	6
1995	+0.40°C	7 (tie)
1990	+0.40°C	7 (tie)
1999	+0.38°C	9
2000	+0.37°C	10

source NATIONAL CLIMATIC DATA CENTER



According to the Intergovernmental Panel on Climate Change, the United Nations forum for established scientific opinion, the world's temperature is expected to increase over the next hundred years by up to 5.8° Celsius. This is much faster than anything experienced so far in human history. The goal of climate policy should be to keep the global mean temperature rise to less than 2°C above pre-industrial levels. At 2°C and above, damage to ecosystems and disruption to the climate system increases dramatically. We have very little time within which we can change our energy system to meet these targets. This means that global emissions will have to peak and start to decline by the end of the next decade at the latest.

Climate change is already harming people and ecosystems. Its reality can be seen in disintegrating polar ice, thawing permafrost, dying coral reefs, rising sea levels and fatal heat waves. It is not only scientists that are witnessing these changes. From the Inuit in the far north to islanders near the Equator, people are already struggling with the impacts of climate change. An average global warming of 2°C threatens millions of people with an increased risk of hunger, malaria, flooding and water shortages.

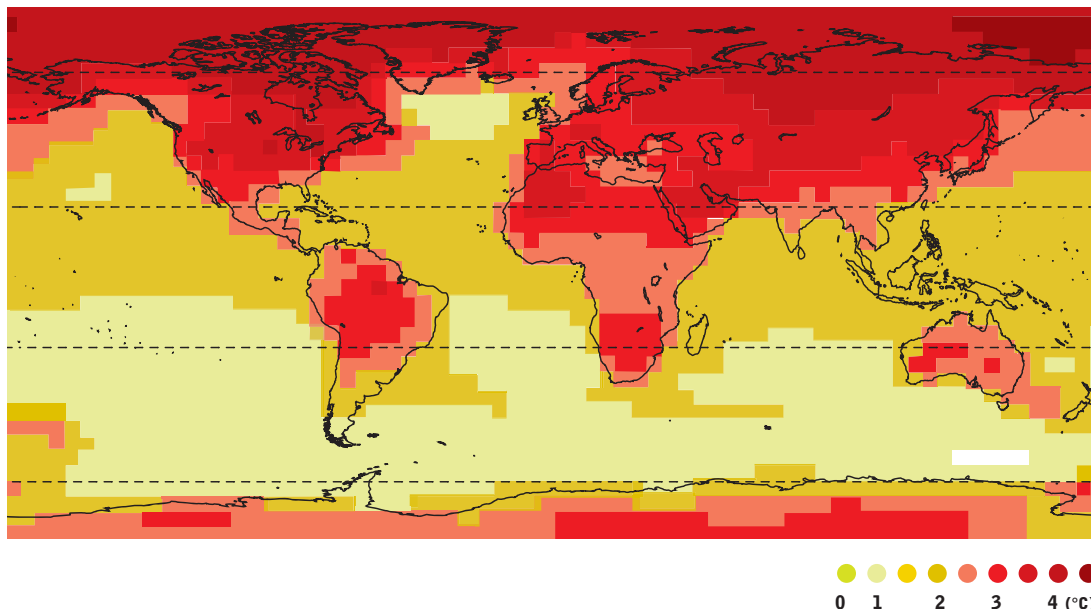
Never before has humanity been forced to grapple with such an immense environmental crisis. If we do not take urgent and immediate action to stop global warming, the damage could become irreversible. This can only happen through a rapid reduction in the emission of greenhouse gases into the atmosphere.

this is a summary of some likely effects if we allow current trends to continue:

likely effects of small to moderate warming

- Sea level rise due to melting glaciers and the thermal expansion of the oceans as global temperature increases.
- Massive releases of greenhouse gases from melting permafrost and dying forests.
- A high risk of more extreme weather events such as heat waves, droughts and floods. Already, the global incidence of drought has doubled over the past 30 years.
- Severe regional impacts. In Europe, river flooding will increase, as well as coastal flooding, erosion and wetland loss. Flooding will also severely affect low-lying areas in developing countries such as Bangladesh and South China.
- Natural systems, including glaciers, coral reefs, mangroves, alpine ecosystems, boreal forests, tropical forests, prairie wetlands and native grasslands will be severely threatened.
- Increased risk of species extinction and biodiversity loss.
- The greatest impacts will be on poorer countries in sub-Saharan Africa, South Asia, Southeast Asia, Andean South America, as well as small islands least able to protect themselves from increasing droughts, rising sea levels, the spread of disease and decline in agricultural production.

figure 3: mean surface temperature distribution for a global temperature increase of 2°C
+2°C AVERAGE



note EMPLOYED LINEAR PATTERN SCALING METHOD AS IMPLEMENTED IN THE SCENGEN MODEL (BY WIGLEY ET AL.). THE DISPLAYED PATTERN IS THE AVERAGE OF THE DEFAULT SET OF MODELS, NAMELY CSM (1998), ECHAM3 (1995), ECHAM4 (1998), GFDL (1990), HADAM2 (1995), HADAM3 (2000). THE PATTERN HAS BEEN DERIVED FOR A TEMPERATURE INCREASE OF 2°C ABOVE 1990 IN A TRANSIENT RUN WITH EMISSION SCENARIO IPCC SRES B2. NOTE THAT THE EQUILIBRIUM TEMPERATURE PATTERN FOR A 2°C INCREASE ABOVE PRE-INDUSTRIAL LEVELS WILL BE QUANTITATIVELY DIFFERENT, ALTHOUGH QUALITATIVELY SIMILAR.
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images 1. OYSTER FISHERMAN IOAN MIOC IN THE SMALL VILLAGE OF BURAS RETURNS BACK 21 DAYS AFTER THE HURRICANE KATRINA. HE FINDS HIS HOUSE, AS SO MANY OTHERS, DESTROYED AND PARTIALLY SUBMERGED IN MUD AND CONTAMINATED WATERS. **2.** A FAMILY LIVING NEXT TO THE SEA BUILD A SEA WALL FROM SAND BAGS IN AN ATTEMPT TO PROTECT THEIR PROPERTY FROM UNUSUAL HIGH TIDES CAUSED BY THE 'KING TIDES'. GREENPEACE AND SCIENTISTS ARE CONCERNED THAT LOW LYING ISLANDS FACE PERMANENT INUNDATION FROM RISING SEAS DUE TO CLIMATE CHANGE. **3.** 30TH OCTOBER 2006 - NONTHABURI, THAILAND - VILLAGERS PADDLE A BOAT AT A VILLAGE IN KOH KRED ISLAND WHICH WAS ENGULFED BY RECENT FLOODING. KOH KRED IS A TINY ISLAND IN THE CHAO PHRAYA RIVER, LOCATED IN NONTHABURI PROVINCE OUTSKIRT OF BANGKOK. EARLIER IN THE YEAR, SCIENTISTS WARNED THAT THAILAND WOULD EXPERIENCE MORE FREQUENT EXTREME WEATHER EVENTS DUE TO THE IMPACTS OF CLIMATE CHANGE. **4.** THE DARK CLOUDS OF AN ADVANCING TORNADO, NEAR FORT DODGE, IOWA, USA. **5.** THOUSANDS OF FISH DIE AT THE DRY RIVER BED OF MANAQUIRI LAKE, 150 KILOMETERS FROM AMAZONAS STATE CAPITOL MANAUS, BRAZIL.

longer term catastrophic effects

- Warming from emissions may trigger the irreversible meltdown of the Greenland ice sheet, adding up to seven metres of sea level rise over several centuries. New evidence also shows that the rate of ice discharge from parts of the Antarctic mean it is also at risk of meltdown.
- Slowing, shifting or shutting down of the Atlantic Gulf Stream current will have dramatic effects in Europe, and disrupt the global ocean circulation system.
- Large releases of methane from melting permafrost and from the oceans will lead to rapid increases of the gas in the atmosphere and consequent warming.

kyoto protocol

Recognising these threats the signatories to the 1992 UN Framework Convention on Climate Change - agreed the Kyoto Protocol in 1997. The Kyoto Protocol finally entered into force in early 2005 and its 165 member countries meet twice annually to negotiate further refinement and development of the agreement. Only two major industrialised nations, the United States and Australia, have not ratified Kyoto.

The Kyoto Protocol commits its signatories to reduce their greenhouse gas emissions by 5.2% from their 1990 level by the target period of 2008-2012. This has in turn resulted in the adoption of a series of regional and national reduction targets. In the European Union, for instance, the commitment is to an overall reduction of 8%. In order to reach this target, the EU has also agreed a target to increase its proportion of renewable energy from 6% to 12% by 2010.

At present, the Kyoto countries are negotiating the second phase of the agreement, covering the period from 2013-2017. Greenpeace is calling for industrialised country emissions to be reduced by 18% from 1990 levels for this second commitment period, and by 30% by the third period covering 2018-2022. Only with these cuts do we stand a reasonable chance of meeting the 2°C target.

The Kyoto Protocol's architecture relies fundamentally on legally binding emissions reduction obligations. To achieve these targets, carbon is turned into a commodity which can be traded. The aim is to encourage the most economically efficient emissions reductions, in turn leveraging the necessary investment in clean technology from the private sector to drive a revolution in energy supply. However, because it took so long for Kyoto to enter into force after the US pulled out in early 2001, negotiators are running out of time. This is a crucial year because countries must agree a firm negotiating mandate at the next meeting in Indonesia in December 2007, in order that the second commitment period of the Kyoto Protocol can be agreed in 2008 or 2009 at the absolute latest. This is necessary to give time for it to be ratified and for governments to implement the policies and measures necessary for the next stage of deeper emissions reductions.

nuclear threats

"THE RISK OF NUCLEAR ACCIDENTS, THE PRODUCTION OF HIGHLY RADIOACTIVE WASTE AND THE THREAT OF PROLIFERATING NUCLEAR WEAPONS ARE ONLY A FEW REASONS WHY NUCLEAR POWER NEEDS TO BE PHASED OUT."

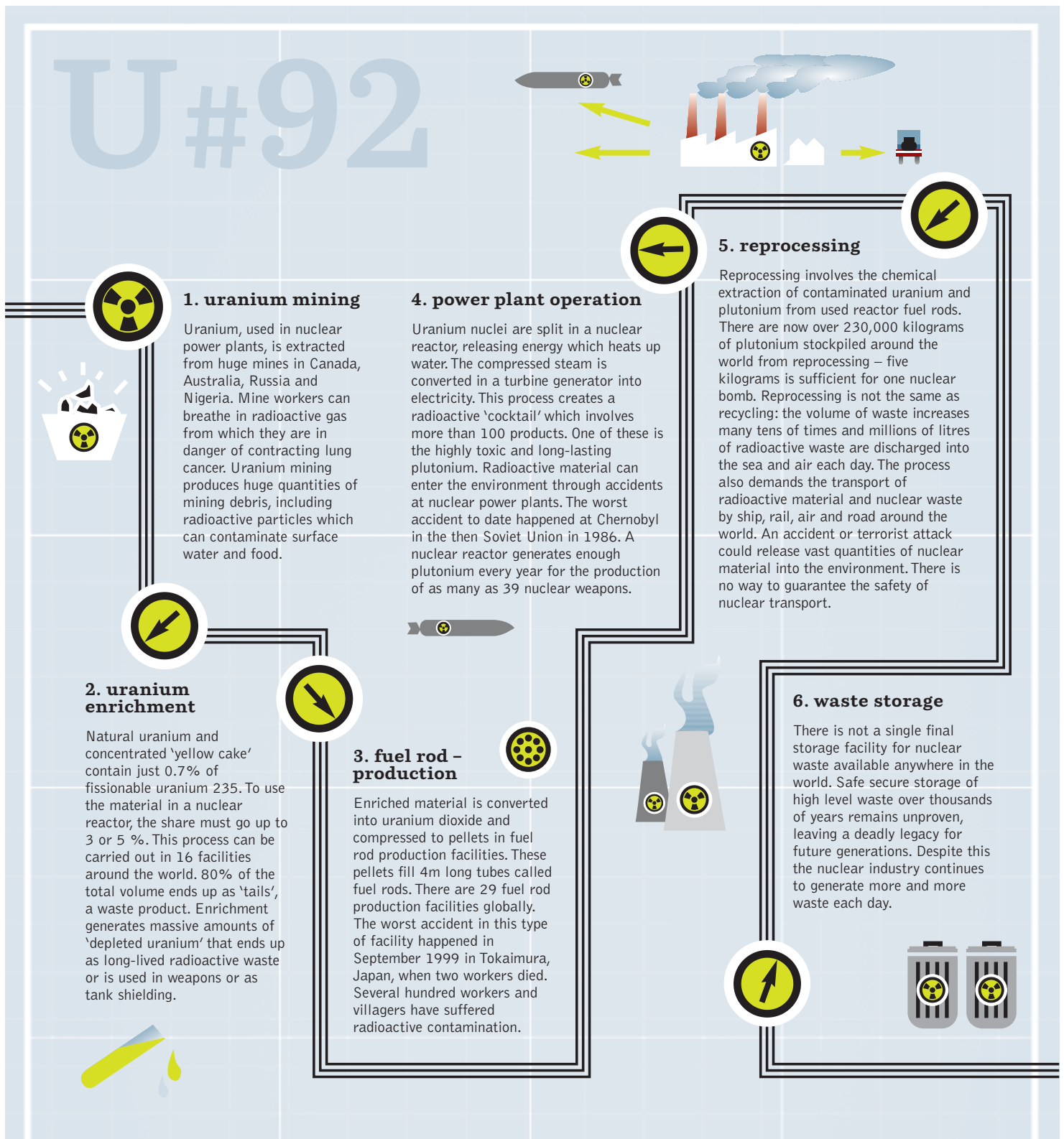


image CHERNOBYL NUCLEAR POWER STATION, UKRAINE.

image IRAQ 17 JUNE 2003. GREENPEACE ACTIVISTS MAKE MEASUREMENTS OUTSIDE THE AL-MAJIDAT SCHOOL FOR GIRLS (900 PUPILS) NEXT TO AL-TOUWAITHA NUCLEAR FACILITY. HAVING FOUND LEVELS OF RADIOACTIVITY 3,000 TIMES HIGHER THAN BACKGROUND LEVEL THEY CORDONED THE AREA OFF.



figure 4: end nuclear threats - from mining to waste storage



nuclear threats

There are multiple threats to people and the environment from nuclear operations. The main risks are:

- Nuclear Proliferation
- Nuclear Waste
- Safety Risks

Together these explain why it has been discounted as a future technology in the energy [r]evolution scenario.

nuclear proliferation

Manufacturing a nuclear bomb requires fissile material - either uranium-235 or plutonium-239. Most nuclear reactors use uranium as a fuel and produce plutonium during their operation. It is impossible to adequately protect a large reprocessing plant to prevent the diversion of plutonium to nuclear weapons. A small-scale plutonium separation plant can be built in four to six months, so any country with an ordinary reactor can produce nuclear weapons relatively quickly.

The result is that nuclear power and nuclear weapons have grown up like Siamese twins. Since international controls on nuclear proliferation began, Israel, India, Pakistan and North Korea have all obtained nuclear weapons, demonstrating the link between civil and military nuclear power. Both the International Atomic Energy Agency (IAEA) and the Nuclear Non-proliferation Treaty (NPT) embody an inherent contradiction - seeking to promote the development of 'peaceful' nuclear power whilst at the same time trying to stop the spread of nuclear weapons.

Israel, India, and Pakistan used their civil nuclear operations to develop weapons capability, operating outside international safeguards. North Korea developed a nuclear weapon even as a signatory of the NPT. A major challenge to nuclear proliferation controls has been the spread of uranium enrichment technology to Iran, Libya and North Korea. The Director General of the International Atomic Energy Agency, Mohamed ElBaradei, has said that "should a state with a fully developed fuel-cycle capability decide, for whatever reason, to break away from its non-proliferation commitments, most experts believe it could produce a nuclear weapon within a matter of months¹."

The United Nations Intergovernmental Panel on Climate Change has also warned that the security threat of trying to tackle climate change with a global fast reactor programme (using plutonium fuel) "would be colossal"². Even without fast reactors, all of the reactor designs currently being promoted around the world could be fuelled by MOX (mixed oxide fuel), from which plutonium can be easily separated.

Restricting the production of fissile material to a few 'trusted' countries will not work. It will engender resentment and create a colossal security threat. A new UN agency is needed to tackle the twin threats of climate change and nuclear proliferation by phasing out nuclear power and promoting sustainable energy, in the process promoting world peace rather than threatening it.

nuclear waste

The nuclear industry claims it can 'dispose' of its nuclear waste by burying it deep underground, but this will not isolate the radioactive material from the environment forever. A deep dump only slows down the release of radioactivity into the environment. The industry tries to predict how fast a dump will leak so that it can claim that radiation doses to the public living nearby in the future will be "acceptably low". But scientific understanding is not sufficiently advanced to make such predictions with any certainty.

As part of its campaign to build new nuclear stations around the world, the industry claims that problems associated with burying nuclear waste are to do with public acceptability rather than technical issues. The industry often points to nuclear dumping proposals in Finland, Sweden or the United States to underline its point.

The most hazardous waste is the highly radioactive waste (or spent) fuel removed from nuclear reactors, which stays radioactive for hundreds of thousands of years. In some countries the situation is exacerbated by 'reprocessing' this spent fuel - which involves dissolving it in nitric acid to separate out weapons-usable plutonium. This process leaves behind a highly radioactive liquid waste. There are about 270,000 tonnes of spent nuclear waste fuel in storage, much of it at reactor sites. Spent fuel is accumulating at around 12,000 tonnes per year, with around a quarter of that going for reprocessing³. No country in the world has a solution for high level waste.

The least damaging option for waste already created at the current time is to store it above ground, in dry storage at the site of origin, although this option also presents major challenges and threats. The only real solution is to stop producing the waste.

safety risks

Windscale (1957), Three Mile Island (1979), Chernobyl (1986) and Tokaimura (1999) are only a few of the hundreds of nuclear accidents which have occurred to date.

A recent simple power failure at a Swedish nuclear plant highlighted our vulnerability to nuclear catastrophe. As a result, Sweden shut down four of its 10 nuclear plants after faults were discovered. Emergency power systems at the Forsmark plant failed for 20 minutes during a power cut. If power was not restored there could have been a major incident within hours. A former director of the plant later said that "it was pure luck there wasn't a meltdown". The closure of the plants removed at a stroke roughly 20% of Sweden's electricity supply.

A nuclear chain reaction must be kept under control, and harmful radiation must, as far as possible, be contained within the reactor, with radioactive products isolated from humans and carefully managed. Nuclear reactions generate high temperatures, and fluids used for cooling are often kept under pressure. Together with the intense radioactivity, these high temperatures and pressures make operating a reactor a difficult and complex task.

The risks from operating reactors are increasing and the likelihood of an accident is now higher than ever. Most of the world's reactors are more than 20 years old and therefore more prone to age related failures. Many utilities are attempting to extend their life from the 40 years or so they were originally designed for to around 60 years, posing new risks.

De-regulation has meanwhile pushed nuclear utilities to decrease safety-related investments and limit staff whilst increasing reactor pressure and operational temperature and the burn-up of the fuel. This accelerates ageing and decreases safety margins. Nuclear regulators are not always able to fully cope with this new regime.

New so-called passively safe reactors have many safety systems replaced by 'natural' processes, such as gravity fed emergency cooling water and air cooling. This can make them more vulnerable to terrorist attack.

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the energy [r]evolution

“THE EXPERT CONSENSUS IS THAT THIS FUNDAMENTAL CHANGE MUST HAPPEN WITHIN THE NEXT TEN YEARS IN ORDER TO AVERT THE WORST IMPACTS.”

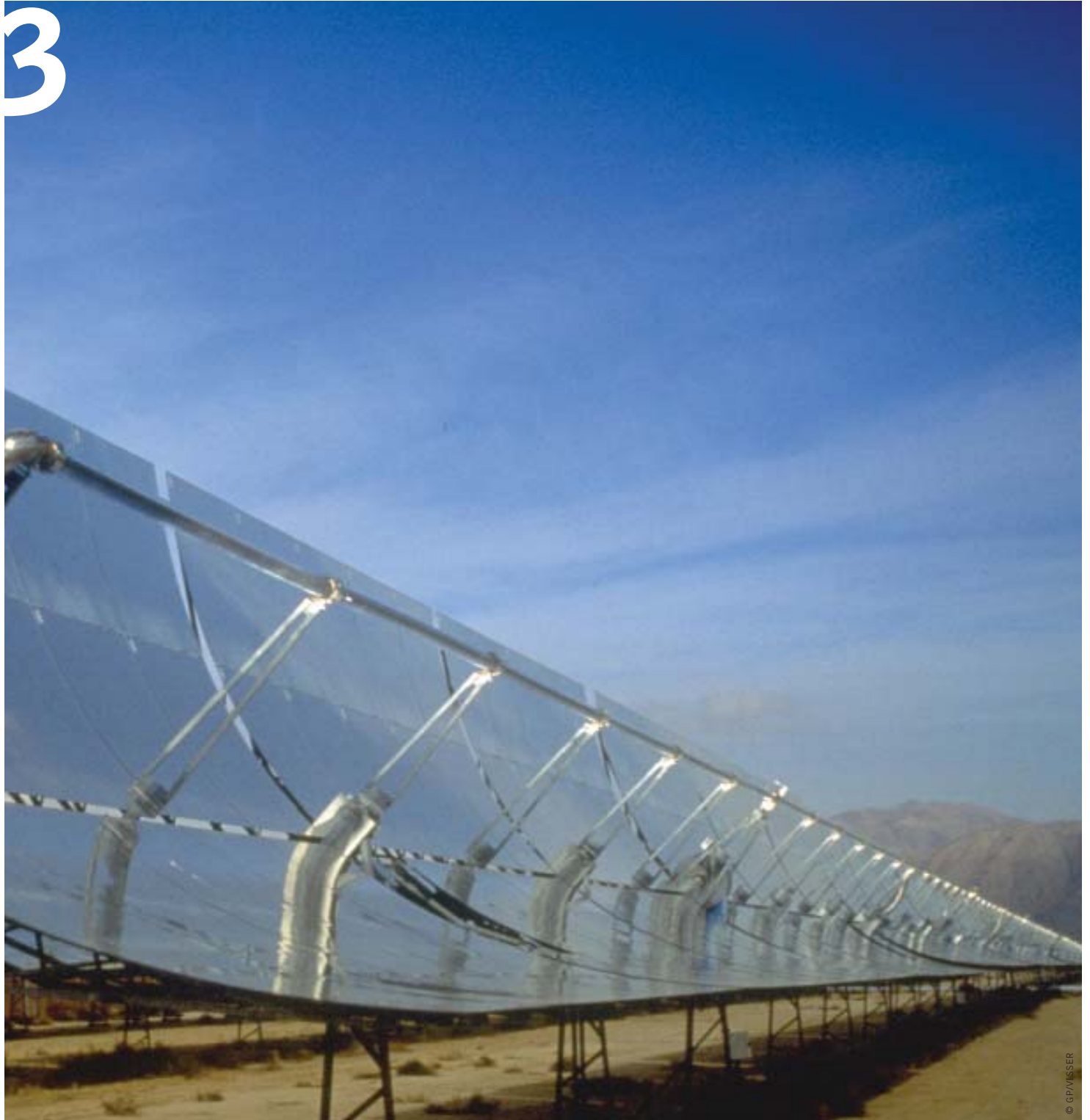


image CONCENTRATING SOLAR POWER (CSP) AT A SOLAR FARM IN DAGGETT, CALIFORNIA, USA.

image PLATFORM/OIL RIG DUNLIN A IN THE NORTH SEA SHOWING OIL POLLUTION.



The climate change imperative demands nothing short of an energy [r]evolution. The expert consensus is that this fundamental change must begin very soon and well underway within the next ten years in order to avert the worst impacts. We do not need nuclear power. What we do need is a complete transformation in the way we produce, consume and distribute energy. Nothing short of such a revolution will enable us to limit global warming to less than 2°Celsius, above which the impacts become devastating.

Current electricity generation relies mainly on burning fossil fuels, with their associated CO₂ emissions, in very large power stations which waste much of their primary input energy. More energy is lost as the power is moved around the electricity grid network and converted from high transmission voltage down to a supply suitable for domestic or commercial consumers. The system is innately vulnerable to disruption: localised technical, weather-related or even deliberately caused faults can quickly cascade, resulting in widespread blackouts. Whichever technology is used to generate electricity within this old fashioned configuration, it will inevitably be subject to some, or all, of these problems. At the core of the energy [r]evolution therefore, there needs to be a change in the way that energy is both produced and distributed.

five key principles

the energy [r]evolution can be achieved by adhering to five key principles:

1 implement clean, renewable solutions and decentralise energy systems

There is no energy shortage. All we need to do is use existing technologies to harness energy effectively and efficiently. Renewable energy and energy efficiency measures are ready, viable and increasingly competitive. Wind, solar and other renewable energy technologies have experienced double digit market growth for the past decade.

Just as climate change is real, so is the renewable energy sector. Sustainable decentralised energy systems produce less carbon emissions, are cheaper and involve less dependence on imported fuel. They create more jobs and empower local communities. Decentralised systems are more secure and more efficient. This is what the energy [r]evolution must aim to create.

2 respect natural limits We must learn to respect natural limits. There is only so much carbon that the atmosphere can absorb. Each year we emit about 23 billion tonnes of CO₂; we are literally filling up the sky. Geological resources of coal could provide several 100 years of fuel, but we cannot burn them and keep within safe limits. Oil and coal development must be ended.

“THE STONE AGE DID NOT END FOR LACK OF STONE, AND THE OIL AGE WILL END LONG BEFORE THE WORLD RUNS OUT OF OIL.”

Sheikh Zaki Yamani, former Saudi Arabian oil minister

To stop the earth’s climate spinning out of control, most of the world’s fossil fuel reserves – coal, oil and gas – must remain in the ground. Our goal is for humans to live within the natural limits of our small planet.

3 phase out dirty, unsustainable energy We need to phase out coal and nuclear power. We cannot continue to build coal plants at a time when emissions pose a real and present danger to both ecosystems and people. And we cannot continue to fuel the myriad nuclear threats by pretending nuclear power can in any way help to combat climate change. There is no role for nuclear power in the energy [r]evolution.

4 equity and fairness As long as there are natural limits, there needs to be a fair distribution of benefits and costs within societies, between nations and between present and future generations. At one extreme, a third of the world’s population has no access to electricity, whilst the most industrialised countries consume much more than their fair share.

The effects of climate change on the poorest communities are exacerbated by massive global energy inequality. If we are to address climate change, one of the principles must be equity and fairness, so that the benefits of energy services - such as light, heat, power and transport - are available for all: north and south, rich and poor. Only in this way can we create true energy security, as well as the conditions for genuine human security.

5 decouple growth from fossil fuel use Starting in the developed countries, economic growth must fully decouple from fossil fuels. It is a fallacy to suggest that economic growth must be predicated on their increased combustion.

- We need to use the energy we produce much more efficiently.
- We need to make the transition to renewable energy – away from fossil fuels – quickly in order to enable clean and sustainable growth.

from principles to practice

Today, renewable energy sources account for 13% of the world’s primary energy demand. Biomass, which is mainly used for heating, is the main renewable energy source. The share of renewable energy in electricity generation is 18%. The contribution of renewables to primary energy demand for heat supply is around 26%. About 80% of primary energy supply today still comes from fossil fuels, and the remaining 7% from nuclear power⁴.

reference

4 IEA; WORLD ENERGY OUTLOOK 2004

use the current “time window”

The time is right to make substantial structural changes in the energy and power sector within the next decade. Many power plants in industrialised countries, such as the USA, Japan and the European Union, are nearing retirement; more than half of all operating power plants are over 20 years old. At the same time developing countries, such as China, India and Brazil, are looking to satisfy the growing energy demand created by expanding economies.

Within the next ten years, the power sector will decide how this new demand will be met, either by fossil and nuclear fuels or by the efficient use of renewable energy. The energy [r]evolution scenario is based on a new political framework in favour of renewable energy and cogeneration combined with energy efficiency.

To make this happen both renewable energy and co-generation – on a large scale and through decentralised, smaller units – have to grow faster than overall global energy demand. Both approaches must replace old generation and deliver the additional energy required in the developing world.

infrastructure changes

As it is not possible to switch directly from the current large scale fossil and nuclear fuel based energy system to a full renewable energy supply, a transition phase is required to build up the necessary infrastructure. Whilst remaining firmly committed to the promotion of renewable sources of energy, we appreciate that gas, used in appropriately scaled cogeneration plant, is valuable as a transition fuel, able to drive cost-effective decentralisation of the energy infrastructure. With warmer summers, trigeneration, which incorporates heat-fired absorption chillers to deliver cooling capacity in addition to heat and power, will become a particularly valuable means to achieve emission reductions.

a development pathway

The energy [r]evolution envisages a development pathway which turns the present energy supply structure into a sustainable system. There are two main stages to this.

step 1: energy efficiency

The energy [r]evolution is aimed at the ambitious exploitation of the potential for energy efficiency. It focuses on current best practice and available technologies for the future, assuming continuous innovation. The energy savings are fairly equally distributed over the three sectors – industry, transport and domestic/business. Intelligent use, not abstinence, is the basic philosophy for future energy conservation.

The most important energy saving options are improved heat insulation and building design, super efficient electrical machines and drives, replacement of old style electrical heating systems by renewable heat production (such as solar collectors) and a reduction in energy consumption by vehicles used for goods and passenger traffic. Industrialised countries, which currently use energy in the most inefficient way, can reduce their consumption drastically without the loss of either housing comfort or information and entertainment electronics. The energy [r]evolution scenario uses energy saved in OECD countries as a compensation for the increasing power requirements in developing countries. The ultimate goal is stabilisation of global energy consumption within the next two decades. At the same time the aim is to create “energy equity” – shifting the current one-sided waste of energy in the industrialized countries towards a fairer worldwide distribution of efficiently used supply.

A dramatic reduction in primary energy demand compared to the International Energy Agency’s “reference scenario” (see Chapter 4) – but with the same GDP and population development - is a crucial prerequisite for achieving a significant share of renewable energy sources in the overall energy supply system, compensating for the phasing out of nuclear energy and reducing the consumption of fossil fuels.



step 2: structural changes

decentralised energy and large scale renewables

In order to achieve higher fuel efficiencies and reduce distribution losses, the energy [r]evolution scenario makes extensive use of Decentralised Energy (DE). This is energy generated at or near the point of use.

DE is connected to a local distribution network system, supplying homes and offices, rather than the high voltage transmission system. The proximity of electricity generating plant to consumers allows any waste heat from combustion processes to be piped to buildings nearby, a system known as cogeneration or combined heat and power. This means that nearly all the input energy is put to use, not just a fraction as with traditional centralised fossil fuel plant. DE also includes stand-alone systems entirely separate from the public networks.

DE technologies also include dedicated systems such as ground source and air source heat pumps, solar thermal and biomass heating. These can all be commercialised at a domestic level to provide sustainable low emission heating. Although DE technologies can be considered 'disruptive' because they do not fit the existing electricity market and system, with appropriate changes they have the potential for exponential growth, promising 'creative destruction' of the existing energy sector.

A huge fraction of global energy in 2050 will be produced by decentralised energy sources, although large scale renewable energy supply will still be needed in order to achieve a fast transition to a renewables dominated system. Large offshore wind farms and concentrating solar power (CSP) plants in the sunbelt regions of the world will therefore have an important role to play.

cogeneration

The increased use of combined heat and power generation (CHP) will improve the supply system's energy conversion efficiency, whether using natural gas or biomass. In the longer term, decreasing demand for heat and the large potential for producing heat directly from renewable energy sources will limit the further expansion of CHP.

renewable electricity

The electricity sector will be the pioneer of renewable energy utilisation. All renewable electricity technologies have been experiencing steady growth over the past 20 to 30 years of up to 35% per year and are expected to consolidate at a high level between 2030 and 2050. By 2050, the majority of electricity will be produced from renewable energy sources.

renewable heating

In the heat supply sector, the contribution of renewables will increase significantly. Growth rates are expected to be similar to those of the renewable electricity sector. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar thermal collectors and geothermal. By 2050, renewable energy technologies will satisfy the major part of heating and cooling demand.

transport

Before biofuels can play a substantial role in the transport sector, the existing large efficiency potentials should be exploited. In this study, biomass is primarily committed to stationary applications and the use of biofuels for transport is limited by the availability of sustainably grown biomass.

Overall, to achieve an economically attractive growth in renewable energy sources, a balanced and timely mobilisation of all technologies is of great importance. Such a mobilisation depends on the resource availability, cost reduction potential and technological maturity.

scenario principles in a nutshell

- Smart consumption, generation and distribution
- Energy production moves closer to the consumer
- Maximum use of locally available, environmentally friendly fuels

figure 5: a decentralised energy future

THE CITY CENTRES OF TOMORROW'S NETWORKED WORLD WILL PRODUCE POWER AND HEAT AS WELL AS CONSUME IT. THE ROOFS AND FACADES OF PUBLIC BUILDINGS ARE IDEAL FOR HARVESTING SOLAR ENERGY. 'LOW ENERGY' WILL BECOME THE STANDARD FOR ALL BUILDINGS. GOVERNMENTS COMMITTED TO TIGHT CLIMATE-PROTECTION TARGETS WILL HAVE TO IMPOSE STRICT CONDITIONS AND OFFER INCENTIVES FOR RENOVATING THESE BUILDINGS. THIS WILL HELP TO CREATE JOBS.

city



1. PHOTOVOLTAIC, SOLAR FASCADA WILL BE A DECORATIVE ELEMENT ON OFFICE AND APARTMENT BUILDINGS. PHOTOVOLTAIC SYSTEMS WILL BECOME MORE COMPETITIVE AND IMPROVED DESIGN WILL ENABLE ARCHITECTS TO USE THEM MORE WIDELY.
2. RENOVATION CAN CUT ENERGY CONSUMPTION OF OLD BUILDINGS BY AS MUCH AS 80% - WITH IMPROVED HEAT INSULATION, INSULATED WINDOWS AND MODERN VENTILATION SYSTEMS.
3. SOLAR THERMAL COLLECTORS PRODUCE HOT WATER FOR BOTH THEIR OWN AND NEIGHBOURING BUILDINGS.
4. EFFICIENT THERMAL POWER (CHP) STATIONS WILL COME IN A VARIETY OF SIZES - FITTING THE CELLAR OF A DETACHED HOUSE OR SUPPLYING WHOLE BUILDING COMPLEXES OR APARTMENT BLOCKS WITH POWER AND WARMTH WITHOUT LOSSES IN TRANSMISSION.
5. CLEAN ELECTRICITY FOR THE CITIES WILL ALSO COME FROM FARTHER AFIELD. OFFSHORE WIND PARKS AND SOLAR POWER STATIONS IN DESERTS HAVE ENORMOUS POTENTIAL.

suburbs



1. PHOTOVOLTAIC
2. MINI-COGENERATION POWER PLANT = COMBINED HEAT AND POWER [CHP]
3. SOLAR COLLECTORS (HEATING)
4. LOW-ENERGY BUILDINGS
5. GEOTHERMAL HEAT- AND POWER PLANT[CHP]

image SOLON AG PHOTOVOLTAICS FACILITY IN ARNSTEIN, GERMANY OPERATING 1500 HORIZONTAL AND VERTICAL SOLAR 'MOVERS'.



optimised integration of renewable energy

Modification of the energy system will be necessary to accommodate the significantly higher shares of renewable energy expected under the energy [r]evolution scenario. This is not unlike what happened in the 1970s and 1980s, when most of the centralised power plants now operating were constructed in OECD countries. New high voltage power lines were built, night storage heaters marketed and large electric-powered hot water boilers installed in order to sell the electricity produced by nuclear and coal-fired plants at night.

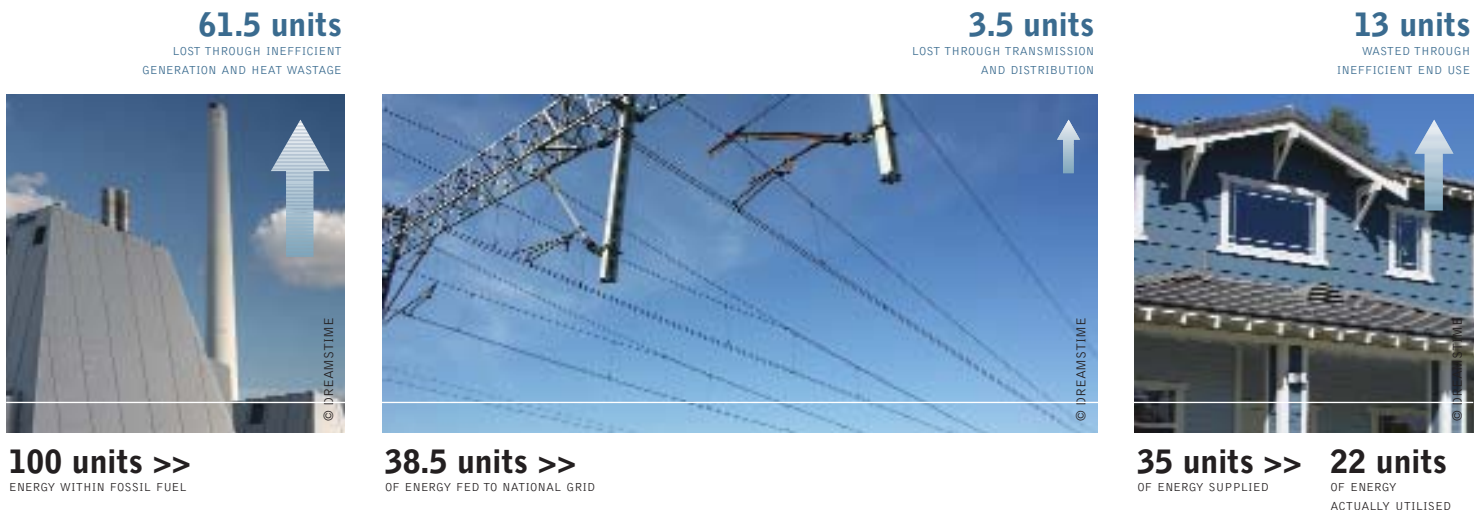
Several OECD countries have demonstrated that it is possible to smoothly integrate a large proportion of decentralised energy including variable sources such as wind. A good example is Denmark, which has the highest percentage of combined heat and power generation and wind power in Europe. With strong political support, 50% of electricity and 80% of district heat is now supplied by cogeneration plants. The contribution of wind power has reached more than 18% of Danish electricity demand. Under some conditions, electricity generation from cogeneration and wind turbines even exceeds demand. The load compensation required for grid stability in Denmark is managed both through regulating the capacity of the few large power stations and through import and export to neighbouring countries. A three tier tariff system enables balancing of power generation from the decentralised power plants with electricity consumption on a daily basis.

It is important to optimise the energy system as a whole through intelligent management by both producers and consumers, by an appropriate mix of power stations and through new systems for storing electricity.

appropriate power station mix The power supply in OECD countries is mostly generated by coal and - in some cases - nuclear power stations, which are difficult to regulate. Modern gas power stations, by contrast, are not only highly efficient but easier and faster to regulate and thus better able to compensate for fluctuating loads. Coal and nuclear power stations have lower fuel and operation costs but comparably high investment costs. They must therefore run round-the-clock as "base load" in order to earn back their investment. Gas power stations have lower investment costs and are profitable even at low output, making them better suited to balancing out the variations in supply from renewable energy sources.

load management The level and timing of demand for electricity can be managed by providing consumers with financial incentives to reduce or shut off their supply at periods of peak consumption. Control technology can be used to manage the arrangement. This system is already used for some large industrial customers. A Norwegian power supplier even involves private household customers by sending them a text message with a signal to shut down. Each household can decide in advance whether or not they want to participate. In Germany, experiments are being conducted with time flexible tariffs so that washing machines operate at night and refrigerators turn off temporarily during periods of high demand.

figure 6: centralised energy infrastructures waste more than two thirds of their energy



This type of load management has been simplified by advances in communications technology. In Italy, for example, 30 million innovative electricity counters have been installed to allow remote meter reading and control of consumer and service information. Many household electrical products or systems, such as refrigerators, dishwashers, washing machines, storage heaters, water pumps and air conditioning, can be managed either by temporary shut-off or by rescheduling their time of operation, thus freeing up electricity load for other uses.

generation management Renewable electricity generation systems can also be involved in load optimisation. Wind farms, for example, can be temporarily switched off when too much power is available on the network.

energy storage Another method of balancing out electricity supply and demand is through intermediate storage. This storage can be decentralised, for example in batteries, or centralised. So far, pumped storage hydropower stations have been the main method of storing large amounts of electric power. In a pumped storage system, energy from power generation is stored in a lake and then allowed to flow back when required, driving turbines and generating electricity. 280 such pumped storage plants exist worldwide. They already provide an important contribution to security of supply, but their operation could be better adjusted to the requirements of a future renewable energy system.

In the long term, other storage solutions are beginning to emerge. One promising solution besides the use of hydrogen is the use of compressed air. In these systems, electricity is used to compress air into deep salt domes 600 metres underground and at pressures of up to 70 bar. At peak times, when electricity demand is high, the air is allowed to flow back out of the cavern and drive a turbine. Although this system, known as CAES (Compressed Air Energy Storage) currently still requires fossil fuel auxiliary power, a so-called “adiabatic” plant is being developed which does not. To achieve this, the heat from the compressed air is intermediately stored in a giant heat store. Such a power station can achieve a storage efficiency of 70%.

The **forecasting** of renewable electricity generation is also continually improving. Regulating supply is particularly expensive when it has to be found at short notice. However, prediction techniques for wind power generation have considerably improved in the last years and are still being improved. The demand for balancing supply will therefore decrease in the future.

the “virtual power station”

The rapid development of information technologies is helping to pave the way for a decentralised energy supply based on cogeneration plants, renewable energy systems and conventional power stations.

Manufacturers of small cogeneration plants already offer internet interfaces which enable remote control of the system. It is now possible for individual householders to control their electricity and heat usage so that expensive electricity drawn from the grid can be minimised - and the electricity demand profile is smoothed. This is part of the trend towards the “smart house” where its mini cogeneration plant becomes an energy management centre. We can go one step further than this with a “virtual power station”. Virtual does not mean that the power station does not produce real electricity. It refers to the fact that there is no large, spatially located power house with turbines and generators. The hub of the virtual power station is a control unit which processes data from many decentralised power stations, compares them with predictions of power demand, generation and weather conditions, retrieves the prevailing power market prices and then intelligently optimises the overall power station activity. Some public utilities already use such systems, integrating cogeneration plants, wind farms, photovoltaic systems and other power plants. The virtual power station can also link consumers into the management process.

future power grids

The **power grid network** must also change in order to realise decentralised structures with a high share of renewable energy. Whereas today’s grids are designed to transport power from a few centralised power stations out to the consumers, a future system must be more versatile. Large power stations will feed electricity into the high voltage grid but small decentralised systems such as solar, cogeneration and wind plants will deliver their power into the low or medium voltage grid. In order to transport electricity from renewable generation such as offshore wind farms in remote areas, a limited number of new high voltage transmission lines will also need to be constructed. These power lines will also be available for cross-border power trade. Within the energy [r]evolution scenario, the share of variable renewable energy sources is expected to reach about 30% of total electricity demand by 2020 and about 40% by 2050.

image PHOTOVOLTAICS FACILITY AT 'WISSENSCHAFTS UND TECHNOLOGIEZENTRUM ADLERSHOF' NEAR BERLIN, GERMANY. SHEEP BETWEEN THE 'MOVERS' KEEPING THE GRASS SHORT.



rural electrification⁵

Energy is central to reducing poverty, providing major benefits in the areas of health, literacy and equity. More than a quarter of the world's population has no access to modern energy services. In sub-Saharan Africa, 80% of people have no electricity supply. For cooking and heating, they depend almost exclusively on burning biomass – wood, charcoal and dung.

Poor people spend up to a third of their income on energy, mostly to cook food. Women in particular devote a considerable amount of time to collecting, processing and using traditional fuel for cooking. In India, two to seven hours each day can be devoted to the collection of cooking fuel. This is time that could be spent on child care, education or income generation. The World Health Organisation estimates that 2.5 million women and young children in developing countries die prematurely each year from breathing the fumes from indoor biomass stoves.

The Millennium Development Goal of halving global poverty by 2015 will not be reached without energy to increase production, income and education, create jobs and reduce the daily grind involved in having to just survive. Halving hunger will not come about without energy for more productive growing, harvesting, processing and marketing of food. Improving health and reducing death rates will not happen without energy for the refrigeration needed for clinics, hospitals and vaccination campaigns. The world's greatest child killer, acute respiratory infection, will not be tackled without dealing with smoke from cooking fires in the home. Children will not study at night without light in their homes. Clean water will not be pumped or treated without energy.

The UN Commission on Sustainable Development argues that "to implement the goal accepted by the international community of halving the proportion of people living on less than US \$1 per day by 2015, access to affordable energy services is a prerequisite".

reference

⁵ SUSTAINABLE ENERGY FOR POVERTY REDUCTION: AN ACTION PLAN, IT-POWER, GREENPEACE INTERNATIONAL SEPTEMBER 2002

the role of sustainable, clean renewable energy

To achieve the dramatic emissions cuts needed to avoid climate change – in the order of 80% in OECD countries by 2050 – will require a massive uptake of renewable energy. The targets for renewable energy must be greatly expanded in industrialised countries both to substitute for fossil fuel and nuclear generation and to create the necessary economies of scale necessary for global expansion. Within the energy [r]evolution scenario we assume that modern renewable energy sources, such as solar collectors, solar cookers and modern forms of bio energy, will replace inefficient, traditional biomass use.

scenario principles in a nutshell

- Smart consumption, generation and distribution
- Energy production moves closer to the consumer
- Maximum use of locally available, environmentally friendly fuels

scenarios for a future energy supply

“ANY ANALYSIS THAT SEEKS TO TACKLE ENERGY AND ENVIRONMENTAL ISSUES NEEDS TO LOOK AHEAD AT LEAST HALF A CENTURY.”



image SOLAR AND WIND-FACILITY NEAR ROSTOCK, GERMANY.

image THE TECHNOLOGY FOR SOLAR PANELS WAS ORIGINAL INSPIRED BY NATURE.



Moving from principles to action on energy supply and climate change mitigation requires a long-term perspective. Energy infrastructure takes time to build up; new energy technologies take time to develop. Policy shifts often also need many years to have an effect. Any analysis that seeks to tackle energy and environmental issues therefore needs to look ahead at least half a century.

Scenarios are important in describing possible development paths, to give decision-makers an overview of future perspectives and to indicate how far they can shape the future energy system. Two different scenarios are used here to characterise the wide range of possible paths for the future energy supply system: a reference scenario, reflecting a continuation of current trends and policies, and the energy [r]evolution scenario, which is designed to achieve a set of dedicated environmental policy targets.

the reference scenario is based on the reference scenario published by the International Energy Agency in World Energy Outlook 2004 (WEO 2004)⁶. This only takes existing policies into account. The assumptions include, for example, continuing progress in electricity and gas market reforms, the liberalisation of cross border energy trade and recent policies designed to combat environmental pollution. The reference scenario does not include additional policies to reduce greenhouse gas emissions. As the IEA's scenario only covers a time horizon up to 2030, it has been extended by extrapolating its key macroeconomic indicators. This provides a baseline for comparison with the energy [r]evolution scenario.

the energy [r]evolution scenario has a key target for the reduction of worldwide carbon dioxide emissions down to a level of around 11 Gigatonnes per year by 2050 in order for the increase in global temperature to remain under +2°C. A second objective is to show that this is even possible with the global phasing out of nuclear energy. To achieve these targets, the scenario is characterised by significant efforts to fully exploit the large potential for energy efficiency. At the same time, cost-effective renewable energy sources are accessed for both heat and electricity generation as well as the production of biofuels. The general framework parameters for population and GDP growth remain unchanged from the reference scenario.

These scenarios by no means claim to predict the future; they simply describe two potential development paths out of the broad range of possible 'futures'. The energy [r]evolution scenario is designed to indicate the efforts and actions required to achieve its ambitious objectives and to illustrate the options we have at hand to change our energy supply system into one that is sustainable.

scenario background

The scenarios in this report were jointly commissioned by Greenpeace and the European Renewable Energy Council from DLR, the German Aerospace Centre. The supply scenarios were calculated using the MESAP/PlaNet simulation model used for a similar study by DLR covering the EU-25 countries⁷. Energy demand projections were developed by Ecofys based on the analysis of future potential for energy efficiency measures.

energy efficiency study

The aim of the Ecofys study was to develop low energy demand scenarios for the period 2003 to 2050 on a sectoral level for the IEA regions as defined in the World Energy Outlook report series. Calculations were made for each decade from 2010 onwards. Energy demand was split up into electricity and fuels. The sectors which were taken into account were industry, transport and other consumers, including households and services.

Two low energy demand scenarios were developed, a reference version and a more ambitious energy efficiency version. This more advanced scenario focuses on current best practice and available technologies in the future, assuming continuous innovation in the field of energy efficiency. Worldwide final energy demand is reduced by 47% in 2050 in comparison to the reference scenario, resulting in a final energy demand of 350 EJ in 2050. The energy savings are fairly equally distributed over the three sectors of industry, transport and other uses. The most important energy saving options are efficient passenger and freight transport and improved heat insulation and building design, together accounting for 46% of the worldwide energy savings.

main scenario assumptions

Development of a global energy scenario requires the use of a multi-region model in order to reflect the significant structural differences between energy supply systems. The International Energy Association's breakdown of world regions, as used in the ongoing series of World Energy Outlook reports, has been chosen because the IEA also provides the most comprehensive global energy statistics. The list of countries covered by each of the ten world regions in the IEA's breakdown is shown in Figure 7.

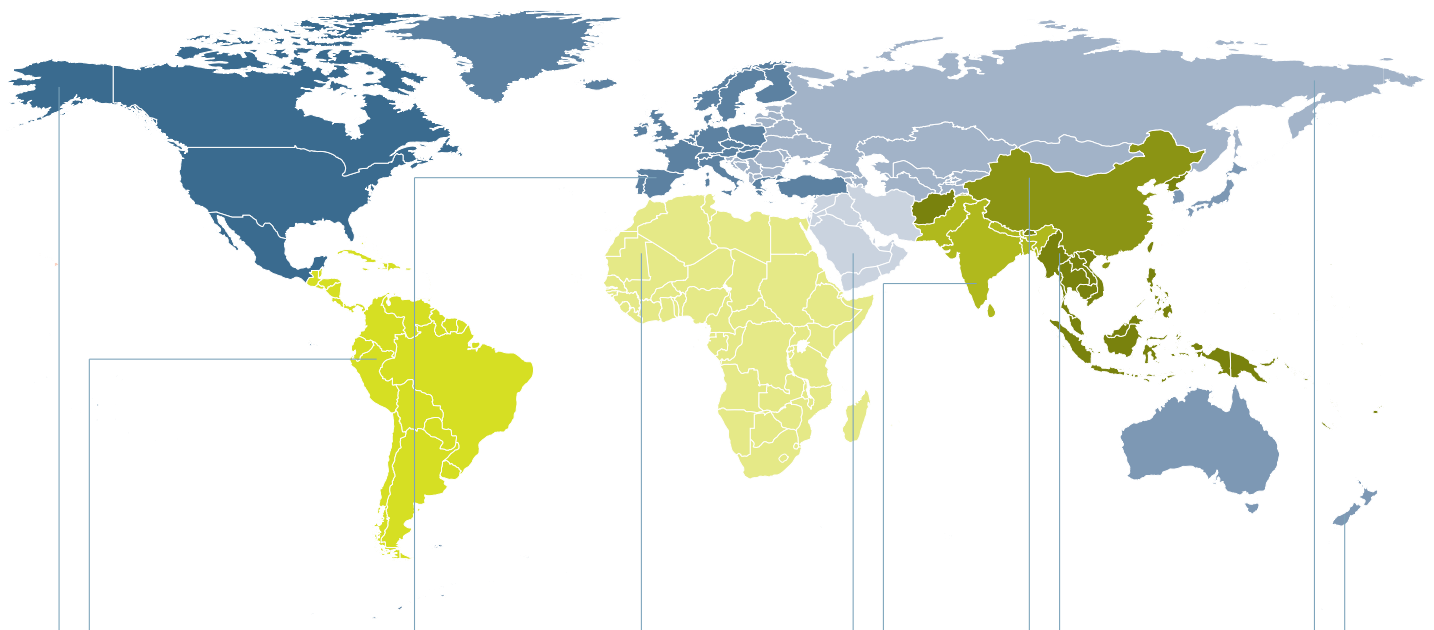
references

⁶ INTERNATIONAL ENERGY AGENCY, WORLD ENERGY OUTLOOK 2004, PARIS 2004 - A NEW WORLD ENERGY OUTLOOK HAS BEEN PUBLISHED IN NOVEMBER 2007 - BASIC PARAMETERS SUCH AS GDP DEVELOPMENT AND POPULATION REMAIN IN THE SAME RANGE (SEE BOX "SENSITIVITY ANALYSIS IEA WEO 2004 -> 2006")

⁷ "ENERGY REVOLUTION: A SUSTAINABLE PATHWAY TO A CLEAN ENERGY FUTURE FOR EUROPE", GREENPEACE INTERNATIONAL, SEPTEMBER 2005

figure 7: definition of world regions

WEO 2004



oecd north america

Canada, Mexico, United States

latin america

Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Domenica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, St. Kitts-Nevis-Anguila, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay, Venezuela

oecd europe

Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom

africa

Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malati, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe

middle east

Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

south asia

Bangladesh, India, Nepal, Pakistan, Sri Lanka

china

China

east asia

Afghanistan, Bhutan, Brunei, Cambodia, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Malaysia, Maldives, Myanmar, New Caledonia, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Vietnam, Vanuatu

transition economies

Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, Federal Republic of Yugoslavia, Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, Gibraltar*), Malta*)

oecd pacific

Japan, South-Korea, Australia, New Zealand

* ALLOCATION OF GIBRALTAR AND MALTA TO TRANSITION ECONOMIES FOR STATISTICAL REASONS

image SOLAR PANELS ON REFRIGERATION PLANT (FOR KEEPING FISH FRESH). LIKIEP ATOLL, MARSHALL ISLANDS.



population growth

Population growth rates for the regions of the world are taken from WEO 2004 up to the end of its projection period in 2030. From 2030 to 2050, data is taken from the 2004 revision of the United Nations' World Population Prospects.

The world's population is expected to grow by 0.78 % over the period 2003 to 2050, rising from 6.3 to almost 8.9 billion. Population growth will slow over the projection period, from 1.2% between 2003 and 2010 to 0.42% from 2040 to 2050. The developing regions will continue to grow most rapidly, whilst the transition economies are expected to undergo a continuous decline. Populations in the OECD Europe and OECD Pacific countries are expected to peak around 2020/2030, followed by a significant decline. OECD North America's population will continue to grow, maintaining its global share.

The population share for those countries classified now as 'developing regions' will increase from 76% to 82% by 2050. The OECD's share of the world population will decrease, as will China's, from 20.8% today to 16%. Africa will remain the region with the highest population growth, leading to a share of 21% of world population in 2050. Satisfying the energy needs of a growing population in the developing regions of the world in an environmentally friendly manner is a key challenge for achieving a global sustainable energy supply.

economic growth

Economic growth is a key driver for energy demand. Since 1971, each 1% increase in global Gross Domestic Product (GDP) has been accompanied by a 0.6% increase in primary energy consumption. The decoupling of energy demand and GDP growth is therefore a prerequisite for reducing demand in the future.

To make a fairer comparison between economic growth in different countries, and more thoroughly reflect comparative standards of living, an adaptation to GDP has been made by using purchasing power parity (PPP) exchange rates. All data on economic development in the WEO 2004 is based on PPP adjusted GDP. This study follows that approach, and all GDP data in this report is expressed in year 2000 US dollars using PPP rather than market exchange rates.

As the WEO 2004 reference scenario only covers the period up to 2030, we have had to look for other assumptions on economic growth after that. The 2000 IPCC Emission Scenarios provide guidance on potential development pathways to the year 2050, offering four basic storylines and related scenario families. The WEO annual average world GDP growth rate between 2002 and 2010 (3.7%) is significantly higher than in any of the IPCC scenarios, but it shows a rapid decline to 2.7% in the period 2020-2030. From 2030 onwards we have therefore chosen the IPCC B2 scenario family, which describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability combined with an intermediate level of economic development.

figure 8: growth of world population by regions

2003 AND 2050

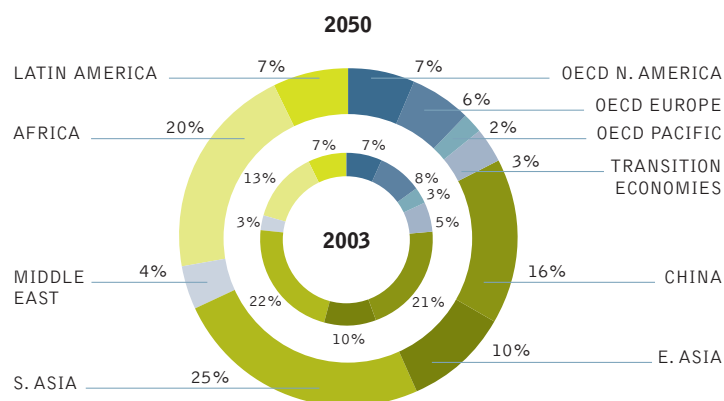


table 2: growth of world population by regions

THOUSANDS

REGION	2003	2010	2020	2030	2040	2050
World	6309590	6848630	7561980	8138960	8593660	8887550
OECD Europe	527300	538470	543880	543880	527560	508970
OECD N. America	425800	456520	499310	535380	563110	586060
OECD Pacific	199000	201800	201800	197800	190990	182570
Transition Economies	345000	340200	333460	320360	303170	284030
China	1311300	1376920	1447330	1461870	1448710	1407150
E. Asia	622600	686240	765570	829070	871470	889060
S. Asia	1410000	1575710	1792960	1980540	2123630	2210120
Latin America	439570	481170	536790	581310	612610	630020
Africa	847660	980400	1183430	1387010	1615780	1835730
Middle East	181360	211200	257450	301740	336630	353840

source UNITED NATIONS (UN)

The result of this analysis is that GDP growth in all regions of the world is expected to slow gradually over the coming decades. World GDP is assumed to grow by an average of 3.2% per year over the period 2002-2030, compared to 3.3% from 1971 to 2002, and by 2.7% per year over the entire period. China and other Asian countries are expected to grow fastest, followed by Africa and the Transition Economies. The Chinese economy will slow as it becomes more mature, but will nonetheless become the largest in the world by the early 2020s. GDP in OECD Europe and OECD Pacific is assumed to grow by slightly less than 2% per year over the projection period, while economic growth in OECD North America is expected to be slightly higher. The OECD share of global PPP adjusted GDP will decrease from 58% in 2002 to 38% in 2050.

Compared to the 2004 IEA projections, the new World Energy Outlook 2006 assumes a slightly higher average annual growth rate of world GDP of 3.4%, instead of 3.2%, for the 2004-2030 time horizon. At the same time, WEO 2006 expects final energy consumption in 2030 to be 4% higher than in WEO 2004. A sensitivity analysis on the impact of economic growth on energy demand under the energy [r]evolution scenario shows that an increase of average world GDP of 0.1% (over the whole time period 2003-2050) leads to an increase in final energy demand of about 0.2%.

The cost of electricity supply is a key parameter for the evaluation of future energy scenarios. The main drivers are the prices of fuels, the investment costs of future power plant technologies and the potential costs of CO₂ emissions.

Future energy prices have been based on projections by the IEA, the US Department of Energy and the European Commission. Future investment costs for power plants have been estimated using a learning curve approach.

Technology specific learning factors (progress ratios) have been derived from a literature review. The development of cumulative capacity for each technology is taken from the results of the energy [r]evolution scenario. All prices are given in \$₂₀₀₀.

fossil fuel price projections

The recent dramatic increase in global oil prices has resulted in much higher forward price projections. Under the 2004 'high oil and gas price' scenario by the European Commission, for example, an oil price of just \$34/bbl was assumed in 2030. Ongoing modelling funded by the Commission (CASCADE-MINTS 2006), on the other hand, assumes an oil price of \$94/bbl in 2050, a gas price of \$15/GJ and an international coal price of \$95/t. Current projections of oil prices in 2030 range from the IEA's \$52/bbl (55 \$2005/bbl) up to over \$100.

As the supply of natural gas is limited by the availability of pipeline infrastructure, there is no world market price for natural gas. In most regions of the world the gas price is directly tied to the price of oil. Current projections of gas prices in 2030 range from the US Department of Energy's \$4.5/GJ up to its highest figure of \$6.9/GJ.

Taking into account the recent development of energy prices, these projections might be considered too conservative. Considering the growing global demand for oil and gas we have assumed a price development path for fossil fuels in which the price of oil reaches \$85/bbl by 2030 and \$100/bbl in 2050. Gas prices are assumed to increase to \$9-\$10/GJ by 2050.

figure 9: growth of world GDP by regions, 2002 and 2050 future development of costs

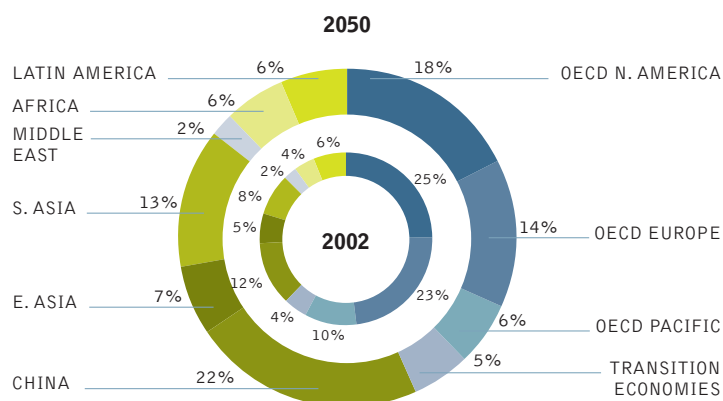


table 2: GDP growth projections

(AVERAGE ANNUAL GROWTH RATES)

REGION	2002 - 2010	2010 - 2020	2020 - 2030	2030 - 2040	2040 - 2050	2002 - 2050
World	3.7%	3.2%	2.7%	2.3%	2.0%	2.7%
OECD Europe	2.4%	2.2%	1.7%	1.3%	1.1%	1.7%
OECD North America	3.2%	2.4%	1.9%	1.6%	1.5%	2.1%
OECD Pacific	2.5%	1.9%	1.7%	1.5%	1.4%	1.8%
Transition Economies	4.6%	3.7%	2.9%	2.6%	2.5%	3.2%
China	6.4%	4.9%	4.0%	3.2%	2.6%	4.1%
East Asia	4.5%	3.9%	3.1%	2.5%	2.2%	3.2%
South Asia	5.5%	4.8%	4.0%	3.2%	2.5%	3.9%
Latin America	3.4%	3.2%	2.9%	2.6%	2.4%	2.9%
Africa	4.1%	3.8%	3.4%	3.4%	3.4%	3.6%
Middle East	3.5%	3.0%	2.6%	2.3%	2.0%	2.6%

source (2002-2030: IEA 2004; 2030-2050: OWN ASSUMPTIONS)



biomass price projections

Compared to fossil fuels, biomass prices are highly variable, ranging from no or low costs for residues or traditional biomass in Africa or Asia to comparatively high costs for biofuels from cultivated energy crops. Despite this variability a biomass price was aggregated for Europe⁸ up to 2030 and supplemented with our own assumptions up to 2050. The increasing biomass prices reflect the continuing link between biofuel and

table 3: assumptions for fossil fuel prices

FOSSIL FUELS	2003	2010	2020	2030	2040	2050
Crude oil in \$2000/bbl	28.0	62.0	75.0	85.0	93.0	100.0
Natural gas in \$2000/GJ						
- America	3.1	4.4	5.6	6.7	8.0	9.2
- Europe	3.5	4.9	6.2	7.5	8.8	10.1
- Asia	5.3	7.4	7.8	8.0	9.2	10.5
Hard coal \$2000/t	42.3	59.4	66.2	72.9	79.7	86.4

table 4: assumptions for biomass prices

BIOMASS	2003	2010	2020	2030	2040	2050
Biomass in \$2000/GJ						
- Europe	4.8	5.8	6.4	7.0	7.3	7.6
- other Regions	1.4	1.8	2.3	2.7	3.0	3.2

table 6: efficiency and investment costs for selected power plant technologies

		2010	2030	2050
Coal-fired condensing power plant	Efficiency (%)	41	45	48
	Investment costs (\$/kW)	980	930	880
	Electricity generation costs including CO ₂ emission costs (\$ cents/kWh)	6.0	7.5	8.7
	CO ₂ emissions ^{a)} (g/kWh)	837	728	697
Oil fired condensing power plant	Efficiency (%)	39	41	41
	Investment costs (\$/kW)	670	620	570
	Electricity generation costs including CO ₂ emission costs (\$ cents/kWh)	22.5	31.0	46.1
	CO ₂ emissions ^{a)} (g/kWh)	1,024	929	888
Natural gas combined cycle	Efficiency (%)	55	60	62
	Investment costs (\$/kW)	530	490	440
	Electricity generation costs including CO ₂ emission costs (\$ cents/kWh)	6.7	8.6	10.6
	CO ₂ emissions ^{a)} (g/kWh)	348	336	325

reference

8 (EUROPE ONLY) NITSCH ET AL. (2004) AND THE GEMIS-DATABASE (ÖKO-INSTITUT, 2005)

fossil fuel prices and a rising share of energy crops. For other regions prices were assumed to be lower, considering the large amount of traditional biomass use in developing countries and the high potential of yet unused residues in North America and the Transition Economies.

cost of CO₂ emissions

Assuming that a CO₂ emissions trading system will be established in all world regions in the long term, the cost of CO₂ allowances needs to be included in the calculation of electricity generation costs. Projections of emission costs are even more uncertain than energy prices, however. The IEA assumes a 'CO₂ reduction incentive' of \$25/tCO₂ in 2050. The European CASCADE-MINTS project, on the other hand, assumes CO₂ costs of \$50/tCO₂ in 2020 and \$100/tCO₂ beyond 2030. For this scenario we have assumed CO₂ costs of \$50/tCO₂ in 2050, which is twice as high as the IEA's projection, but still conservative compared with other studies. We assume that CO₂ emission costs will be accounted for in Non-Annex B countries only after 2020.

summary of conventional energy cost development

Table 6 gives a summary of expected investment costs for different fossil fuel technologies with varying levels of efficiency.

table 5: assumptions for CO₂ prices

COUNTRIES	2010	2020	2030	2040	2050
Kyoto Annex B countries	10	20	30	40	50
Non-Annex B countries		20	30	40	50

source DLR, 2006 ^{a)} REFERS TO DIRECT EMISSIONS ONLY, LIFE-CYCLE EMISSIONS ARE NOT CONSIDERED HERE.

renewable energy price projections

The range of renewable energy technologies available today display marked differences in terms of their technical maturity, costs and development potential. Whereas hydro power has been widely used for decades, other technologies, such as the gasification of biomass, have yet to find their way to market maturity. Some renewable sources by their very nature, including wind and solar power, provide a variable supply, requiring a revised coordination with the grid network. But although in many cases these are 'distributed' technologies - their output generated and used locally to the consumer - the future will also see large-scale applications in the form of offshore wind parks or concentrating solar power (CSP) stations.

By using the individual advantages of the different technologies, and linking them with each other, a wide spectrum of available options can be developed to market maturity and integrated step by step into the existing supply structures. This will eventually provide a complementary portfolio of environmentally friendly technologies for heat and power supply and the provision of fuels.

Most of the renewable technologies employed today are at an early stage of market development. Accordingly, their costs are generally higher than for competing conventional systems. Costs can also depend on local conditions such as the wind regime, the availability of cheap

biomass supplies or the need for nature conservation requirements when building a new hydro power plant. There is a large potential for cost reduction, however, through technical and manufacturing improvements and large-scale production, especially over the long timescale of this study.

To identify long-term cost developments, learning curves have been applied which reflect the correlation between cumulative capacity and the development of costs. For many technologies, the learning factor (or progress ratio) falls in the range between 0.75 for less mature systems to 0.95 and higher for well-established technologies. A learning factor of 0.9 means that costs are expected to fall by 10% every time the cumulative output from the technology doubles. Technology specific progress ratios are derived from a literature review⁹. This shows, for example, that the learning factor for PV solar modules has been fairly constant at 0.8 over 30 years whilst that for wind energy varies from 0.75 in the UK to 0.94 in the more advanced German market.

figure 10: range of current electricity generation costs from renewable energy sources in europe

(EXCLUDING PV, WITH COSTS OF 25 TO 50 \$ CENT/kWh). HIGH (LIGHT SHADING) AND LOW (DARK SHADING) ENDS OF RANGE REFLECT VARYING LOCAL CONDITIONS - WIND SPEED, SOLAR RADIATION ETC.

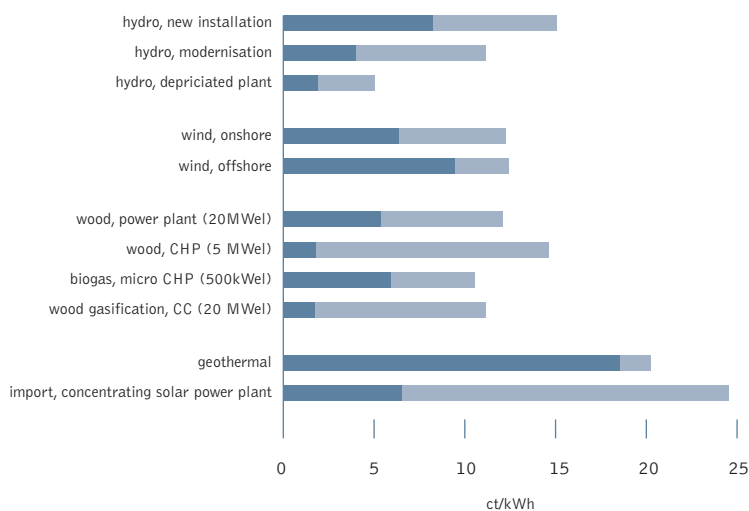


image GREENPEACE DONATES A SOLAR POWER SYSTEM TO A COASTAL VILLAGE IN ACEH, INDONESIA, ONE OF THE WORST HIT AREAS BY THE TSUNAMI IN DECEMBER 2004. IN COOPERATION WITH UPLINK, A LOCAL DEVELOPMENT NGO, GREENPEACE OFFERED ITS EXPERTISE ON ENERGY EFFICIENCY AND RENEWABLE ENERGY AND INSTALLED RENEWABLE ENERGY GENERATORS FOR ONE OF THE BADLY HIT VILLAGES BY THE TSUNAMI LAST YEAR.



1. photovoltaics (PV)

Although the worldwide PV market has been growing at over 40% per annum in recent years, the contribution it makes to electricity generation is still very small. Development work is focused on improving existing modules and system components and developing new types of cells in the thin-film sector and new materials for crystalline cells. It is expected that the efficiency of commercial crystalline cells will improve by between 15 and 20% in the next few years, and that thin-film cells using less raw material will become commercially available.

The learning factor for PV modules has been fairly constant over a period of 30 years at around 0.8, indicating a continuously high rate of technical learning and cost reduction. Assuming a globally installed capacity of 2,000 GW in 2050, and a decrease in the learning rate after 2030, we can expect that electricity generation costs of around 5-9 cents/kWh will be possible by 2030⁹. Compared with other technologies for utilising renewables, photovoltaic power must therefore be classified as a long-term option. Its importance derives from its great flexibility and its enormous technical potential for rural electrification for the 2 billion people currently having no access to electricity.

2. concentrating solar power plants

Solar thermal 'concentrating' power stations can only use direct sunlight and are therefore dependent on high irradiation locations. North Africa, for example, has a technical potential which far exceeds local demand. The various solar thermal technologies (parabolic trough, power towers and parabolic dish concentrators) offer good prospects for further development and cost reductions. One important objective is the creation of large thermal energy reservoirs in order to extend the operating time of these systems beyond the sunlight period.

Owing to the small number of Concentrating Solar Power (CSP) plants built to date, it is difficult to arrive at reliable learning factors for this sector. Here it is assumed that the learning factor of 0.88 derived from the data for parabolic trough reflectors built in California will change to 0.95 in the course of market introduction up to 2030. The UN's World Energy Assessment expects solar thermal electricity generation will enjoy a dynamic market growth similar to the wind industry, but with a time lag of 20 years. Depending on the level of irradiation and mode of operation, electricity generation costs of 5-8 cents/kWh are expected. This presupposes rapid market introduction in the next few years.

3. solar thermal collectors for heating and cooling

Small solar thermal collector systems for water and auxiliary heating are well developed today and used for a wide variety of applications. By contrast, large seasonal heat reservoirs that store heat from the summer until it is needed in the winter are only available as pilot plants. Only by means of local heating systems with seasonal storage would it be possible to supply large parts of the low temperature heat market with solar energy. Crucial factors for market launch will be low storage costs and an adequate usable heat yield.

Data for the European collector market show a learning factor of nearly 0.90 for solar collectors, which indicate a relatively well developed system from a technological point of view. By contrast, the construction of seasonal heat reservoirs is expected to show a long term cost reduction of over 70%. Depending on the configuration of the system, it will be possible in the long term to achieve solar thermal costs of between 4 and 7 cents/kWh_{thermal}.

4. wind power

Within a short period of time, the dynamic development of wind power has resulted in the establishment of a flourishing global market. The world's largest wind turbines, several of which have been installed in Germany, have a capacity of 6 MW. The cost of new systems has, however, stagnated in some countries in recent years due to the continuing high level of demand and the manufacturers' considerable advance investment in the development and introduction of a succession of new systems. The result is that the learning factor observed for wind turbines built between 1990 and 2000 in Germany was only 0.94. Nevertheless, since technical developments have led to increases in specific yield, electricity generation costs should reduce further. Owing to the relative lack of experience in the offshore sector, a larger cost reduction potential is expected here, with the learning rate correspondingly higher.

Whilst the IEA's World Energy Outlook 2004 expects worldwide wind capacity to grow to only 330 GW by 2030, the United Nations' World Energy Assessment assumes a global saturation level of around 1,900 GW by the same time. The Global Wind Energy Outlook (2006)¹¹ projects a global capacity of up to 3,000 GW by 2050. An experience curve for wind turbines is derived by combining the currently observed learning factors with a high market growth assumption, oriented towards the Global Wind Energy Outlook, indicating that costs for wind turbines will reduce by 40% up to 2050.

references

⁹ DLR 2006, DR. WOLFRAM KREWITT ET. AL.

¹⁰ EPIA/GREENPEACE INTERNATIONAL: SOLARGENERATION 2006

¹¹ EUROPEAN WIND ENERGY ASSOCIATION AND GREENPEACE

5. biomass

The crucial factor for the economics of biomass utilisation is the cost of the feedstock, which today ranges from a negative cost for waste wood (credit for waste disposal costs avoided) through inexpensive residual materials to the more expensive energy crops. The resulting spectrum of energy generation costs is correspondingly broad. One of the most economic options is the use of waste wood in steam turbine combined heat and power (CHP) plants. Gasification of solid bio fuels, on the other hand, which opens up a wide range of applications, is still relatively expensive. In the long term it is expected that favourable electricity production costs will be achieved by using wood gas both in micro CHP units (engines and fuel cells) and in gas-and-steam power plants. Great potential for the utilisation of solid biomass also exists for heat generation in both small and large heating centres linked to local heating networks. Converting crops into ethanol and 'bio diesel' made from rapeseed methyl ester (RME) has become increasingly important in recent years, for example in Brazil and the USA. Processes for obtaining synthetic fuels from biogenic synthesis gases will also play a growing role.

A great potential for exploiting modern technologies exists in Latin America, Europe and the Transition Economies either in stationary appliances or the transport sector. For these regions it is assumed that in the long term 60% of the potential for biomass will come from energy crops, the rest from forest residues, industrial wood waste and straw.

In other regions, like the Middle East, South Asia or China, the additional use of biomass is restricted, either due to a generally low availability or already high traditional use. For the latter, using more efficient technologies will improve the sustainability of current biomass use.

6. geothermal

Geothermal energy has long been used worldwide for supplying heat, whilst electricity generation is limited to a few sites with specific geological conditions. Further intensive research and development work is needed to speed up progress. In particular, the creation of large underground heat-exchange surfaces (HDR technology) and the improvement of heat-and-power machines with Organic Rankine Cycle (ORC) must be optimised in future projects.

As a large part of the costs for a geothermal power plant come from deep drilling, data from the oil sector can be used, with learning factors observed there of less than 0.8. Assuming a global average market growth for geothermal power capacity of 9% per year until 2020, reducing to 4% beyond 2030, the result would be a cost reduction potential of 50% by 2050. Thus, despite the present high figures (about 20 cents/kWh), electricity production costs – depending on payments for heat supply – are expected to come down to around 6-10 cents/kWh in the long term. Because of its non-fluctuating supply, geothermal energy is considered to be a key element in a future supply structure based on renewable sources.

7. hydro power

Hydro power is a mature technology that has long been used for economic generation of electricity. Additional potential can be exploited primarily by modernising and expanding existing systems. The remaining limited cost reduction potential will probably be offset by increasing site development problems and growing environmental requirements. It can be assumed that for small scale systems, where power generation costs are generally higher, the need to comply with ecological requirements will involve proportionately higher costs than for large systems.

summary of renewable energy cost development

Figure 12 summarises the cost trends for renewable energy technologies as derived from the respective learning curves. It should be emphasised that the expected cost reduction is basically not a function of time, but of cumulative capacity, so dynamic market development is required. Most of the technologies will be able to reduce their specific investment costs to between 30% and 60% of current levels by 2020, and to between 20% and 50% once they have achieved full development (after 2040).

Reduced investment costs for renewable energy technologies lead directly to reduced heat and electricity generation costs, as shown in Figure 12. Generation costs today are around 8 to 20 cents/kWh for the most important technologies, with the exception of photovoltaics. In the long term, costs are expected to converge at around 4 to 10 cents/kWh. These estimates depend on site-specific conditions such as the local wind regime or solar irradiation, the availability of biomass at reasonable prices or the credit granted for heat supply in the case of combined heat and power generation.

references for the cost assumptions section INTERNATIONAL ENERGY AGENCY: "ENERGY TECHNOLOGY PERSPECTIVES - SCENARIOS AND STRATEGIES TO 2050" (IEA 2006); "WORLD ENERGY OUTLOOK 2005" (IEA 2005); "WORLD ENERGY OUTLOOK 2004" (IEA 2004). ENERGY INFORMATION ADMINISTRATION, US DEPARTMENT OF ENERGY: "ANNUAL ENERGY OUTLOOK 2006 WITH PROJECTIONS TO 2030" (EIA 2006). EUROPEAN COMMISSION: "EUROPEAN ENERGY AND TRANSPORT - SCENARIOS ON KEY DRIVERS" (EUROPEAN COMMISSION, 2004). CASCADE (2006): [HTTP://WWW.E3MLAB.NTUA.GR/CASCADE.HTML](http://www.e3mlab.ntua.gr/cascade.html). NITSCH, J.; KREWITT, W.; NAST, M.; VIEBAHN, P.; GÄRTNER, S.; PEHNT, M.; REINHARDT, G.; SCHMIDT, R.; UIHLEIN, A.; BARTHEL, C.; FISCHEDICK, M.; MERTEN, F.; SCHEURLIN, K. (2004): ÖKOLOGISCH OPTIMIERTER AUSBAU DER NUTZUNG ERNEUERBARER ENERGIEN IN DEUTSCHLAND. IN: BUNDESMINISTERIUM FÜR UMWELT, NATURSCHUTZ UND REAKTORSICHERHEIT (ED.): UMWELTPOLITIK, KÖLLEN DRUCK. ÖKO-INSTITUT (2005): GLOBAL EMISSION MODEL FOR INTEGRATED SYSTEMS (GEMIS), VERSION 4.3; INSTITUTE FOR APPLIED ECOLOGY E.V.; [HTTP://WWW.GEMIS.DE](http://www.gemis.de). WBGU (2003): ÜBER KIOTO HINAUS DENKEN - KLIMASCHUTZSTRATEGIEN FÜR DAS 21. JAHRHUNDERT. SONDERGUTACHTEN DES WISSENSCHAFTLICHEN BEIRATS DER BUNDESREGIERUNG FÜR GLOBALE UMWELTVERÄNDERUNG, BERLIN, 2003. [HTTP://WWW.WBGU.DE/WBGU_SN2003.HTML](http://www.wbgu.de/wbgu_sn2003.html)

image NUCLEAR POWER STATION WITH COOLING TOWERS.



figure 11: future investment costs for selected energy generation technologies

(NORMALISED TO CURRENT COST LEVELS) FOR RENEWABLE ENERGY TECHNOLOGIES, DERIVED FROM LEARNING CURVES

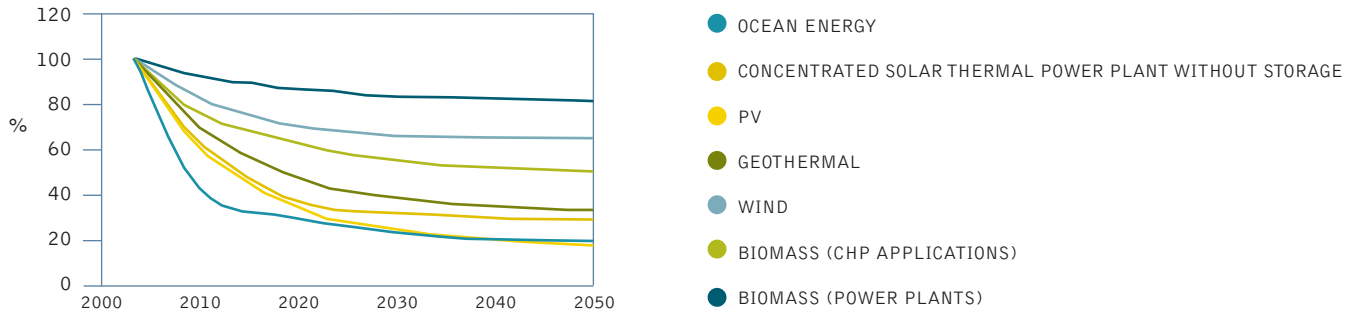
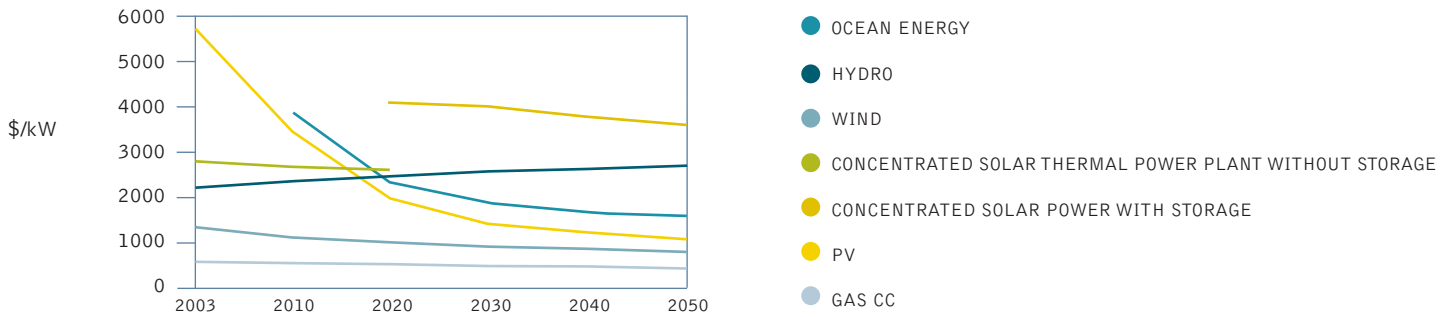
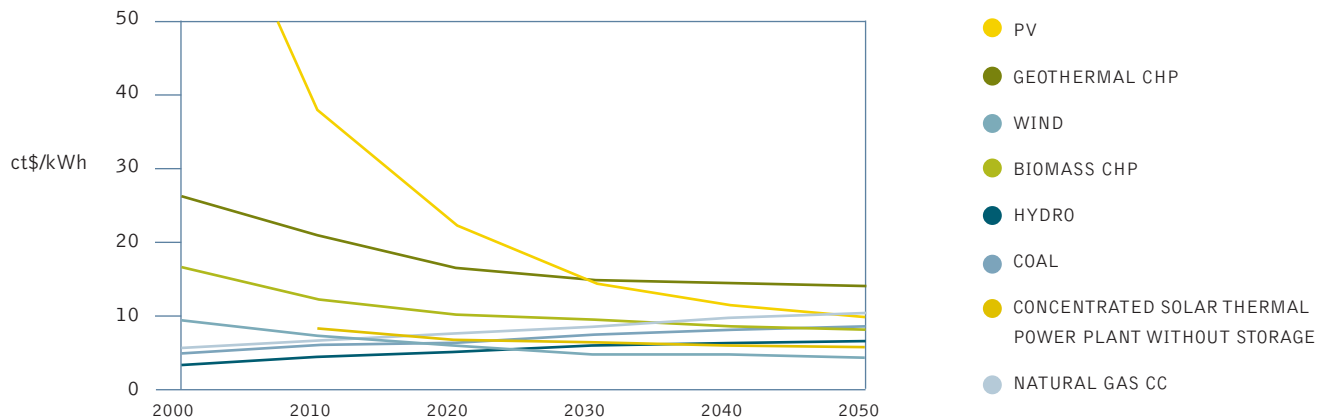


figure 12: future investment costs for selected energy generation technologies



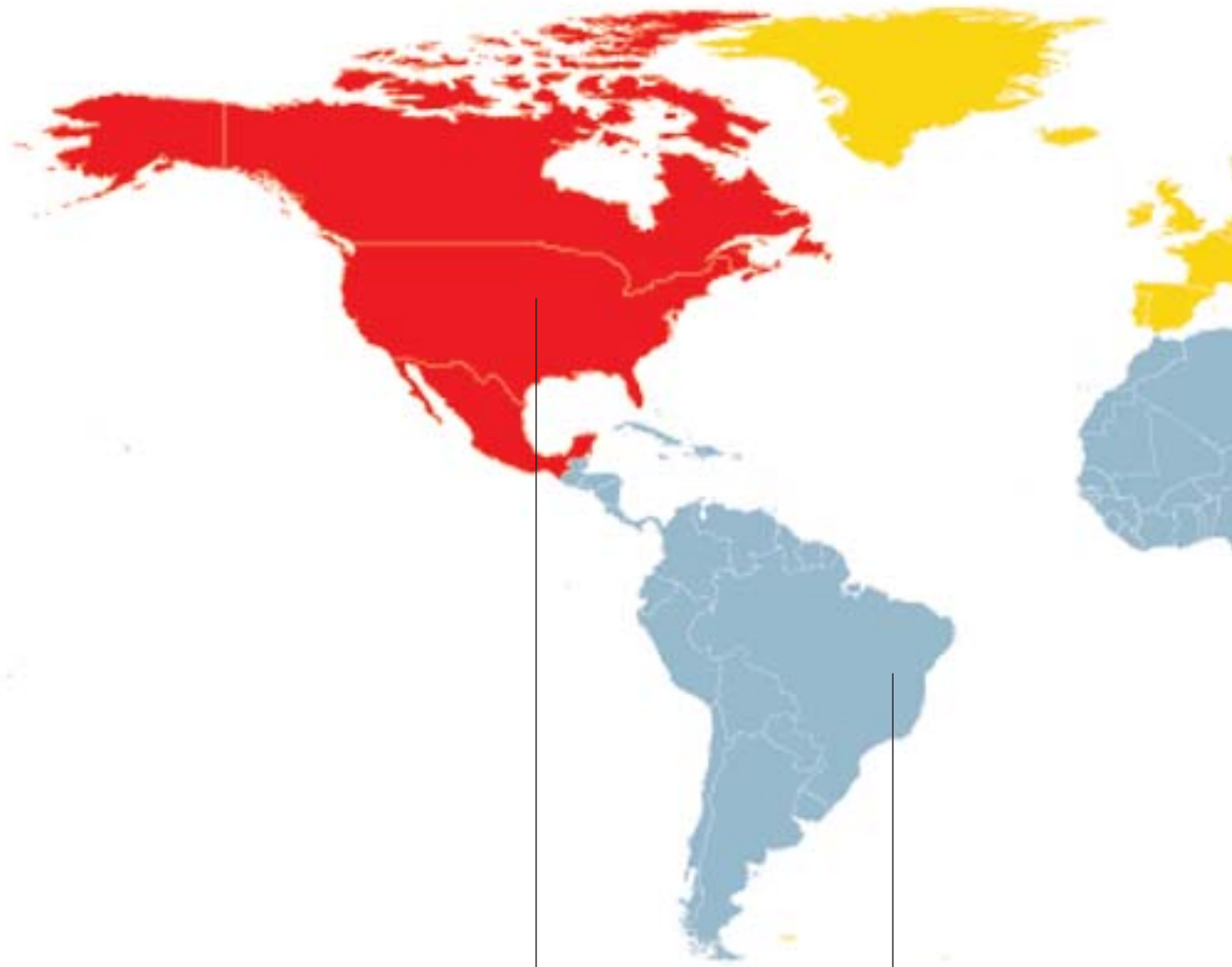
reference FIGURES FOR OECD EUROPE, CONCENTRATED SOLAR THERMAL POWER PLANT WITHOUT STORAGE FOR MIDDLE EAST. (*GENERATION COSTS DEPEND PARTLY ON SITE SPECIFIC FUEL COSTS AND HEAT CREDITS.)

figure 13: expected electricity generation costs from fossil and renewable options



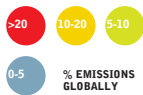
reference FIGURES FOR OECD EUROPE, CONCENTRATED SOLAR THERMAL POWER PLANT WITHOUT STORAGE FOR MIDDLE EAST. (GENERATION COSTS DEPEND PARTLY ON SITE SPECIFIC FUEL COSTS AND HEAT CREDITS.)

map 1: CO₂ emissions reference scenario and the energy [r]evolution scenario
WORLDWIDE SCENARIO



EMISSIONS CO₂

LEGEND



REF REFERENCE SCENARIO
ALT ALTERNATIVE SCENARIO

0 1000 KM

CO₂ EMISSIONS TOTAL
MILLION TONNES [mio t] | % INCREASE/DECREASE FROM 2003 | % INCREASE/DECREASE FROM 1990

PERSON EMISSIONS PER PERSON TONNES [t]

H HIGHEST | **M** MIDDLE | **L** LOWEST

OECD NORTH AMERICA

	REF		ALT	
	mio t	%	mio t	%
CO₂ 2003	6,646 ^H		6,646 ^H	
2050	9,297 ^H	+40	1,787	-73L/-68
PERSON 2003	16 ^H		16 ^H	
2050	16 ^H		3	

LATIN AMERICA

	REF		ALT	
	mio t	%	mio t	%
CO₂ 2003	802		802	
2050	3,200	+300	442 ^L	-45M/-34
PERSON 2003	2		2	
2050	5		1	

OECD EUROPE

	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	3,886	3,886	
	2050	5,210	34%	1,160M -70/-71
	t			
Population	2003	7	7	
	2050	10	2M	

MIDDLE EAST

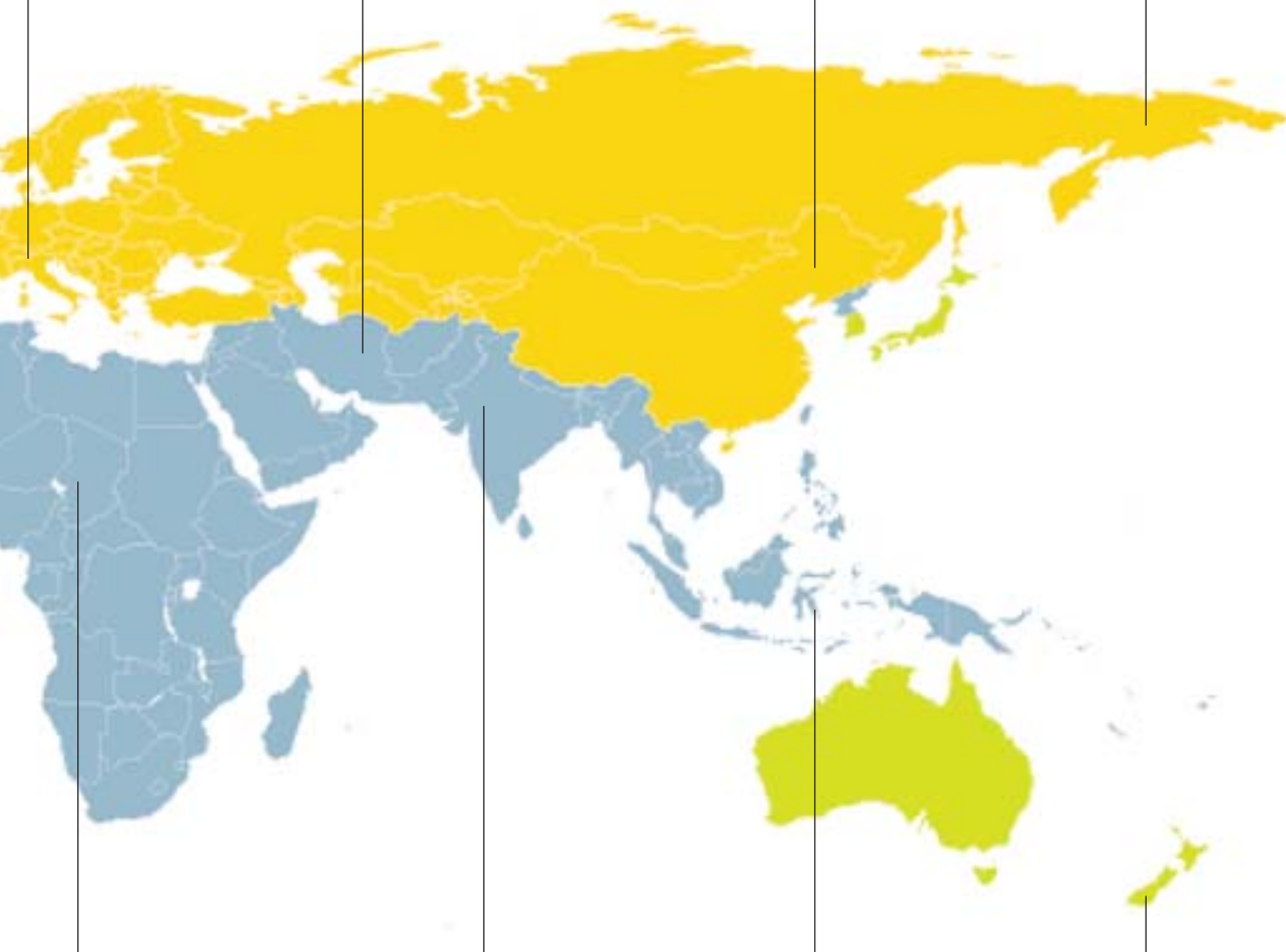
	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	1,004	1,004	
	2050	2,116L	+111	493 -51/-22
	t			
Population	2003	6M	6M	
	2050	6M	1	

CHINA

	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	3,313	3,313	
	2050	8,547	+158	3,284H -1/+30
	t			
Population	2003	3	3	
	2050	6M	2M	

TRANSITION ECONOMIES

	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	2,685M	2,685M	
	2050	3,655	+36	745 -72/-81
	t			
Population	2003	8	8	
	2050	13	3	



AFRICA

	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	727L	727L	
	2050	3,440	+373H	1,075 +48H/+21
	t			
Population	2003	1L	1L	
	2050	2L	1	

SOUTH ASIA

	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	1,126	1,126	
	2050	4,039M	+259	1,077 -4/+47
	t			
Population	2003	1L	1L	
	2050	2L	0.5L	

EAST ASIA

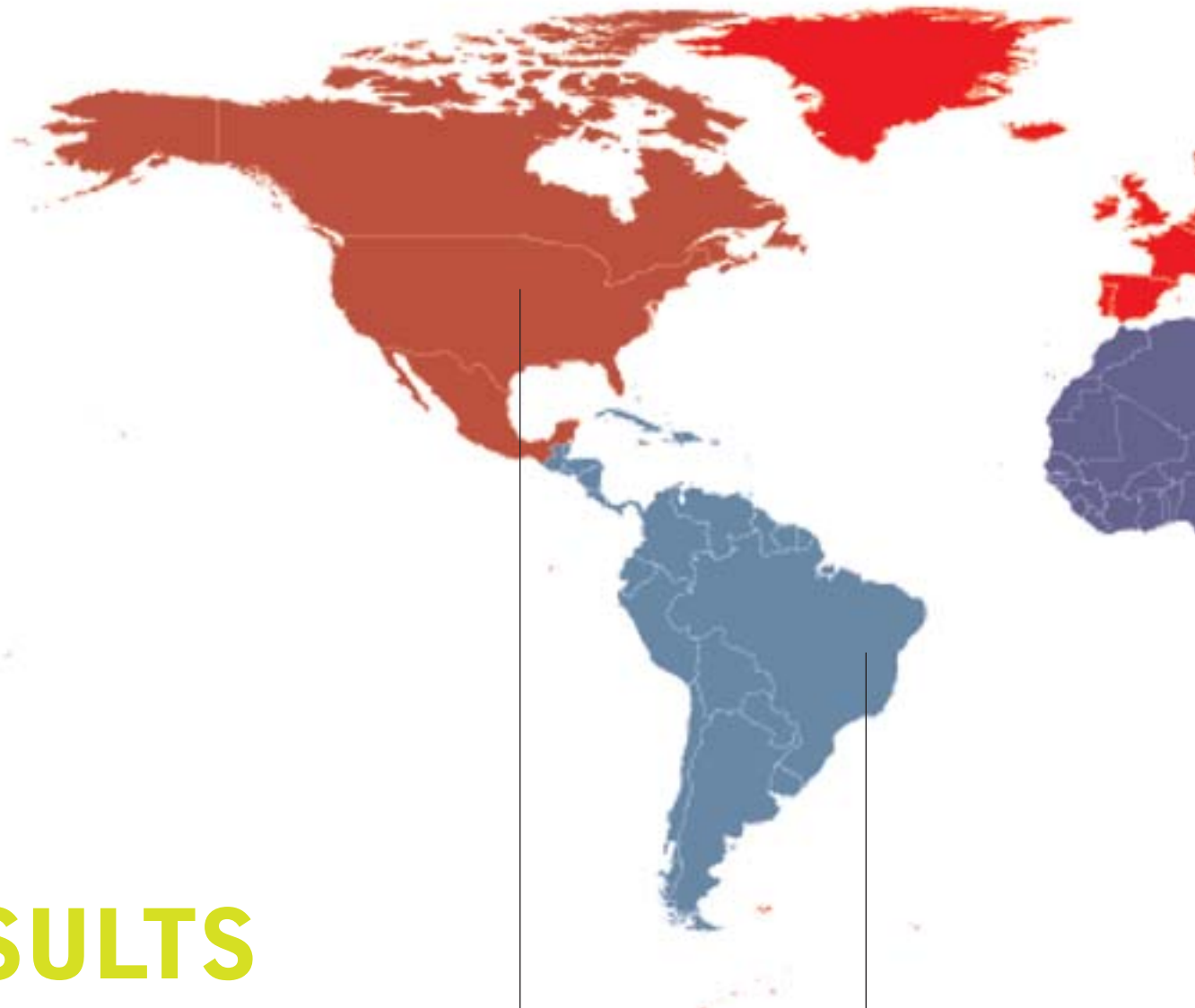
	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	1,063	1,063	
	2050	3,726	+250	831 -22/+22
	t			
Population	2003	2	2	
	2050	4	1	

OECD PACIFIC

	REF		ALT	
	mio t	%	mio t	%
CO ₂	2003	1,871	1,871	
	2050	2,259	+21	700 -63/-29
	t			
Population	2003	9	9	
	2050	12	4H	

map 2: results reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



SCENARIO

RESULTS

LEGEND

● > -50 ● > -40 ● > -30 ● REF REFERENCE SCENARIO
● > -20 ● > -10 ● > 0 ● ALT ALTERNATIVE SCENARIO
● > +10 ● > +20 ● > +30
● > +40 ● > +50

☀ SHARE OF RENEWABLES %
💧 SHARE OF FOSSIL FUELS %
☢ SHARE OF NUCLEAR ENERGY %

H HIGHEST | M MIDDLE | L LOWEST
PE PRIMARY ENERGY PRODUCTION/DEMAND IN PETA JOULE [PJ]
EL ELECTRICITY PRODUCTION/GENERATION IN TERAWATT HOURS [TWh]

0 1000 KM

OECD NORTH AMERICA

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	113,980H	4,857H	113,980H	4,857H
2050	161,936H	8,960H	69,874	4,605
	%	%	%	%
☀ 2003	6	15	6	15
☀ 2050	8	16M	52M	80
	%	%	%	%
💧 2003	86	67M	86	67M
💧 2050	86	75	48	20
	%	%	%	%
☢ 2003	8	18M	NUCLEAR POWER PHASED OUT BY 2030	
☢ 2050	6	9	NUCLEAR POWER PHASED OUT BY 2030	

LATIN AMERICA

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	19,393	830	19,393	830
2050	62,854	3,982	30,220	2,308
	%	%	%	%
☀ 2003	28	71H	28	71H
☀ 2050	15	33H	70H	90H
	%	%	%	%
💧 2003	71	27L	71	27L
💧 2050	84M	66	30L	10L
	%	%	%	%
☢ 2003	1	3	NUCLEAR POWER PHASED OUT BY 2030	
☢ 2050	1	1	NUCLEAR POWER PHASED OUT BY 2030	

OECD EUROPE

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	76,319	3,323	76,319	3,323
2050	93,356	4,988	50,999	3,141
	%		%	
2003	7	18M	7	18%M
2050	12	28	48	80%
	%		%	
2003	79	53	79	53
2050	84M	64	52M	20
	%		%	
2003	14H	30H	NUCLEAR POWER PHASED OUT BY 2030	
2050	4M	8		

MIDDLE EAST

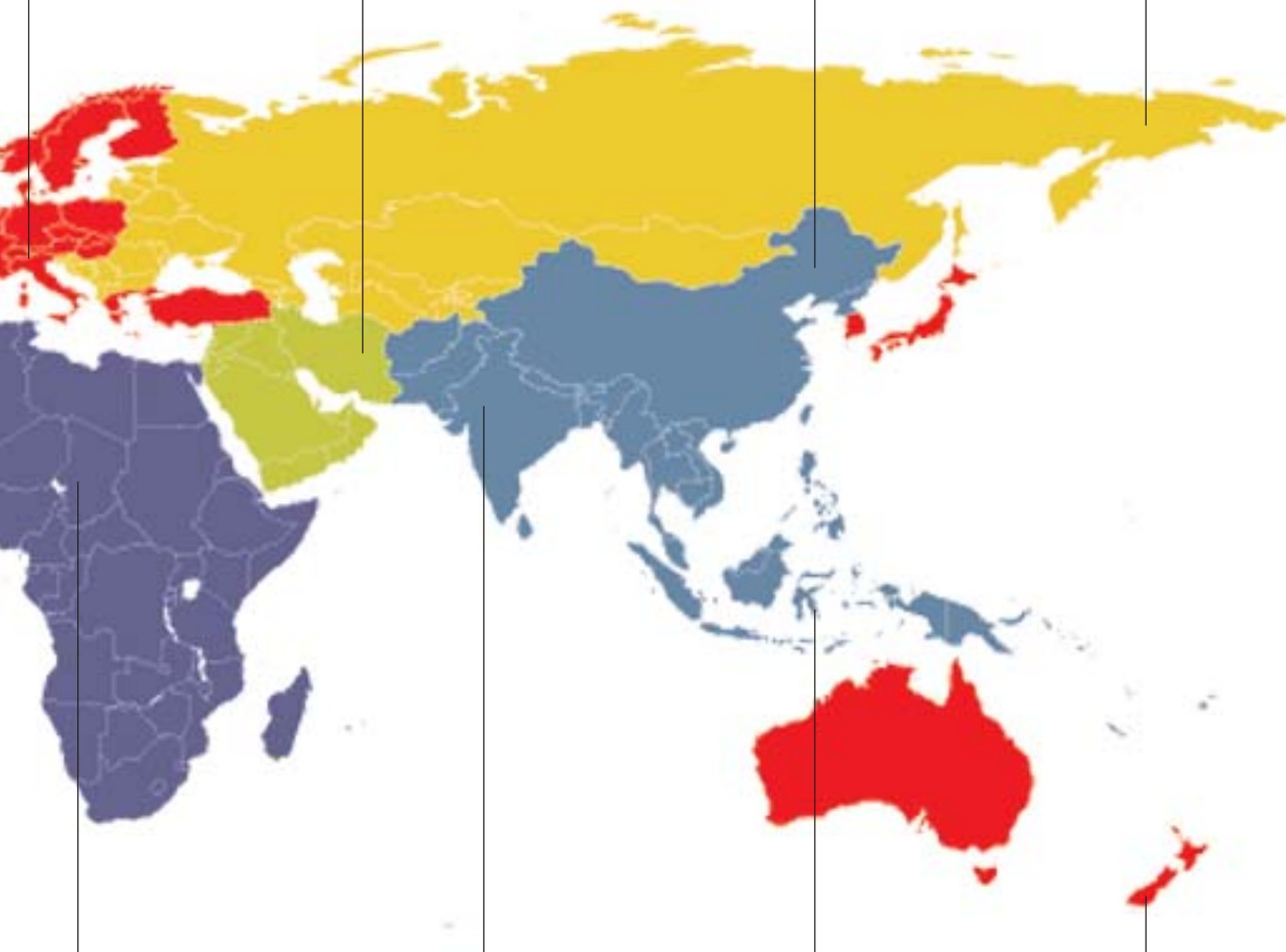
	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	17,569L	554	17,569L	554
2050	39,205L	1,941L	20,171L	1,671
	%		%	
2003	1L	3L	1L	3L
2050	1L	4L	53	84
	%		%	
2003	99H	97H	99H	97H
2050	98H	96H	47	16
	%		%	
2003	0L	0L	NUCLEAR POWER PHASED OUT BY 2030	
2050	0L	0L		

CHINA

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	55,379	1,943	55,379	1,943
2050	127,688	9,045	76,066H	7,556H
	%		%	
2003	19M	15	19M	15
2050	12M	16M	34L	53L
	%		%	
2003	80M	82	80M	82
2050	85	80	66H	47H
	%		%	
2003	1	2	NUCLEAR POWER PHASED OUT BY 2030	
2050	3	4		

TRANSITION ECONOMIES

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	45,472M	1,574	45,472M	1,574
2050	67,537	3,287	37,469M	2,413
	%		%	
2003	4	18M	4	18M
2050	7M	14	58	79
	%		%	
2003	90	64	90	64
2050	90	79M	42	21
	%		%	
2003	7	18M	NUCLEAR POWER PHASED OUT BY 2030	
2050	3	6M		



AFRICA

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	22,292	502L	22,292	502L
2050	74,255M	3,852	43,869	2,698
	%		%	
2003	47H	17	47H	17
2050	29H	5	58	56
	%		%	
2003	53L	80	53L	80
2050	71L	94	42	44
	%		%	
2003	1	3	NUCLEAR POWER PHASED OUT BY 2030	
2050	0L	0L		

SOUTH ASIA

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	26,921	744	26,921	744
2050	71,709	4,551M	37,220	2,790M
	%		%	
2003	41	15	41	15
2050	20	9	50M	59
	%		%	
2003	58	82	58	82
2050	77	87	50	41%
	%		%	
2003	1	3	NUCLEAR POWER PHASED OUT BY 2030	
2050	3	4		

EAST ASIA

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	22,348	686	22,348	686
2050	59,955	3,232	32,400	2,133L
	%		%	
2003	23	14	23	14
2050	10	13	51M	81
	%		%	
2003	75	80	75	80
2050	88	85	49	19
	%		%	
2003	2	6	NUCLEAR POWER PHASED OUT BY 2030	
2050	1	2		

OECD PACIFIC

	REF		ALT	
	PE PJ	EL TWh	PE PJ	EL TWh
2003	35,076	1,649M	35,076	1,649M
2050	46,716	2,661	23,616	1,619
	%		%	
2003	3	10	3	10
2050	7	17	37	70M
	%		%	
2003	85	67M	85	67
2050	79	60L	63	30M
	%		%	
2003	11	22	NUCLEAR POWER PHASED OUT BY 2030	
2050	14H	23H		

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.”

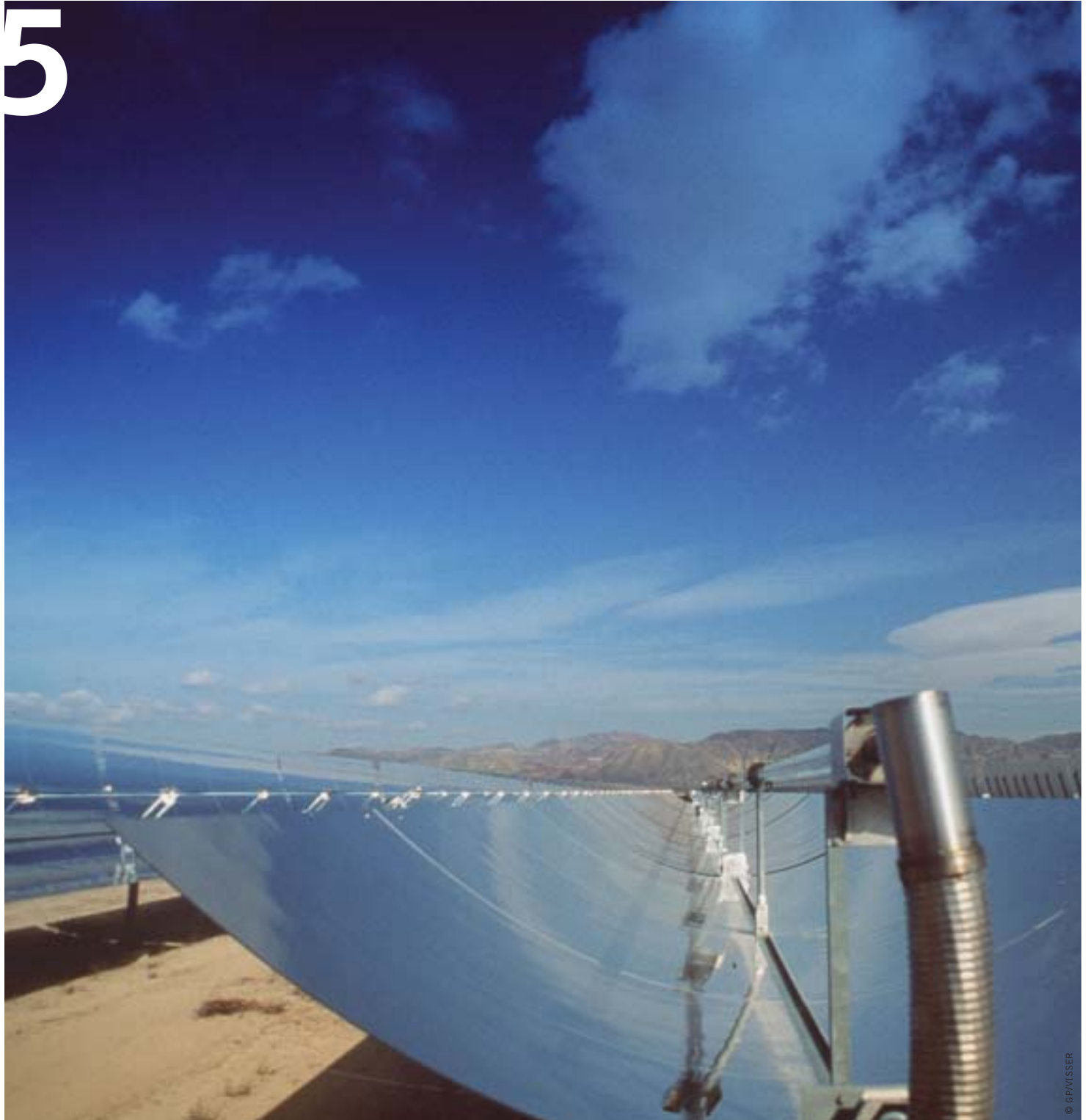


image CONCENTRATING SOLAR POWER (CSP) AT A SOLAR FARM IN DAGGETT, CALIFORNIA, USA.

image NEW CONTROL PANEL WITH STATIC ENERGY METRES.



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 projection

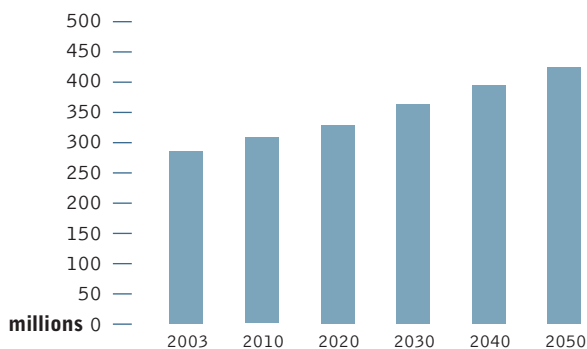
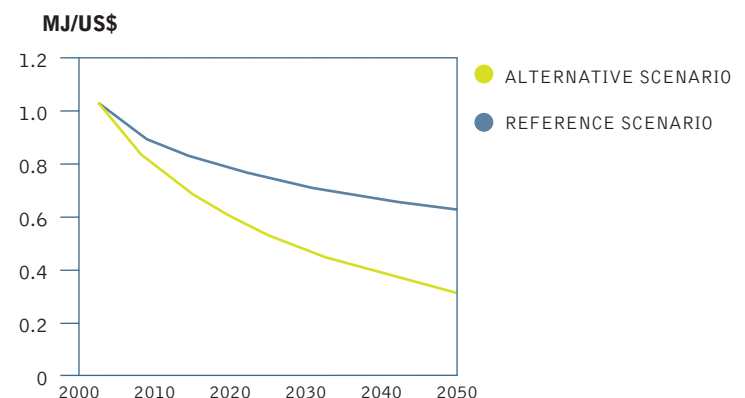


figure 16: usa: projection of energy intensity under the reference and energy [r]evolution scenarios



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

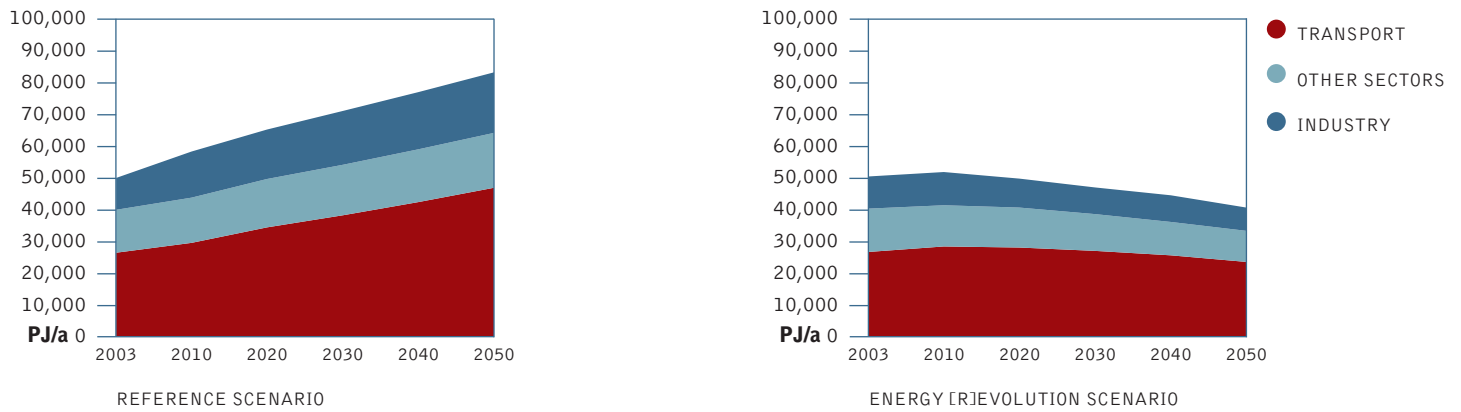


figure 18: usa: electricity demand reductions under energy the energy [r]evolution

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

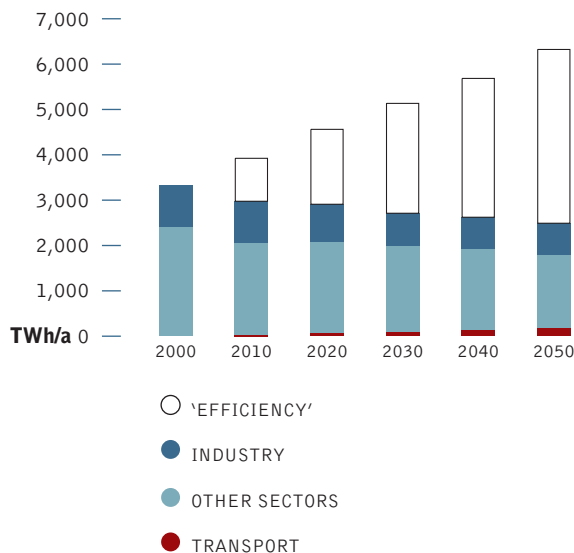


figure 19: usa reductions in energy demand under energy the energy [r]evolution

(‘EFFICIENCY’ = REDUCTION COMPARED TO THE REFERENCE SCENARIO)

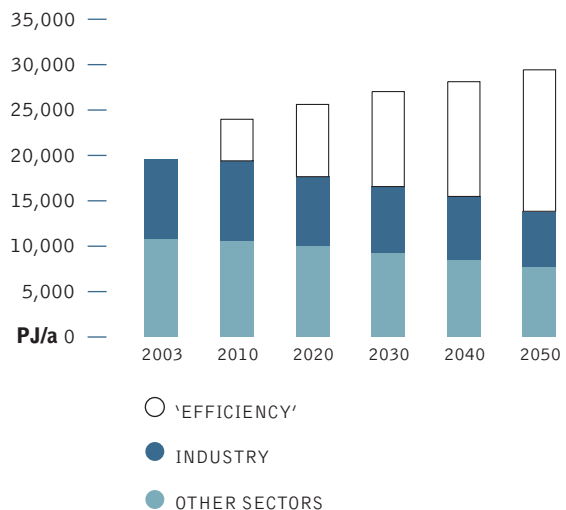


image PHOTOVOLTAIC (SOLAR) PANEL ON TOBI ISLAND, BELAU ISLANDS, PACIFIC. THESE PANELS PRODUCE ALL THE ELECTRICITY USED ON TOBI ISLAND.



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: electricity supply under the reference scenario

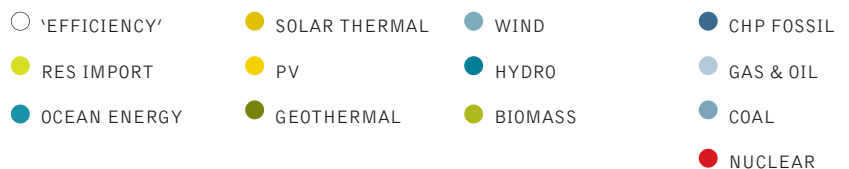
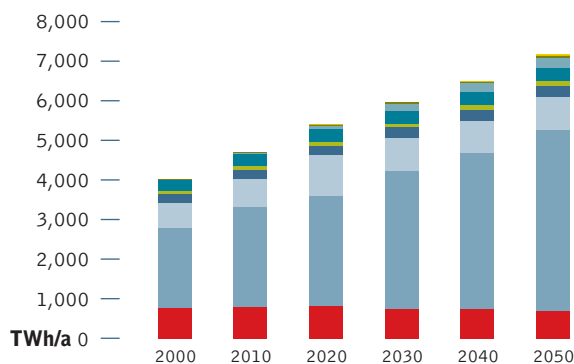


figure 21: usa: electricity supply under the energy [r]evolution scenario

'EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO

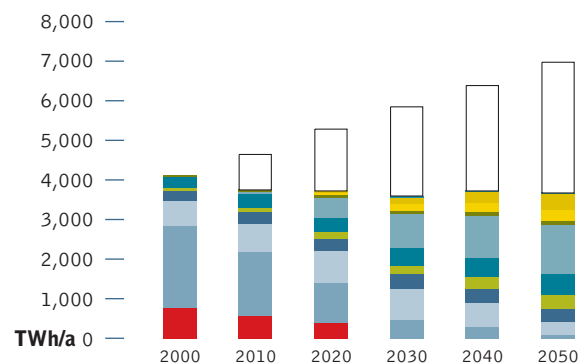


figure 22: usa: growth of renewable electricity generation under the energy [r]evolution scenario

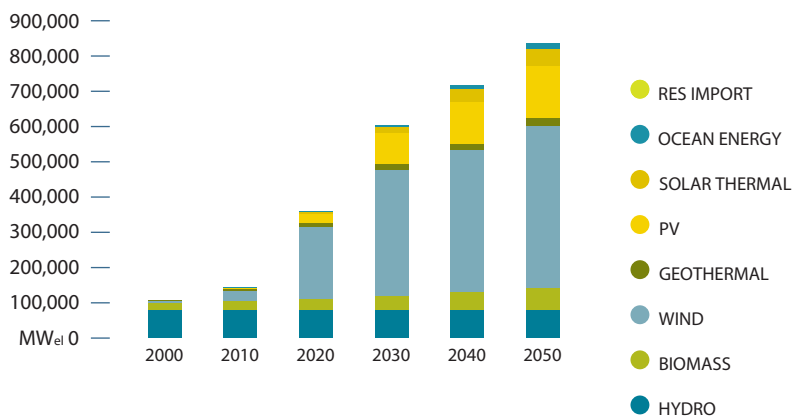


table 7: usa: projection of renewable electricity generation under the energy [r]evolution scenario

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 factors. 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 CO₂ emissions.

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

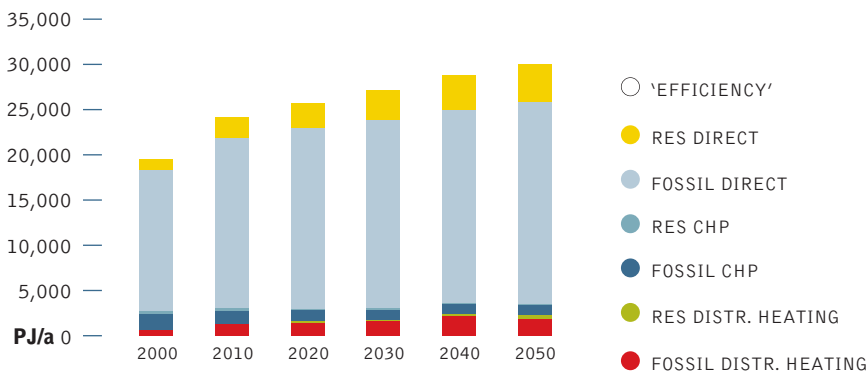
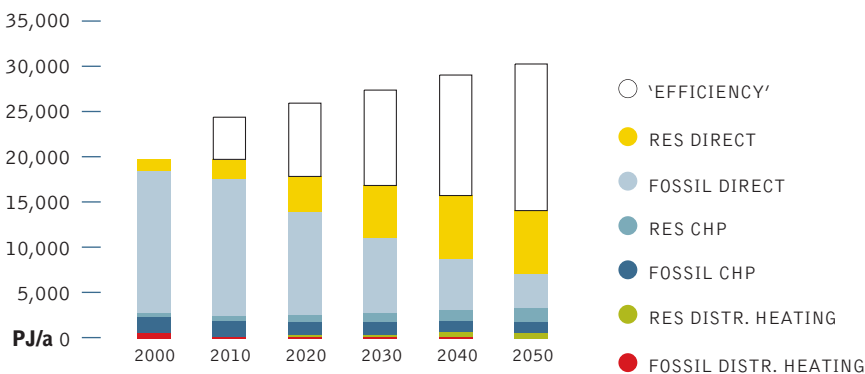


figure 24: usa: reductions in heat supply under the energy [r]evolution scenario

('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 CO₂ emissions

Whilst emissions of CO₂ 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, CO₂ 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 CO₂ emissions in the United States, with a share of 62% in 2050.

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

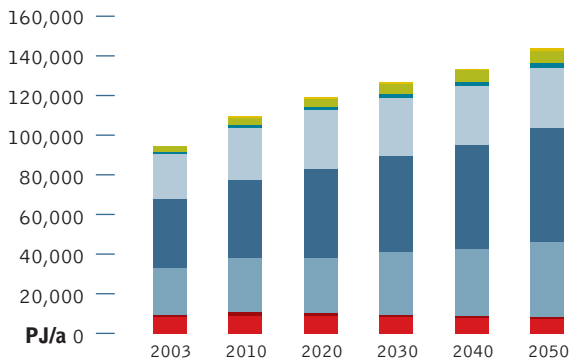
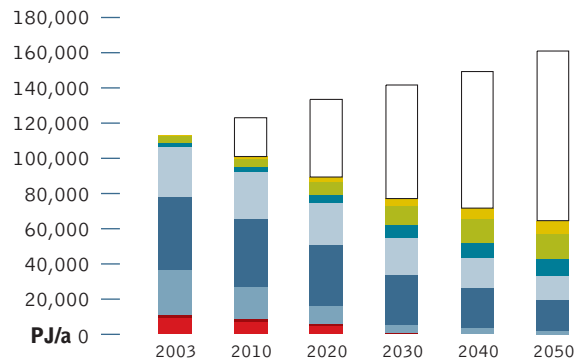


figure 26: usa: primary energy consumption under the energy [r]evolution scenario

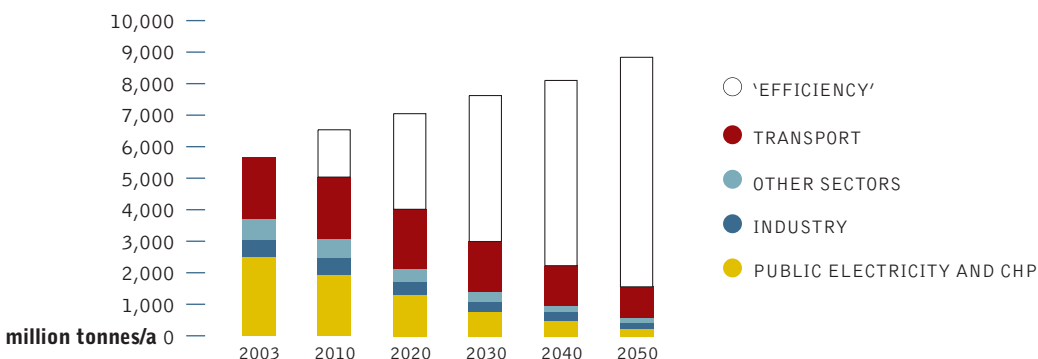
('EFFICIENCY' = REDUCTION COMPARED TO THE REFERENCE SCENARIO)



- 'EFFICIENCY'
- BIOMASS
- NATURAL GAS
- LIGNITE
- RES ELECTRICITY IMPORT
- HYDRO, WIND, PV
- CRUDE OIL
- NUCLEAR
- SOLAR THERMAL/GEOTHERMAL/OCEAN
- COAL

figure 27: usa: CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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: 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_{CO2} IN 2010 TO 50 \$/T_{CO2} IN 2050)

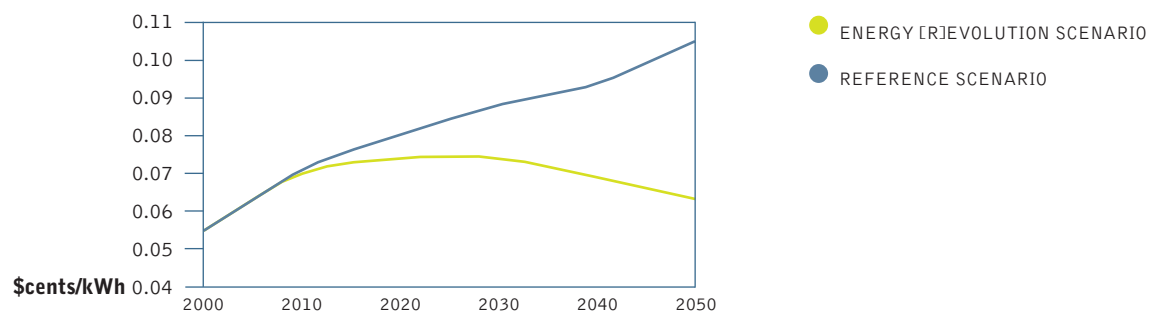
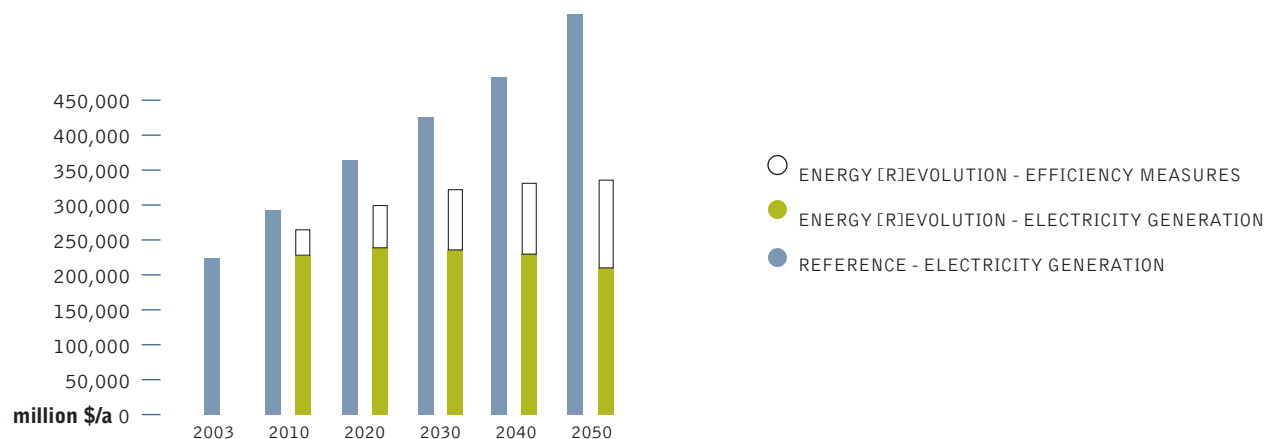


figure 29: usa: total electricity supply costs



energy resources and security of supply

“AT PRESENT AROUND 80% OF GLOBAL ENERGY DEMAND IS MET BY FOSSIL FUELS.
THE UNRELENTING INCREASE IN ENERGY DEMAND IS MATCHED BY THE FINITE NATURE OF THESE SOURCES.”



image GEOTHERMAL ACTIVITY.

image OIL FIELDS NEAR BIBI-HEYDAT
IN AZERBAIJAN. OIL-WELL DERRICKS.



The issue of security of supply is now at the top of the energy policy agenda. Concern is focused both on price security and the security of physical supply. At present around 80% of global energy demand is met by fossil fuels. The unrelenting increase in energy demand is matched by the finite nature of these sources. The regional distribution of oil and gas resources also does not match the distribution of demand. Some countries have to rely almost entirely on fossil fuel imports. The maps on the following pages provide an overview of the availability of different fuels and their regional distribution.

Information in this chapter is based partly on the report *Plugging the Gap* (Renewable Energy Systems/Global Wind Energy Council, 2006).

oil

Oil is the blood of the modern global economy, as the effects of the supply disruptions of the 1970s made clear. It is the number one source of energy, providing 36% of the world's needs and the fuel employed almost exclusively for essential uses such as transportation. However, a passionate debate has developed over the ability of supply to meet increasing consumption, a debate obscured by poor information and stirred by recent soaring prices.

the reserves chaos

Public data about oil and gas reserves is strikingly inconsistent, and potentially unreliable for legal, commercial, historical and sometimes political reasons. The most widely available and quoted figures, those from the industry journals *Oil & Gas Journal* and *World Oil*, have limited value as they report the reserve figures provided by companies and governments without analysis or verification. Moreover, as there is no agreed definition of reserves or standard reporting practice, these figures usually stand for different physical and conceptual magnitudes. Confusing terminology ('proved', 'probable', 'possible', 'recoverable', 'reasonable certainty') only adds to the problem.

Historically, private oil companies consistently underestimated their reserves to comply with conservative stock exchange rules and through natural commercial caution. Whenever a discovery was made, only a portion of the geologist's estimate of recoverable resources was reported; subsequent revisions would then increase the reserves from that same oil field over time. National oil companies, almost fully represented by OPEC (Organisation of Petroleum Exporting Countries), are not subject to any sort of accountability so their reporting practices are even less clear. In the late 1980s, OPEC

countries blatantly overstated their reserves while competing for production quotas, which were allocated as a proportion of the reserves. Although some revision was needed after the companies were nationalised, between 1985 and 1990, OPEC countries increased their joint reserves by 82%. Not only were these dubious revisions never corrected, but many of these countries have reported untouched reserves for years, even if no sizeable discoveries were made and production continued at the same pace. Additionally, the Former Soviet Union's oil and gas reserves have been overestimated by about 30% because the original assessments were later misinterpreted.

Whilst private companies are now becoming more realistic about the extent of their resources, the OPEC countries hold by far the majority of the reported reserves, and information on their resources is as unsatisfactory as ever. In brief, these information sources should be treated with considerable caution. To fairly estimate the world's oil resources a regional assessment of the mean backdated (i.e. 'technical') discoveries would need to be performed.

gas

Natural gas has been the fastest growing fossil energy source in the last two decades, boosted by its increasing share in the electricity generation mix. Gas is generally regarded as a largely abundant resource and public concerns about depletion are limited to oil, even though few in-depth studies address the subject. Gas resources are more concentrated than oil so they were discovered faster because a few massive fields make up for most of the reserves: the largest gas field in the world holds 15% of the "Ultimate Recoverable Resources" (URR), compared to 6% for oil. Unfortunately, information about gas resources suffers from the same bad practices as oil data because gas mostly comes from the same geological formations, and the same stakeholders are involved.

Most reserves are initially understated and then gradually revised upwards, giving an optimistic impression of growth. By contrast, Russia's reserves, the largest in the world, are considered to have been overestimated by about 30%. Owing to geological similarities, gas follows the same depletion dynamic as oil, and thus the same discovery and production cycles. In fact, existing data for gas is of worse quality than for oil and some ambiguities arise as to the amount of gas already produced because flared and vented gas is not always accounted for. As opposed to published reserves, the technical ones have been almost constant since 1980 because discoveries have roughly matched production.

coal

Coal was the world's largest source of primary energy until it was overtaken by oil in the 1960s. Today, coal supplies almost one quarter of the world's energy. Despite being the most abundant of fossil fuels, coal's development is currently threatened by environmental concerns, hence its future will unfold in the context of both energy security and global warming.

Coal is abundant and more equally distributed throughout the world than oil and gas. Global recoverable reserves are the largest of all fossil fuels, and most countries have at least some. Moreover, existing and prospective big energy consumers like the US, China and India are self-sufficient in coal and will be for the foreseeable future. Coal has been exploited on a large scale for two centuries so both the product and the available resources are well known; no substantial new deposits are expected to be discovered. Extrapolating the demand forecast, the world will consume 20% of its current reserves by 2030 and 40% by 2050¹². Hence, if current trends are maintained, coal would still last several 100 years.

table 8: overview of fossil fuel reserves and resources

RESERVES, RESOURCES AND ADDITIONAL OCCURRENCES OF FOSSIL ENERGY CARRIERS ACCORDING TO DIFFERENT AUTHORS. **C** CONVENTIONAL (PETROLEUM WITH A CERTAIN DENSITY, FREE NATURAL GAS, PETROLEUM GAS, **NC** NON-CONVENTIONAL) HEAVY FUEL OIL, VERY HEAVY OILS, TAR SANDS AND OIL SHALE, GAS IN COAL SEAMS, AQUIFER GAS, NATURAL GAS IN TIGHT FORMATIONS, GAS HYDRATES). THE PRESENCE OF ADDITIONAL OCCURRENCES IS ASSUMED BASED ON GEOLOGICAL CONDITIONS, BUT THEIR POTENTIAL FOR ECONOMIC RECOVERY IS CURRENTLY VERY UNCERTAIN. IN COMPARISON: IN 1998, THE GLOBAL PRIMARY ENERGY DEMAND WAS 402EJ (UNDP ET AL., 2000).

ENERGY CARRIER	BROWN, 2002 EJ	IEA, 2002c EJ	IPCC, 2001a EJ	NAKICENOVIC ET AL., 2000 EJ	UNDP ET AL., 2000 EJ	BGR, 1998 EJ				
Gas reserves	6,600	6,200	c	5,400	c	5,900	c	5,500	c	5,300
			nc	8,000	nc	8,000	nc	9,400	nc	100
			c	11,700	c	11,700	c	11,100	c	7,800
resources	9,400	11,100	nc	10,800	nc	10,800	nc	23,800	nc ^{a)}	111,900
				796,000		799,700		930,000		
additional occurrences										
Oil reserves	5,800	5,700	c	5,900	c	6,300	c	6,000	c	6,700
			nc	6,600	nc	8,100	nc	5,100	nc	5,900
			c	7,500	c	6,100	c	6,100	c	3,300
resources	10,200	13,400	nc	15,500	nc	13,900	nc	15,200	nc	25,200
				61,000		79,500		45,000		
additional occurrences										
Coal reserves	23,600	22,500		42,000		25,400		20,700		16,300
				100,000		117,000		179,000		179,000
				121,000		125,600				
resources	26,000	165,000								
additional occurrences										
Total resource (reserves + resources)	180,600	223,900		212,200		213,200		281,900		361,500
Total occurrence				1,204,200		1,218,000		1,256,000		

source SEE TABLE ^{a)} INCLUDING GAS HYDRATES

reference

12 "PLUGGING THE GAP - A SURVEY OF WORLD FUEL RESOURCES AND THEIR IMPACT ON THE DEVELOPMENT OF WIND ENERGY"; GWEC, RES SEPTEMBER 2006

image NEW LIGNITE POWER PLANT BUILT BY RWE NEAR COLOGNE/GERMANY. THIS POWER PLANT WILL EMIT MORE THAN 10 MILLION TONNES CO₂ PER YEAR.



nuclear

Uranium, the fuel used in nuclear power plants, is a finite resource whose economically available resource is limited. Its distribution is almost as concentrated as oil and does not match regional consumption. Five countries - Canada, Australia, Kazakhstan, Russia and Niger - control three quarters of the world's supply. As a significant user of uranium, however, Russia's reserves will be exhausted within ten years.

Secondary sources, such as old deposits, currently make up nearly half of worldwide uranium reserves. However, those sources will soon be used up. Mining capacities will have to be nearly doubled in the next few years to meet current needs.

A joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, (Uranium 2003: Resources, Production and Demand) estimates that all existing nuclear power plants will have used up their nuclear fuel, employing current technology in less than 70 years. In the light of various scenarios for the worldwide development of nuclear power, it is likely that uranium supplies will be exhausted sometime between 2026 and 2070. Assuming a downward trend in the use of nuclear power, realistic estimates indicate that supplies will be enough for only a few countries by 2050. This forecast includes uranium deposits as well as the use of mixed oxide fuel (MOX), a mixture of uranium and plutonium.

tables 9 - 11: assumptions on global fossil fuel use in the energy [r]evolution scenario

Oil	2003	2010	2020	2030	2040	2050
Reference [PJ]	147,425	176,791	206,365	231,237	256,069	284,010
Reference [million barrels]	24,089	28,887	33,720	37,784	41,841	46,407
Alternative [PJ]	147,425	144,085	128,606	110,865	98,832	87,135
Alternative [million barrels]	24,089	23,543	21,014	18,115	16,149	14,238

Gas	2003	2010	2020	2030	2040	2050
Reference [PJ]	93,230	101,344	123,691	145,903	166,033	189,471
Reference [billion cubic metres = 10E9m ³]	2,453	2,667	3,256	3,840	4,369	4,986
Alternative [PJ]	93,230	98,994	103,975	107,023	100,822	93,055
Alternative [billion cubic metres = 10E9m ³]	2,453	2,605	2,736	2,816	2,653	2,449

Coal	2003	2010	2020	2030	2040	2050
Reference [PJ]	107,902	112,992	126,272	146,387	170,053	202,794
Reference [million tonnes]	5,367	5,499	6,006	6,884	7,916	9,356
Alternative [PJ]	107,903	90,125	70,858	51,530	39,717	31,822
Alternative [million tonnes]	5,367	4,380	3,325	2,343	1,748	1,382

map 3: oil reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



NON RENEWABLE RESOURCE OIL

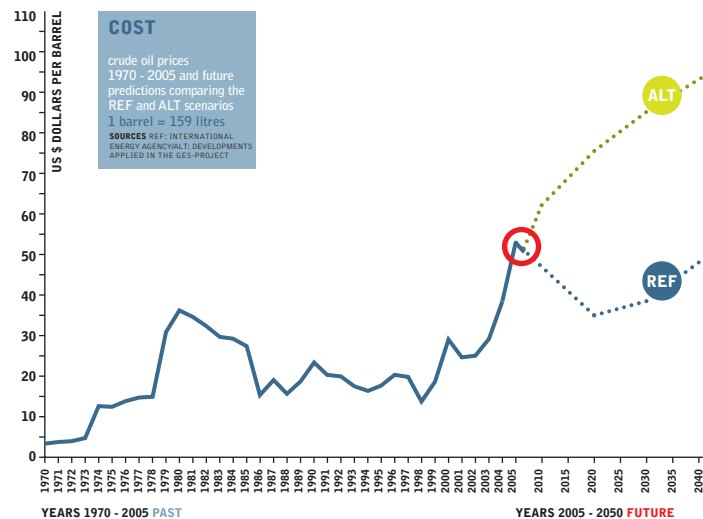
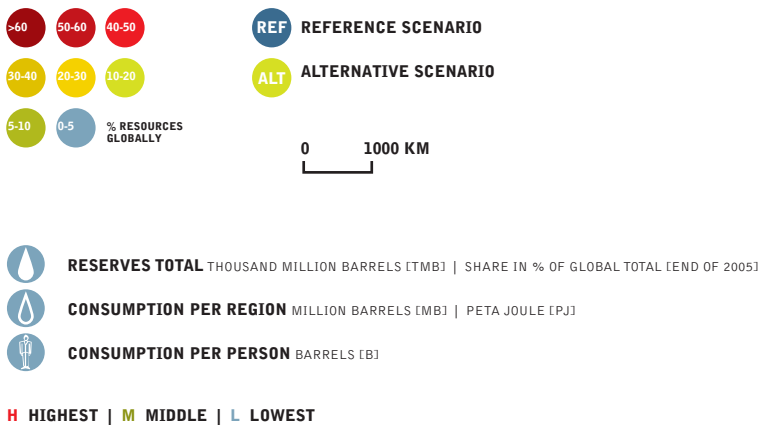
OECD NORTH AMERICA

	REF		ALT	
	TMB	%	TMB	%
2005	59.5	5.0%	59.5	5.0%
	MB	PJ	MB	PJ
2003	6,849 ^H	41,917	6,849 ^H	41,917
2050	10,863 ^H	66,481	2,940 ^H	17,991
	B		B	
2003	16 ^H		16 ^H	
2050	18 ^H		5	

LATIN AMERICA

	REF		ALT	
	TMB	%	TMB	%
2005	103.5	8.6%	103.5	8.6%
	MB	PJ	MB	PJ
2003	1,464	8,961	1,464	8,961
2050	4,319	26,430	750	4,589
	B		B	
2003	3		3	
2050	7		1	

LEGEND



OECD EUROPE

	REF		ALT	
	TMB	%	TMB	%
2005	12.2	1.3%	12.2	1.3%
2003	4,877	29,848	4,877	29,848
2050	4,960M	30,358	2,238	13,695
	B		B	
2003	9	9		
2050	10	4		

MIDDLE EAST

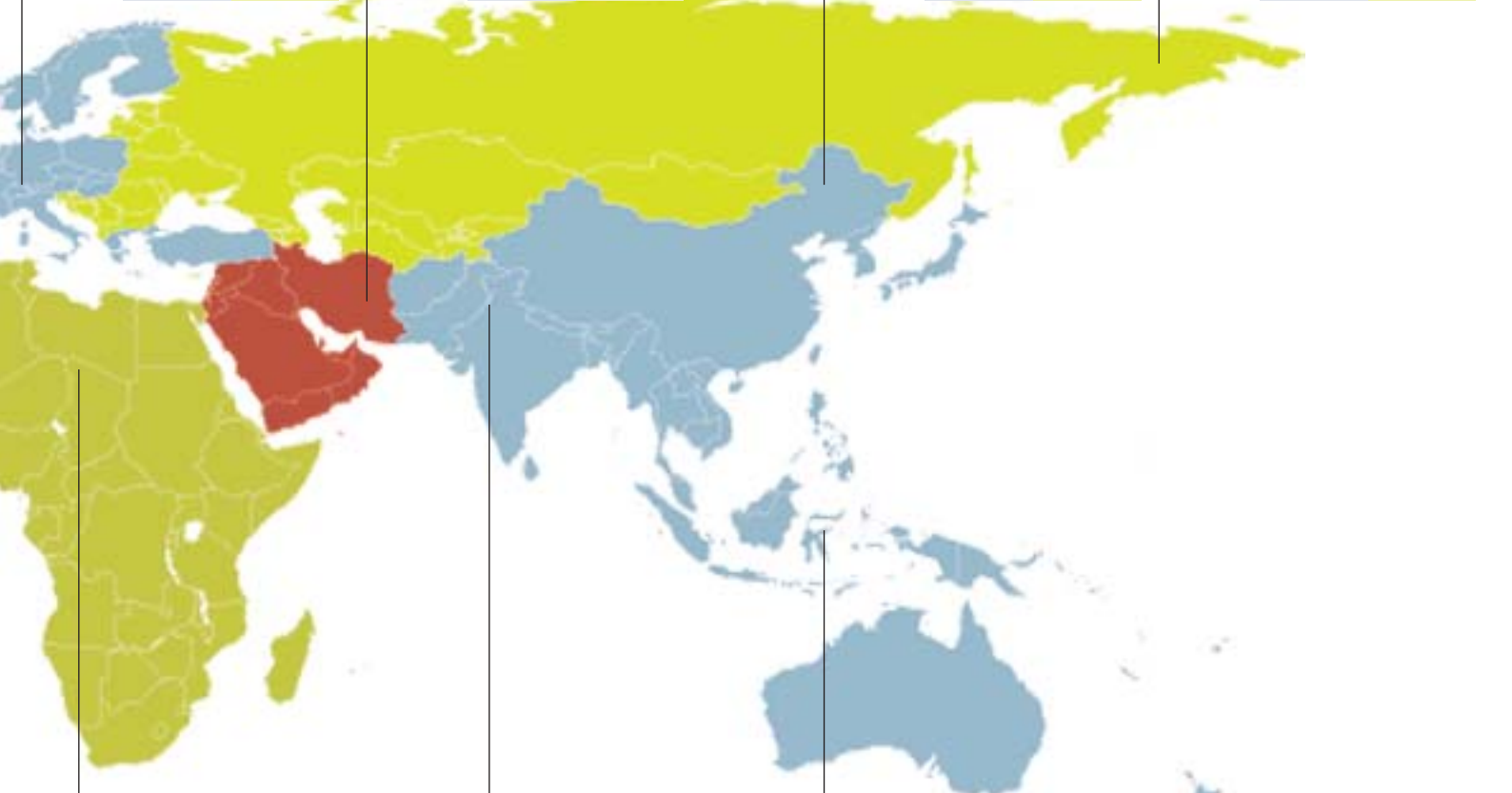
	REF		ALT	
	TMB	%	TMB	%
2005	742.7	61.9% ^H	742.7	61.9% ^H
2003	1,598	9,782	1,598	9,782
2050	3,198	19,570	645L	3,949
	B		B	
2003	9	9		
2050	9M	2		

CHINA

	REF		ALT	
	TMB	%	TMB	%
2005	16.0	1.3%	16.0	1.3%
2003	1,742	10,664	1,742	10,664
2050	6,163	37,718	2,366	14,480
	B		B	
2003	1	1		
2050	4	2		

TRANSITION ECONOMIES

	REF		ALT	
	TMB	%	TMB	%
2005	124.4	10.3% ^M	124.4	10.3% ^M
2003	1,563	9,568	1,563	9,568
2050	3,215	19,678	835	5,110
	B		B	
2003	5M	5M		
2050	11	3M		



AFRICA

	REF		ALT	
	TMB	%	TMB	%
2005	114.3	9.5%	114.3	9.5%
2003	833L	5,099	833L	5,099
2050	3,304	20,220	868	5,312
	B		B	
2003	1	1		
2050	2	0		

SOUTH ASIA

	REF		ALT	
	TMB	%	TMB	%
2005	5.9	0.5%	5.9	0.5%
2003	914	5,597	914	5,597
2050	3,063L	18,747	896	5,481
	B		B	
2003	1L	1L		
2050	1L	0L		

EAST ASIA

	REF		ALT	
	TMB	%	TMB	%
2005	13.2	1.0%	13.2	1.0%
2003	1,411	8,634	1,411	8,634
2050	4,027	24,648	1,404M	8,593
	B		B	
2003	2	2		
2050	5	2		

OECD PACIFIC

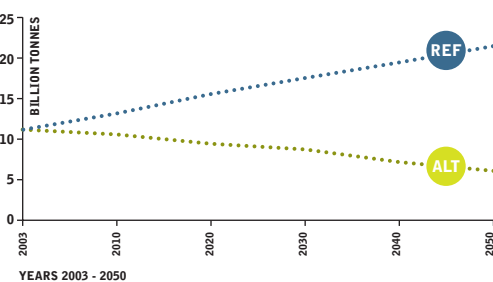
	REF		ALT	
	TMB	%	TMB	%
2005	4.0	0.3% ^L	4.0	0.3% ^L
2003	2,836M	17,355	2,836M	17,355
2050	3,294	20,160	1,296	7,934
	B		B	
2003	14	14		
2050	18	7H		

CO₂ EMISSIONS

comparison between the REF and ALT scenarios 2003 - 2050

billion tonnes

SOURCE: EPI/IEA

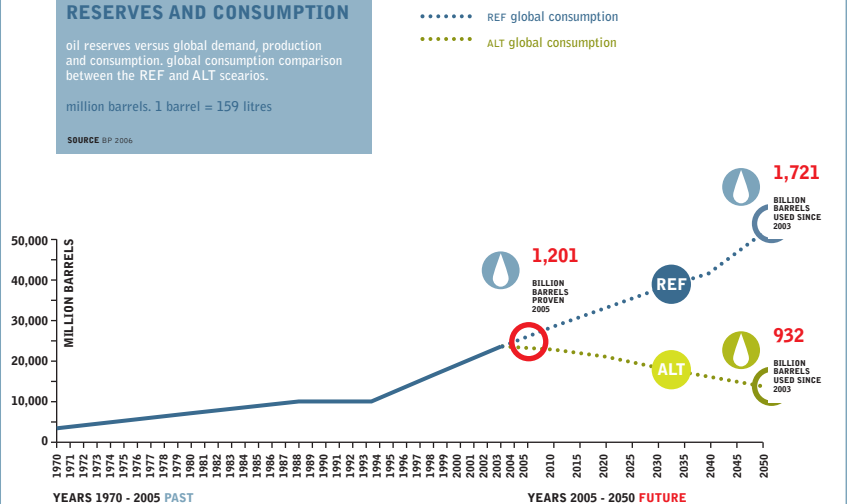


RESERVES AND CONSUMPTION

oil reserves versus global demand, production and consumption. global consumption comparison between the REF and ALT scenarios.

million barrels. 1 barrel = 159 litres

SOURCE: BP 2006



map 4: gas reference scenario and the energy [r]evolution scenario
WORLDWIDE SCENARIO



NON RENEWABLE RESOURCE GAS

OECD NORTH AMERICA

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	7.5	4.1%	7.5	4.1%
	bn m ³	PJ	bn m ³	PJ
2003	752 ^H	28.568	752 ^H	28.568
2050	1,035 ^H	39.312	352 ^H	13.368
	m ³		m ³	
2003	1770 ^H		1770 ^H	
2050	1770		600 ^H	

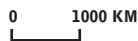
LATIN AMERICA

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	7.0	3.9%	7.0	3.9%
	bn m ³	PJ	bn m ³	PJ
2003	103	3.916	103	3.916
2050	570	21.666	104	3.940
	m ³		m ³	
2003	230		230	
2050	900		170	

LEGEND

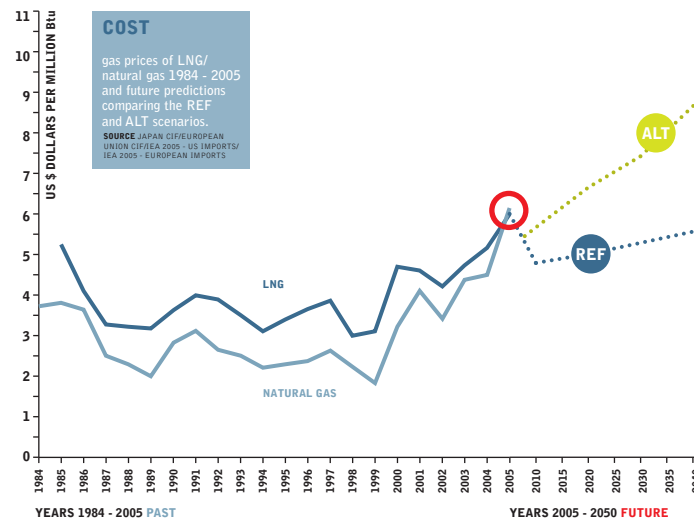


REF REFERENCE SCENARIO
ALT ALTERNATIVE SCENARIO



RESERVES TOTAL TRILLION CUBIC METRES [tn m³] | SHARE IN % OF GLOBAL TOTAL (END OF 2005)
 CONSUMPTION PER REGION BILLION CUBIC METRES [bn m³] | PETA JOULE [PJ]
 CONSUMPTION PER PERSON CUBIC METRES [m³]

H HIGHEST | **M** MIDDLE | **L** LOWEST



OECD EUROPE

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	4.9	2.7%	4.9	2.7%
	bn m ³	PJ	bn m ³	PJ
2003	457	17.354	457	17.354
2050	583	22.139	285	10.935
	m ³	m ³		
2003	870	870		
2050	1140	560M		

MIDDLE EAST

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	72.1	40.1% ^H	72.1	40.1% ^H
	bn m ³	PJ	bn m ³	PJ
2003	191M	7.262	191M	7.262
2050	478M	18.154	142	5.401
	m ³	m ³		
2003	1050	1050		
2050	1350	400		

CHINA

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	2.4	1.3%	2.4	1.3%
	bn m ³	PJ	bn m ³	PJ
2003	35L	1.327	35L	1.327
2050	200L	7.604	551	20,932
	m ³	m ³		
2003	30L	30L		
2050	140L	390		

TRANSITION ECONOMIES

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	59.1	32.9%	59.1	32.9%
	bn m ³	PJ	bn m ³	PJ
2003	559	21.260	559	21.260
2050	897	34.074	266	10.122
	m ³	m ³		
2003	1620	1620		
2050	3160 ^H	940		

AFRICA

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	14.4	8.0% ^M	14.4	8.0% ^M
	bn m ³	PJ	bn m ³	PJ
2003	65	2.472	65	2.472
2050	420	15.952	210	7.978
	m ³	m ³		
2003	80	80		
2050	230	110		

SOUTH ASIA

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	1.1	0.6% ^L	1.1	0.6% ^L
	bn m ³	PJ	bn m ³	PJ
2003	59	2.255	59	2.255
2050	324	12.314	256	9.737
	m ³	m ³		
2003	40	40		
2050	150	120L		

EAST ASIA

	REF		ALT	
	tn m ³	%	tn m ³	%
2005	8.5	4.7%	8.5	4.7%
	bn m ³	PJ	bn m ³	PJ
2003	112	4.241	112	4.241
2050	274	10.395	163M	6.195
	m ³	m ³		
2003	180	180		
2050	310	180		

OECD PACIFIC

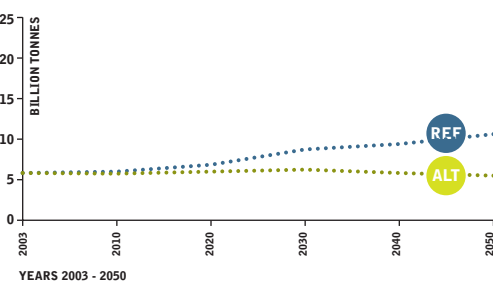
	REF		ALT	
	tn m ³	%	tn m ³	%
2005	2.5	1.4%	2.5	1.4%
	bn m ³	PJ	bn m ³	PJ
2003	120	4.575	120	4.575
2050	207	7.862	117L	4.446
	m ³	m ³		
2003	610M	610M		
2050	1130M	640		

CO₂ EMISSIONS

comparison between the REF and ALT scenarios 2003 - 2050

billion tonnes

SOURCE: GPI/IEEC

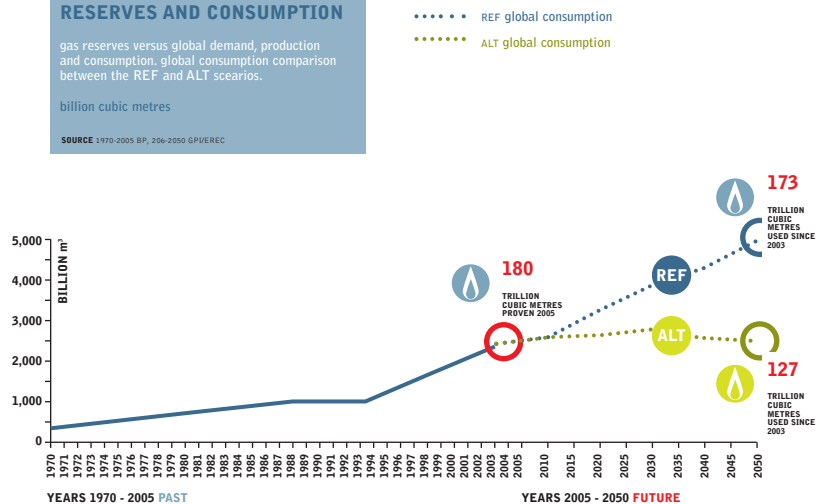


RESERVES AND CONSUMPTION

gas reserves versus global demand, production and consumption, global consumption comparison between the REF and ALT scenarios.

billion cubic metres

SOURCE: 1970-2005 BP, 206-2050 GPI/IEEC



map 5: coal reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



NON RENEWABLE RESOURCE
COAL

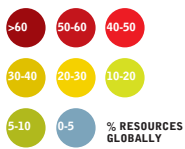
OECD NORTH AMERICA

	REF		ALT	
	mn t	%	mn t	%
2005	254,432	28.0% ^H	254,432	28.0% ^H
2003	1,326	27,417	1,326	27,417
2050	1,618	33,475	84	1,926
2003	3.1 ^H		3.1 ^H	
2050	2.8 ^H		0.1 ^M	

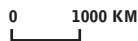
LATIN AMERICA

	REF		ALT	
	mn t	%	mn t	%
2005	19,893	2.2%	19,893	2.2%
2003	38	869	38	869
2050	217	4,997	17	394
2003	0.1L		0.1L	
2050	0.3		0.0L	

LEGEND

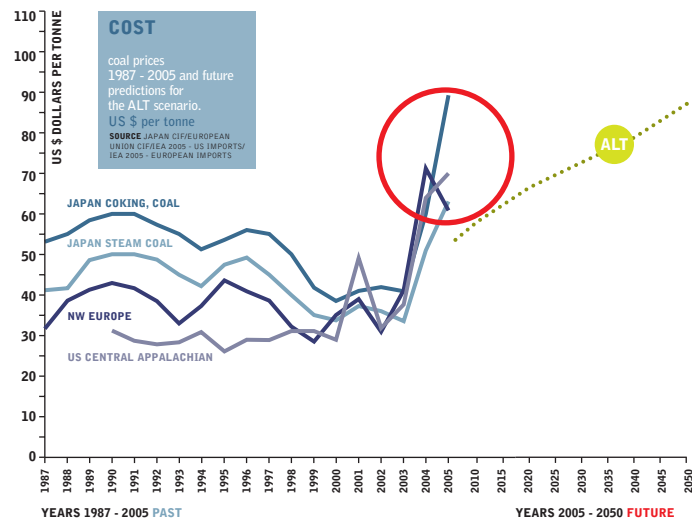


REF REFERENCE SCENARIO
ALT ALTERNATIVE SCENARIO



- RESERVES TOTAL** MILLION TONNES [mn t] | SHARE IN % OF GLOBAL TOTAL (END OF 2005)
- CONSUMPTION PER REGION** MILLION TONNES [mn t] | PETA JOULE [PJ]
- CONSUMPTION PER PERSON** TONNES [t]

H HIGHEST | **M** MIDDLE | **L** LOWEST



OECD EUROPE

	REF		ALT	
	mn t	%	mn t	%
2005	61,972	6.8%	61,972	6.8%
	mn t	PJ	mn t	PJ
2003	839	13,166	839	13,166
2050	1,197	25,539	71	1,635
	t	t	t	t
2003	1.6	1.6		
2050	2.4	0.1		

MIDDLE EAST

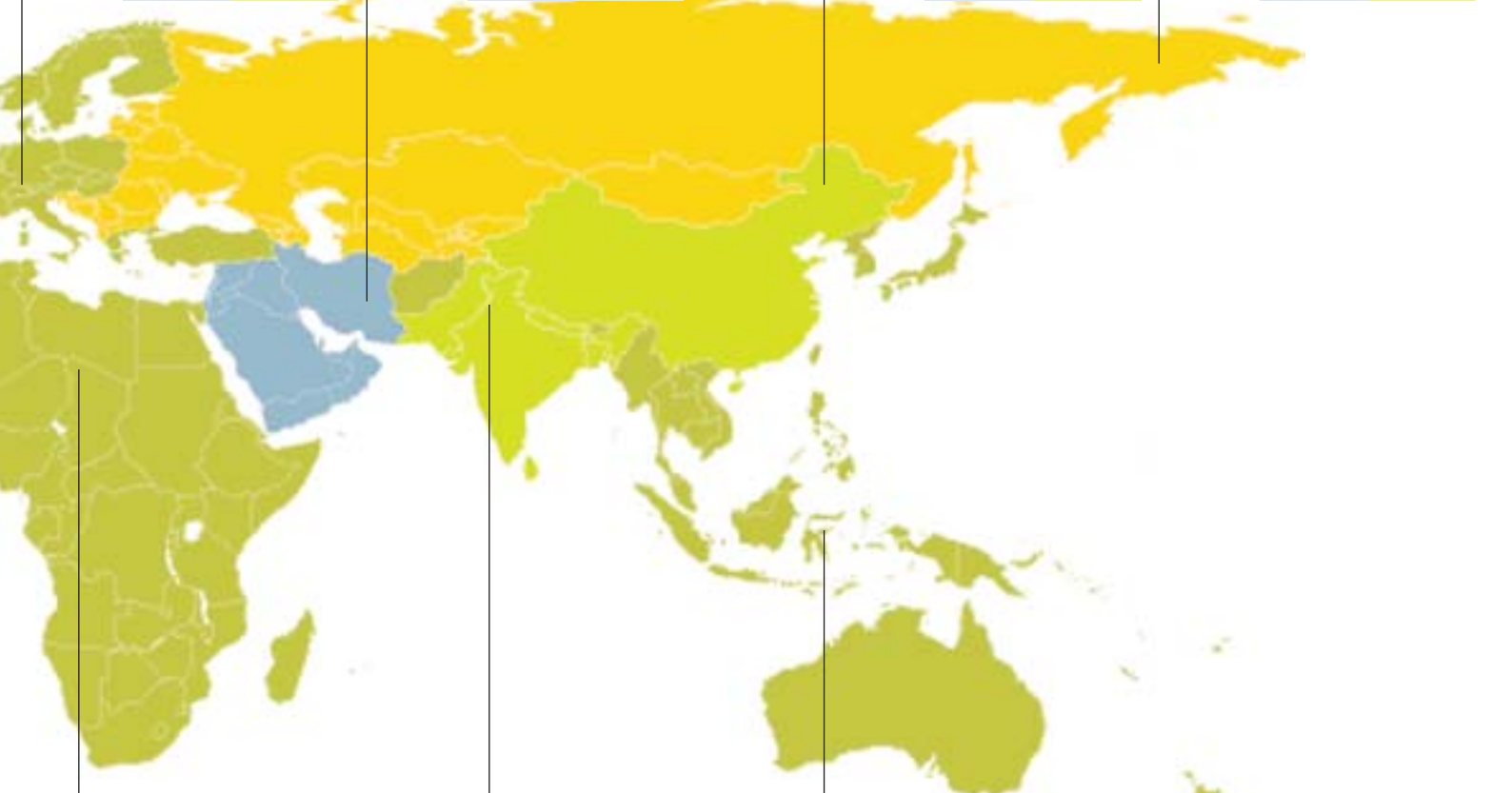
	REF		ALT	
	mn t	%	mn t	%
2005	419	0.0%L	419	0.0%L
	mn t	PJ	mn t	PJ
2003	17L	397	17L	397
2050	38L	861	9L	208
	t	t	t	t
2003	0.1	0.1		
2050	0.1L	0.0		

CHINA

	REF		ALT	
	mn t	%	mn t	%
2005	114,500	12.6%	114,500	12.6%
	mn t	PJ	mn t	PJ
2003	1,400H	32,241	1,400H	32,241
2050	2,754H	63,434	648H	14,916
	t	t	t	t
2003	1.1M	1.1M		
2050	2.0	0.5		

TRANSITION ECONOMIES

	REF		ALT	
	mn t	%	mn t	%
2005	225,123	24.8%	225,123	24.8%
	mn t	PJ	mn t	PJ
2003	634M	9,957	634M	9,957
2050	391	6,923	27	628
	t	t	t	t
2003	1.8	1.8		
2050	1.4M	0.1		



AFRICA

	REF		ALT	
	mn t	%	mn t	%
2005	50,336	5.5%	50,336	5.5%
	mn t	PJ	mn t	PJ
2003	181	4,163	181	4,163
2050	727	16,732	225	5,171
	t	t	t	t
2003	0.2	0.2		
2050	0.4	0.1		

SOUTH ASIA

	REF		ALT	
	mn t	%	mn t	%
2005	95,495	10.5%M	95,495	10.5%M
	mn t	PJ	mn t	PJ
2003	362	7,727	362	7,727
2050	1,103	24,057	152M	3,500
	t	t	t	t
2003	0.3	0.3		
2050	0.5	0.1		

EAST ASIA

	REF		ALT	
	mn t	%	mn t	%
2005	1,287	4.7%	1,287	4.7%
	mn t	PJ	mn t	PJ
2003	190	3,990	190	3,990
2050	902M	17,944	44	1,006
	t	t	t	t
2003	0.3	0.3		
2050	1.0	0.0		

OECD PACIFIC

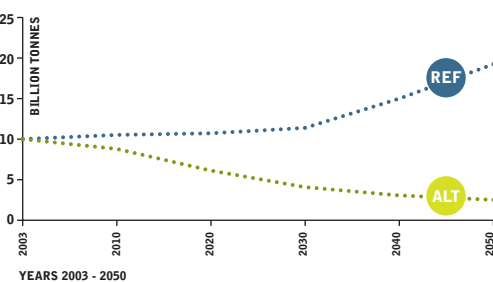
	REF		ALT	
	mn t	%	mn t	%
2005	79,510	8.7%	79,510	8.7%
	mn t	PJ	mn t	PJ
2003	382	7,975	382	7,975
2050	409	8,832	106	2,438
	t	t	t	t
2003	1.9	1.9		
2050	2.2	0.6H		

CO₂ EMISSIONS

comparison between the REF and ALT scenarios 2003 - 2050

billion tonnes

SOURCE: GPI/IECC

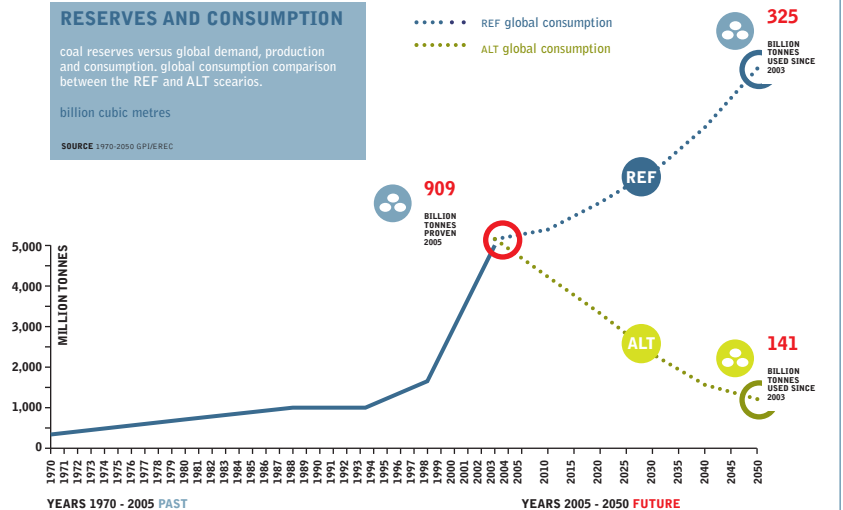


RESERVES AND CONSUMPTION

coal reserves versus global demand, production and consumption, global consumption comparison between the REF and ALT scenarios.

billion cubic metres

SOURCE: 1970-2050: GPI/IECC



map 6: nuclear reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



NON RENEWABLE RESOURCE
NUCLEAR

OECD NORTH AMERICA

	REF		ALT	
	t	%	t	%
2005	680,109	21%	680,109	21%
	TWh		TWh	
2003	873		PHASED OUT BY 2030	
2050	840 ^H		PHASED OUT BY 2030	
	PJ		PJ	
2003	9,526		9,526	
2050	9,164 ^H		0	
	kWh		kWh	
2003	2,051 ^H		2,051 ^H	
2050	1,433		0	

LATIN AMERICA

	REF		ALT	
	t	%	t	%
2005	95,045	3%	95,045	3%
	TWh		TWh	
2003	21		PHASED OUT BY 2030	
2050	29		PHASED OUT BY 2030	
	PJ		PJ	
2003	228		228	
2050	316		0	
	kWh		kWh	
2003	48		48	
2050	46		0	

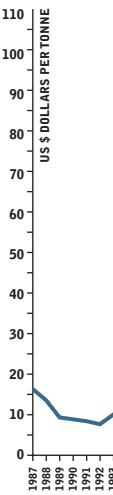
LEGEND



REF REFERENCE SCENARIO
ALT ALTERNATIVE SCENARIO



- RESERVES TOTAL TONNES** | SHARE IN % OF GLOBAL TOTAL (END OF 2005)
 - GENERATION PER REGION** TERA-WATT HOURS [TWh]
 - CONSUMPTION PER REGION** PETA JOULE [PJ]
 - CONSUMPTION PER PERSON** KILOWATT HOURS [kWh]
- H** HIGHEST | **M** MIDDLE | **L** LOWEST



OECD EUROPE

	REF		ALT	
	t	%	t	%
2005	56,445	2%	56,445	2%
TWh	TWh		TWh	
2003	981 ^H		PHASED OUT BY 2030	
2050	385		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	10,696 ^H		10,696 ^H	
2050	4,200		0	
kWh	kWh		kWh	
2003	1,859		1,859	
2050	756		0	

MIDDLE EAST

	REF		ALT	
	t	%	t	%
2005	0	0% ^L	0	0% ^L
TWh	TWh		TWh	
2003	0 ^L		PHASED OUT BY 2030	
2050	6 ^L		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	0 ^L		0 ^L	
2050	65 ^L		0	
kWh	kWh		kWh	
2003	0 ^L		0 ^L	
2050	17		0	

CHINA

	REF		ALT	
	t	%	t	%
2005	35,060	1%	35,060	1%
TWh	TWh		TWh	
2003	43		PHASED OUT BY 2030	
2050	377		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	472		472	
2050	4,116		0	
kWh	kWh		kWh	
2003	33		33	
2050	268		0	

TRANSITION ECONOMIES

	REF		ALT	
	t	%	t	%
2005	997,487	31% ^H	997,487	31% ^H
TWh	TWh		TWh	
2003	282 ^M		PHASED OUT BY 2030	
2050	210 ^M		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	3,074 ^M		3,074 ^M	
2050	2,291 ^M		0	
kWh	kWh		kWh	
2003	817 ^M		817 ^M	
2050	739 ^M		0	

AFRICA

	REF		ALT	
	t	%	t	%
2005	470,312	15% ^M	470,312	15% ^M
TWh	TWh		TWh	
2003	13		PHASED OUT BY 2030	
2050	13		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	139		139	
2050	142		0	
kWh	kWh		kWh	
2003	15		15	
2050	7 ^L		0	

SOUTH ASIA

	REF		ALT	
	t	%	t	%
2005	40,980	1%	40,980	1%
TWh	TWh		TWh	
2003	20		PHASED OUT BY 2030	
2050	190		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	213		213	
2050	2,073		0	
kWh	kWh		kWh	
2003	14		14	
2050	86		0	

EAST ASIA

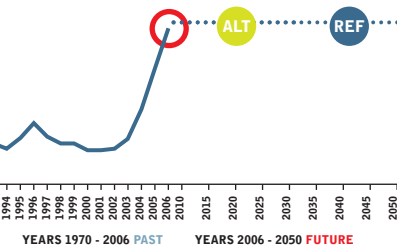
	REF		ALT	
	t	%	t	%
2005	5,630	0%	5,630	0%
TWh	TWh		TWh	
2003	39		PHASED OUT BY 2030	
2050	70		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	424		424	
2050	764		0	
kWh	kWh		kWh	
2003	62		62	
2050	79		0	

OECD PACIFIC

	REF		ALT	
	t	%	t	%
2005	741,600	23%	741,600	23%
TWh	TWh		TWh	
2003	370		PHASED OUT BY 2030	
2050	610		PHASED OUT BY 2030	
PJ	PJ		PJ	
2003	4,033		4,033	
2050	6,655		0	
kWh	kWh		kWh	
2003	1,858		1,858	
2050	3,341 ^H		0	

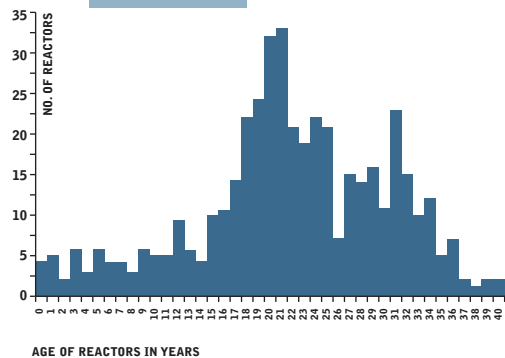
COST

yellow cake prices 1987 - 2006 and future predictions comparing the REF and ALT scenarios
tonnes
SOURCES REF: INTERNATIONAL ENERGY AGENCY; DEVELOPMENTS APPLIED IN THE GCS-PROJECT



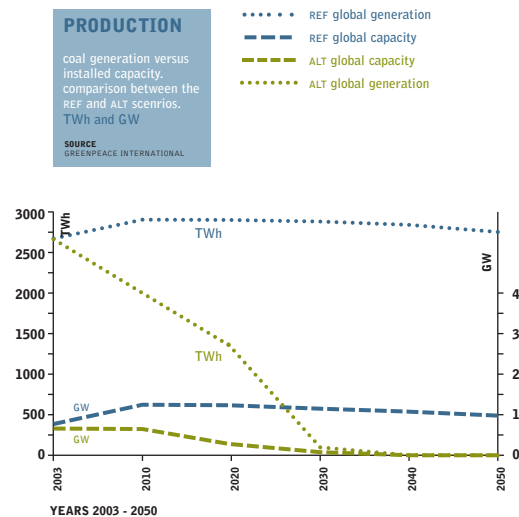
REACTORS

age and number of reactors worldwide
SOURCE: WISE



PRODUCTION

coal generation versus installed capacity, comparison between the REF and ALT scenarios. TWh and GW
SOURCE: GREENPEACE INTERNATIONAL

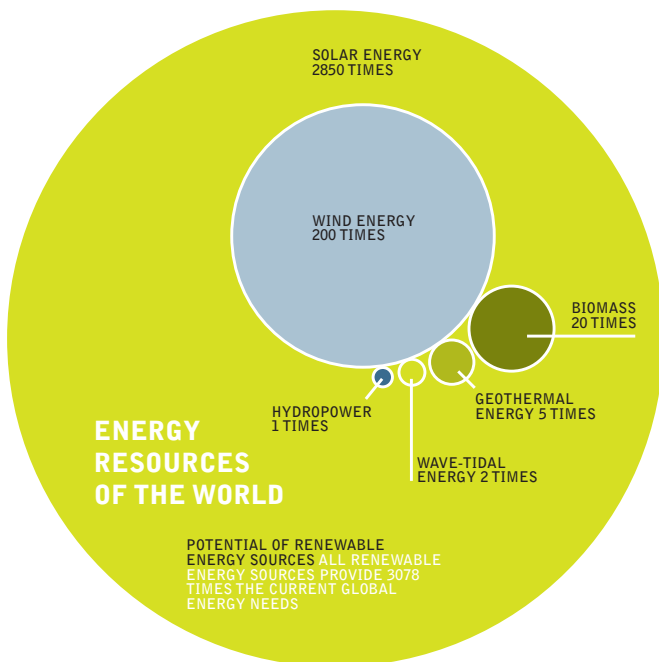


renewable energy

Nature offers a variety of freely available options for producing energy. It is mainly a question of how to convert sunlight, wind, biomass or water into electricity, heat or power as efficiently, sustainably and cost-effectively as possible.

On average, the energy in the sunshine that reaches the earth is about one kilowatt per square metre worldwide. According to the Research Association for Solar Power, power is gushing from renewable energy sources at a rate of 3,078 times more energy than is needed in the world today. In one day, the sunlight which reaches the earth produces enough energy to satisfy the world's current power requirements for eight years. Even though only a percentage of that potential is technically accessible, this is still enough to provide just under six times more energy than the world currently requires.

figure 30: energy resources of the world



source WBGU

table 12: technically accessible today

THE AMOUNT OF ENERGY THAT CAN BE ACCESSED WITH CURRENT TECHNOLOGIES SUPPLIES A TOTAL OF 5.9 TIMES THE GLOBAL DEMAND FOR ENERGY

Sun	3.8 times
Geothermal heat	1 time
Wind	0.5 times
Biomass	0.4 times
Hydrodynamic power	0.15 times
Ocean power	0.05 times

source DR. JOACHIM NITSCH



definition of types of energy resource potential¹³

theoretical potentials

The theoretical potential identifies the physical upper limit of the energy available from a certain source. For solar energy, for example, this would be the total solar radiation falling on a particular surface.

conversion potential

This is derived from the annual efficiency of the respective conversion technology. It is therefore not a strictly defined value, since the efficiency of a particular technology depends on technological progress.

technical potential

This takes into account additional restrictions regarding the area that is realistically available for energy generation. Technological, structural and ecological restrictions, as well as legislative requirements, are accounted for.

economic potential

The proportion of the technical potential that can be utilised economically. For biomass, for example, those quantities are included that can be exploited economically in competition with other products and land uses.

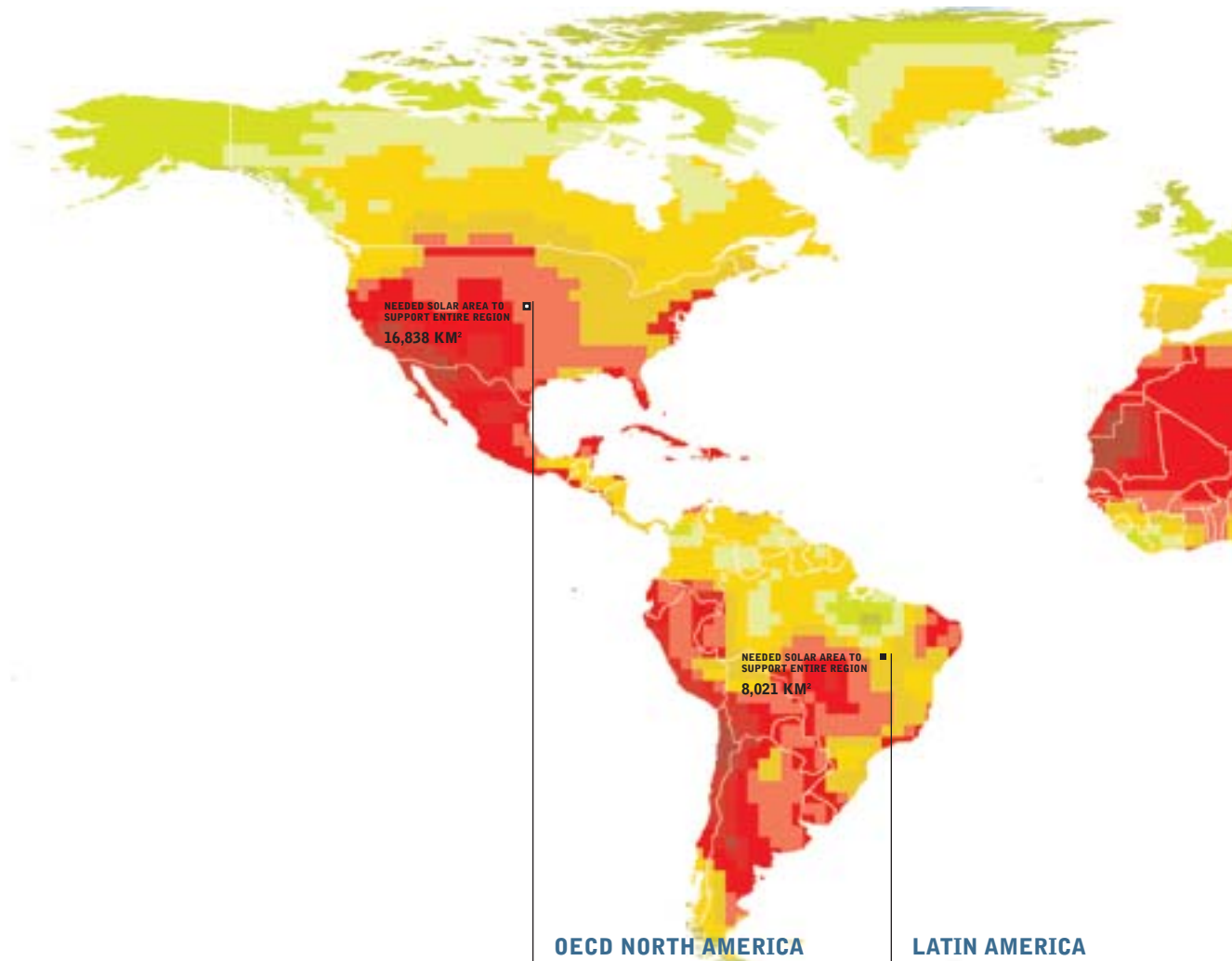
sustainable potential

This limits the potential of an energy source based on evaluation of ecological and socio-economic factors.

The accompanying resource maps show the regional distribution of the estimated energy that can be recovered and utilised. The calculations were carried out based on a global grid with a resolution of 0.5° longitude and latitude. The resulting potential is specified as average power density per surface area or per tilted module/converter area, so that the unit of measurement is always 'output per area'.

map 7: solar reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



RENEWABLE RESOURCE SOLAR

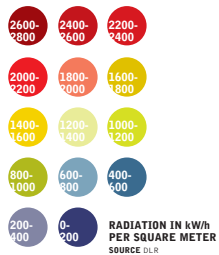
OECD NORTH AMERICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.05M	57H		
2050	0.26M	423	6.7	4,677
	kWh		kWh	
2003	37			
2050	201		2,217M	

LATIN AMERICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.01	2		
2050	0.03	16L	7.4	2,228
	kWh		kWh	
2003	1			
2050	7		982	

LEGEND



REF REFERENCE SCENARIO
ALT ALTERNATIVE SCENARIO

0 1000 KM

PRODUCTION PER REGION % OF GLOBAL SHARE | PETA JOULE [PJ]

PRODUCTION PER PERSON KILOWATT HOUR [kWh]

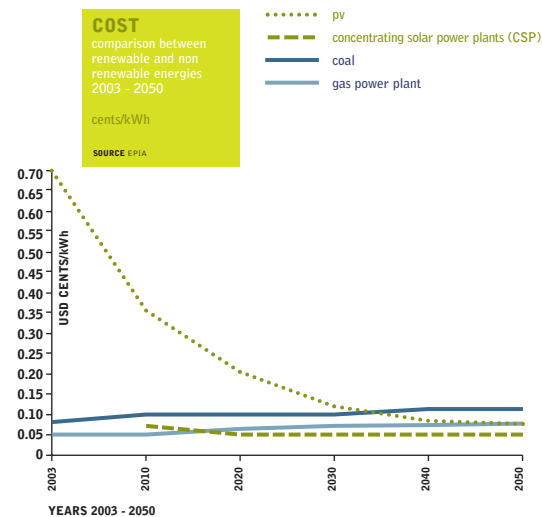
H HIGHEST | **M** MIDDLE | **L** LOWEST

COST

comparison between renewable and non renewable energies 2003 - 2050

cents/kWh

SOURCE EPIA

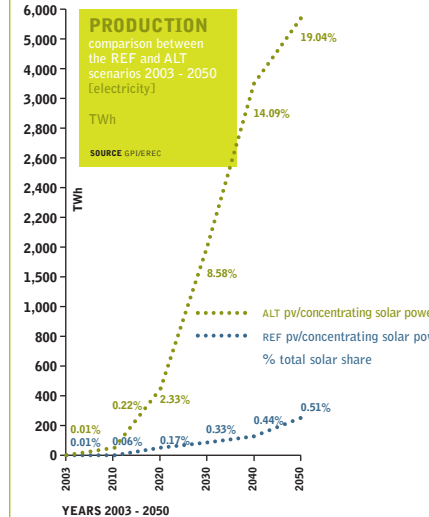


PRODUCTION

comparison between the REF and ALT scenarios 2003 - 2050 (electricity)

TWh

SOURCE IPI/ENERC



OECD EUROPE

	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.05M	39		
☀️ 2050	0.25	233M	6	3,062
	kWh		kWh	
💡 2003		20M		
💡 2050		127M		1,671

MIDDLE EAST

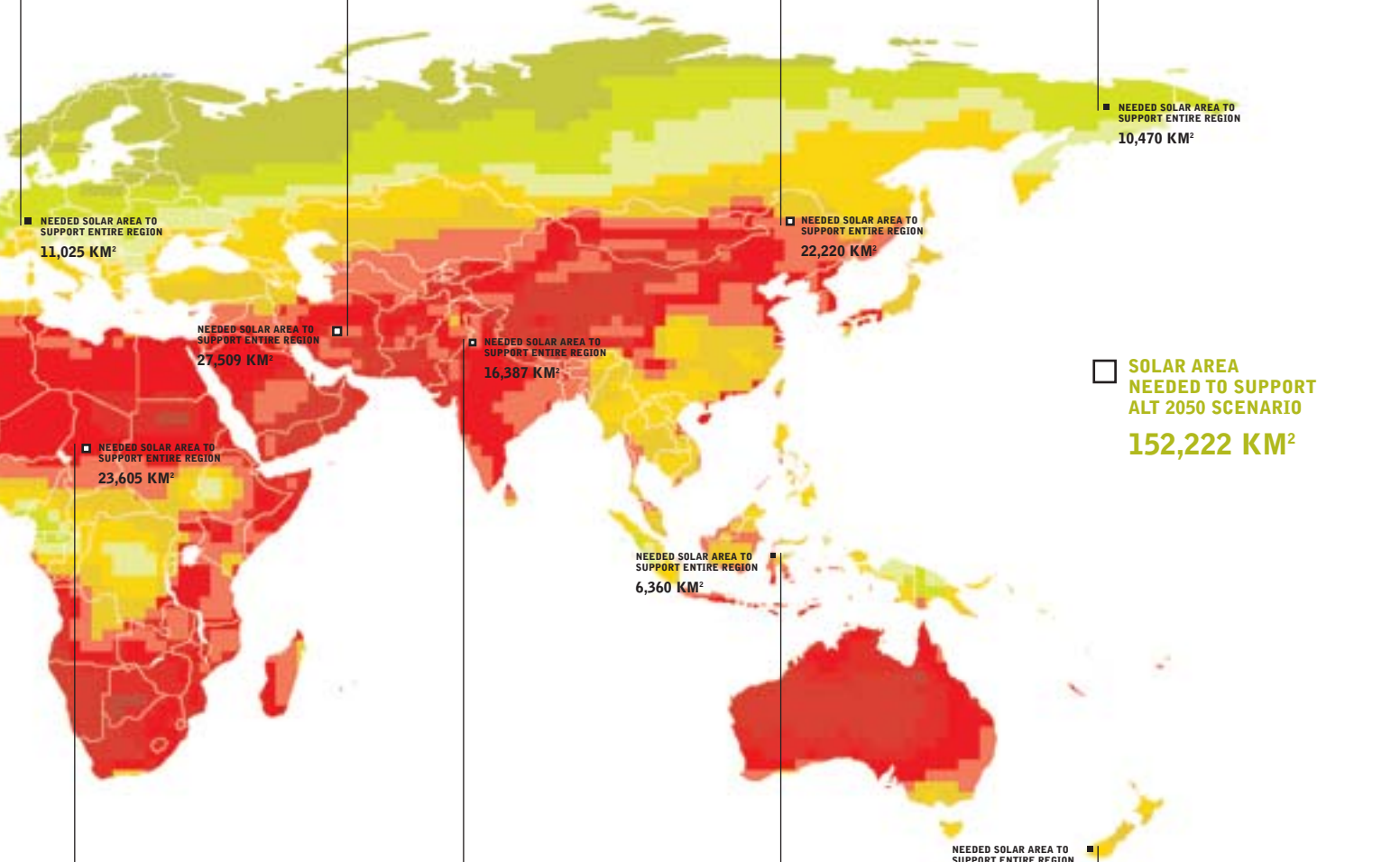
	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.18H	32		
☀️ 2050	0.32	125	38H	7,641H
	kWh		kWh	
💡 2003		49H		
💡 2050		98		5,999H

CHINA

	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.00L	0L		
☀️ 2050	0.46	584H	8.1	6,172
	kWh		kWh	
💡 2003		0L		
💡 2050		115		1,218

TRANSITION ECONOMIES

	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.00	1		
☀️ 2050	0.00	3	7.8	2,908
	kWh		kWh	
💡 2003		1		
💡 2050		3L		2,844



AFRICA

	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.00L	0L		
☀️ 2050	0.17	127	14.9	6,557
	kWh		kWh	
💡 2003		0L		
💡 2050		19		992

SOUTH ASIA

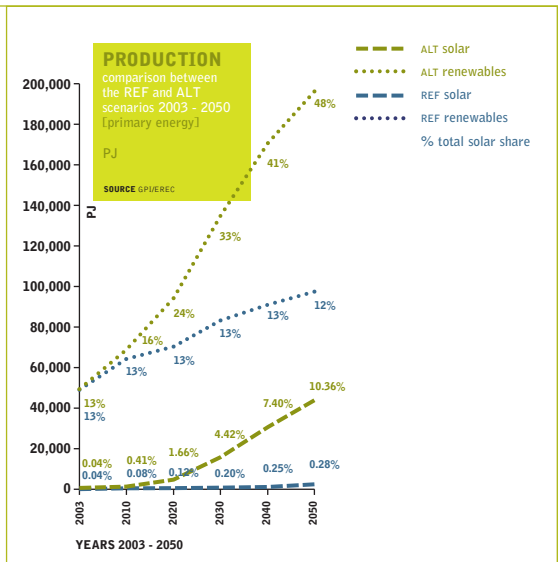
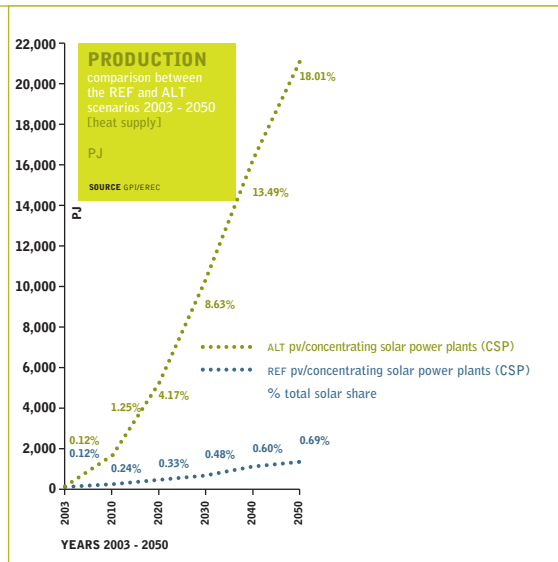
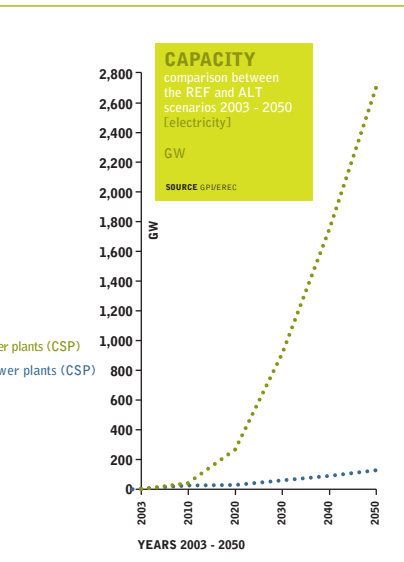
	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.00L	0L		
☀️ 2050	0.17	121	12.2M	4,552M
	kWh		kWh	
💡 2003		0L		
💡 2050		15		572

EAST ASIA

	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.00L	0L		
☀️ 2050	0.39	235	5.5L	1,767L
	kWh		kWh	
💡 2003		0L		
💡 2050		73		552L

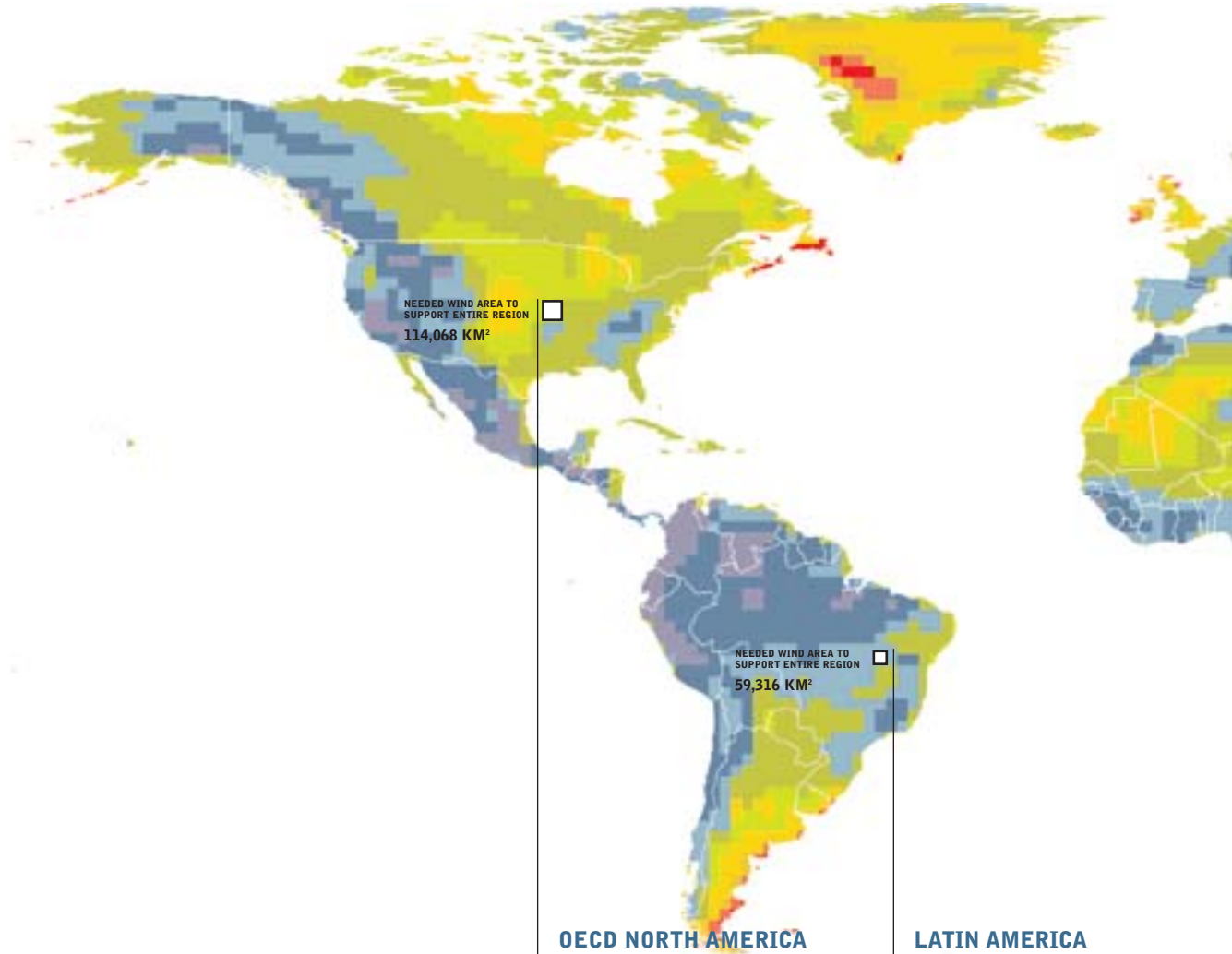
OECD PACIFIC

	REF		ALT	
	%	PJ	%	PJ
☀️ 2003	0.09	31M		
☀️ 2050	0.85H	397	11.5	2,719
	kWh		kWh	
💡 2003		44		
💡 2050		604H		4,137



map 8: wind reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



RENEWABLE RESOURCE
WIND

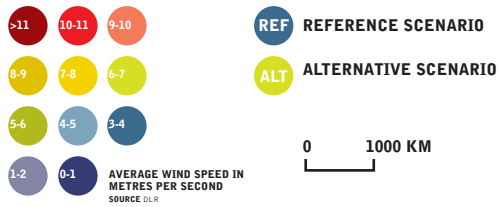
OECD NORTH AMERICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.04M	44		
2050	0.73	1,188	7.7	5,400 ^H
	kWh		kWh	
2003	28			
2050	563		2,559	

LATIN AMERICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.01	1		
2050	0.32	198	9.3 ^H	2,808 ^M
	kWh		kWh	
2003	1			
2050	87		1,238 ^M	

LEGEND



PRODUCTION PER REGION % OF GLOBAL SHARE | PETA JOULE (PJ)

PRODUCTION PER PERSON KILOWATT HOUR (kWh)

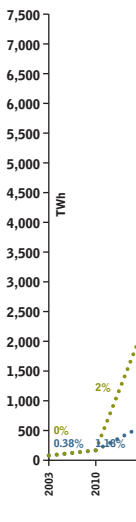
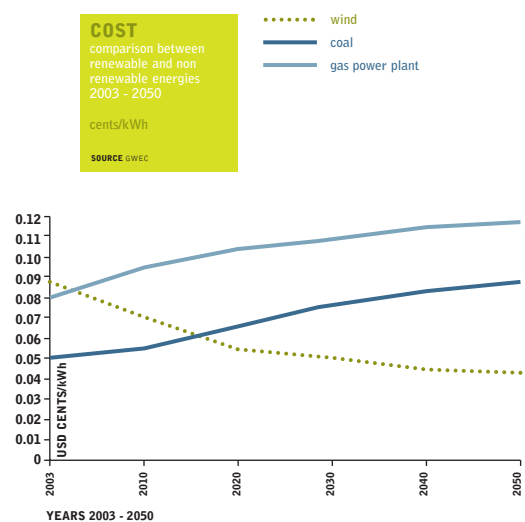
^H HIGHEST | ^M MIDDLE | ^L LOWEST

COST

comparison between renewable and non renewable energies 2003 - 2050

cents/kWh

SOURCE: GWEC



OECD EUROPE

	REF		ALT	
	%	PJ	%	PJ
2003	0.21H	160H		
2050	2.10H	1,962H	7.2	3,654
	kWh		kWh	
2003		84H		
2050		1,071H		1,994

MIDDLE EAST

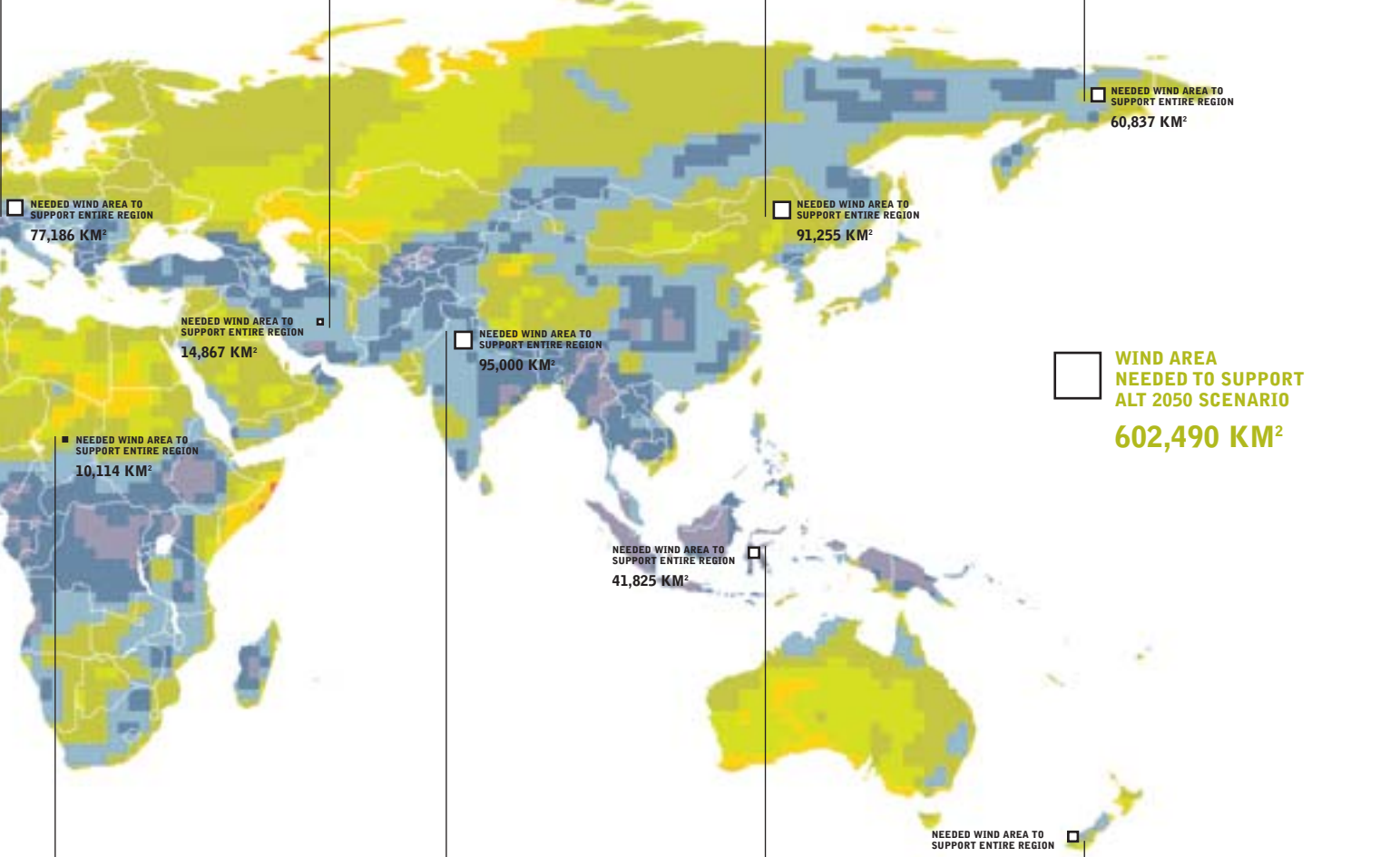
	REF		ALT	
	%	PJ	%	PJ
2003	0.00L	0L		
2050	0.18	72L	3.5	704
	kWh		kWh	
2003		0L		
2050		57		553

CHINA

	REF		ALT	
	%	PJ	%	PJ
2003	0.01	4		
2050	0.53M	681	5.7	4,320
	kWh		kWh	
2003		1		
2050		135		853

TRANSITION ECONOMIES

	REF		ALT	
	%	PJ	%	PJ
2003	0.00L	0L		
2050	0.21	139	7.7	2,880
	kWh		kWh	
2003		0		
2050		136M		2,817H



AFRICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.01	2		
2050	0.14L	104	1.1L	479L
	kWh		kWh	
2003		1		
2050		16L		72L

SOUTH ASIA

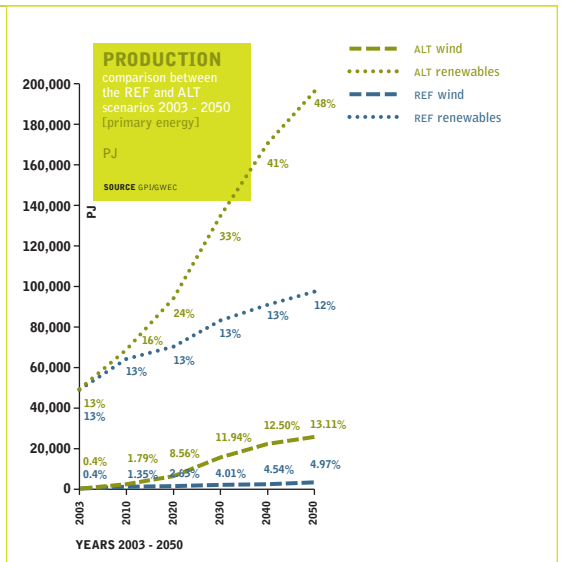
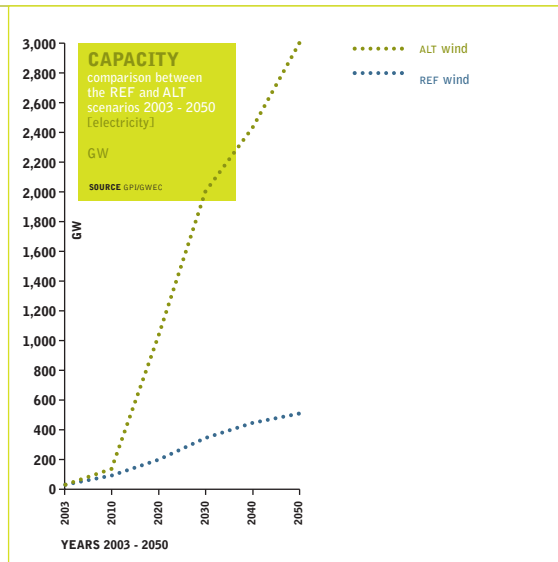
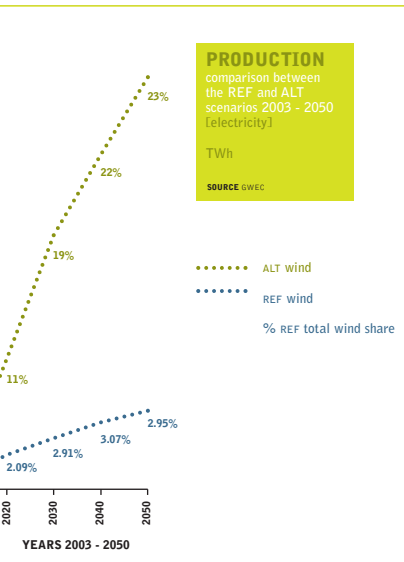
	REF		ALT	
	%	PJ	%	PJ
2003	0.05M	13M		
2050	0.26M	137	4.6	1,710
	kWh		kWh	
2003		3		
2050		17		215

EAST ASIA

	REF		ALT	
	%	PJ	%	PJ
2003	0.00L	0L		
2050	0.21	126	6.1M	1,980
	kWh		kWh	
2003		0L		
2050		39		619

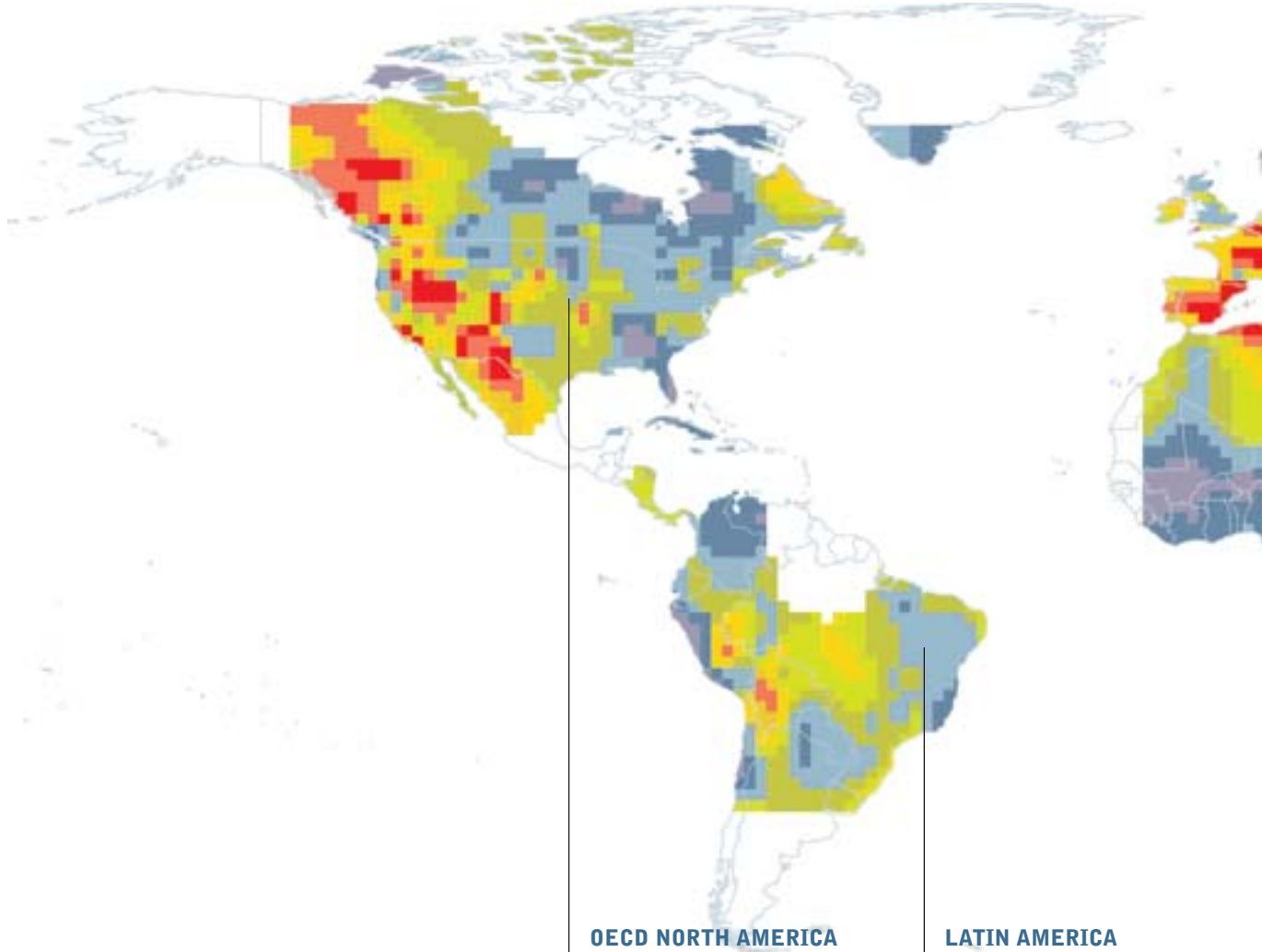
OECD PACIFIC

	REF		ALT	
	%	PJ	%	PJ
2003	0.02	6		
2050	0.69	324M	7.6	1,800
	kWh		kWh	
2003		9M		
2050		493		2,739



map 9: geothermal reference scenario and the energy [r]evolution scenario

WORLDWIDE SCENARIO



RENEWABLE RESOURCE

GEO THERMAL

OECD NORTH AMERICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.54H	621H		
2050	0.78H	1,270H	5.5M	3,810
	kWh		kWh	
2003	405H			
2050	602H			1,806

LATIN AMERICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.31M	61		
2050	0.54	338M	3.6	1,083
	kWh		kWh	
2003	38			
2050	149			478

LEGEND

REF REFERENCE SCENARIO
ALT ALTERNATIVE SCENARIO

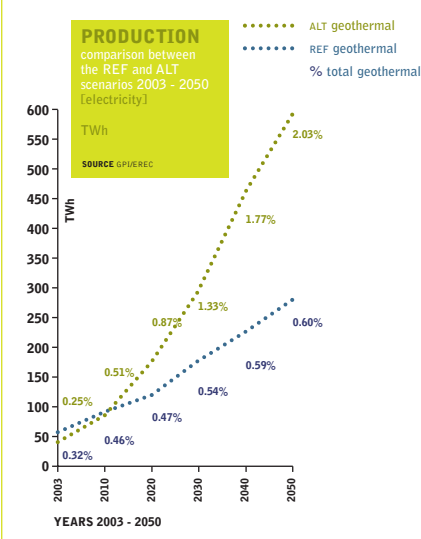
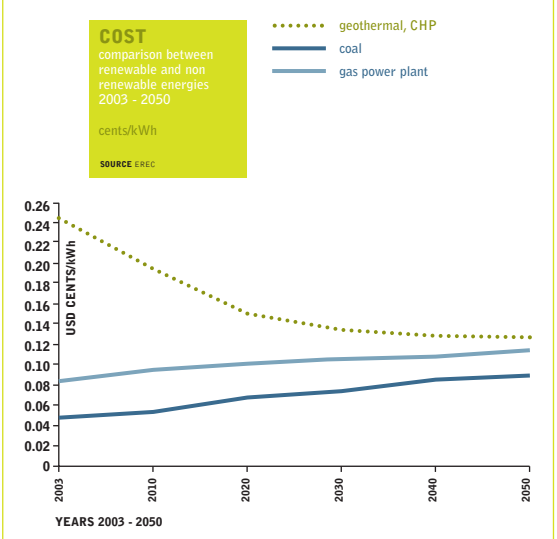
0 1000 KM

20 10 SURFACE HEAT FLOW IN mW/m²
SOURCE ARTEMIEVA AND MOONEY, 2003
WHITE = NO DATA

PRODUCTION PER REGION % OF GLOBAL SHARE | PETA JOULE [PJ]

PRODUCTION PER PERSON KILOWATT HOUR [kWh]

H HIGHEST | M MIDDLE | L LOWEST



OECD EUROPE

	REF		ALT	
	%	PJ	%	PJ
2003	0.20	150M		
2050	0.61	567	8.6	4,392H
	kWh		kWh	
2003		79M		
2050		310		2,397

MIDDLE EAST

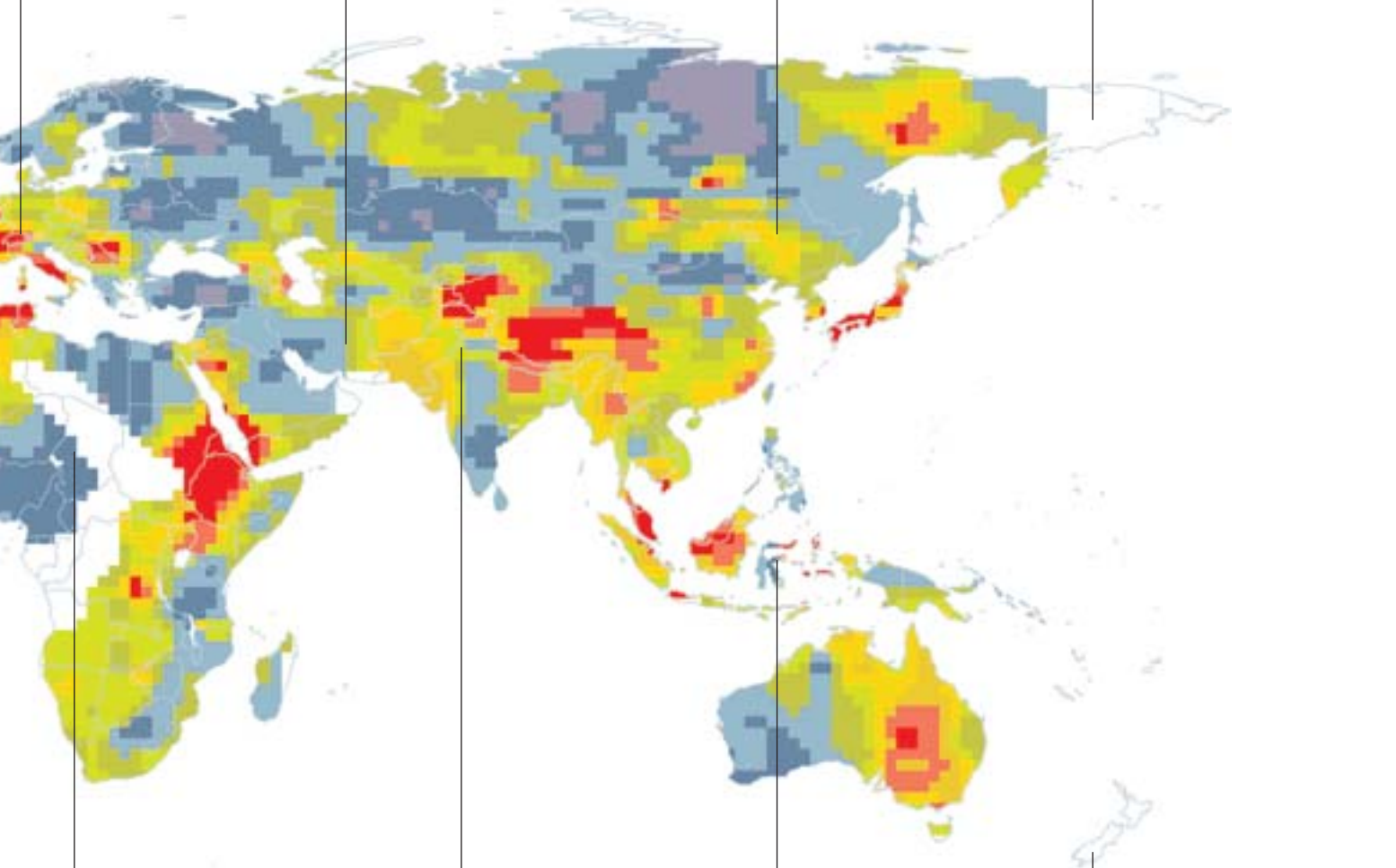
	REF		ALT	
	%	PJ	%	PJ
2003	0.00L	0L		
2050	0.00L	1L	6.89	1,384
	kWh		kWh	
2003		0L		
2050		1L		1,087M

CHINA

	REF		ALT	
	%	PJ	%	PJ
2003	0.00	0		
2050	0.06	76	0.12L	93L
	kWh		kWh	
2003		0		
2050		15		18L

TRANSITION ECONOMIES

	REF		ALT	
	%	PJ	%	PJ
2003	0.00	2		
2050	0.30	201	7.8	2,930
	kWh		kWh	
2003		2		
2050		196M		2,866H



AFRICA

	REF		ALT	
	%	PJ	%	PJ
2003	0.10	22		
2050	0.05	34	2.26	981
	kWh		kWh	
2003		7		
2050		5		148

SOUTH ASIA

	REF		ALT	
	%	PJ	%	PJ
2003	0.00	0		
2050	0.17	122	4.02	1,480M
	kWh		kWh	
2003		0		
2050		15		186

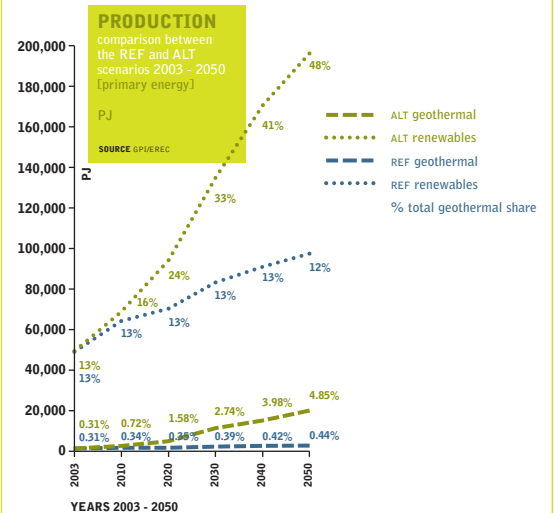
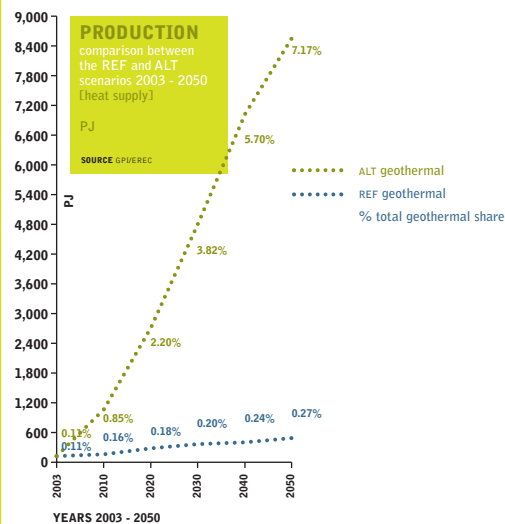
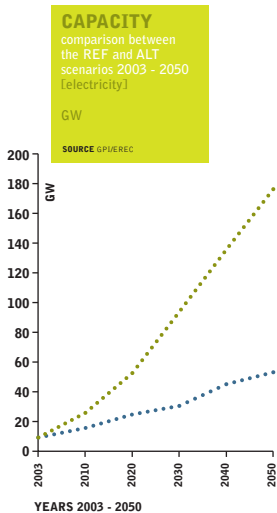
EAST ASIA

	REF		ALT	
	%	PJ	%	PJ
2003	2.00	446		
2050	1.33	798	9.2H	2,978
	kWh		kWh	
2003		199		
2050		249		931

OECD PACIFIC

	REF		ALT	
	%	PJ	%	PJ
2003	0.10	34		
2050	0.38M	176	2.81	654
	kWh		kWh	
2003		48		
2050		268		995

share



energy technologies

“THE ENERGY [R]EVOLUTION SCENARIO IS FOCUSED ON THE POTENTIAL FOR ENERGY SAVINGS AND RENEWABLE SOURCES, PRIMARILY IN THE ELECTRICITY AND HEAT GENERATING SECTORS.”

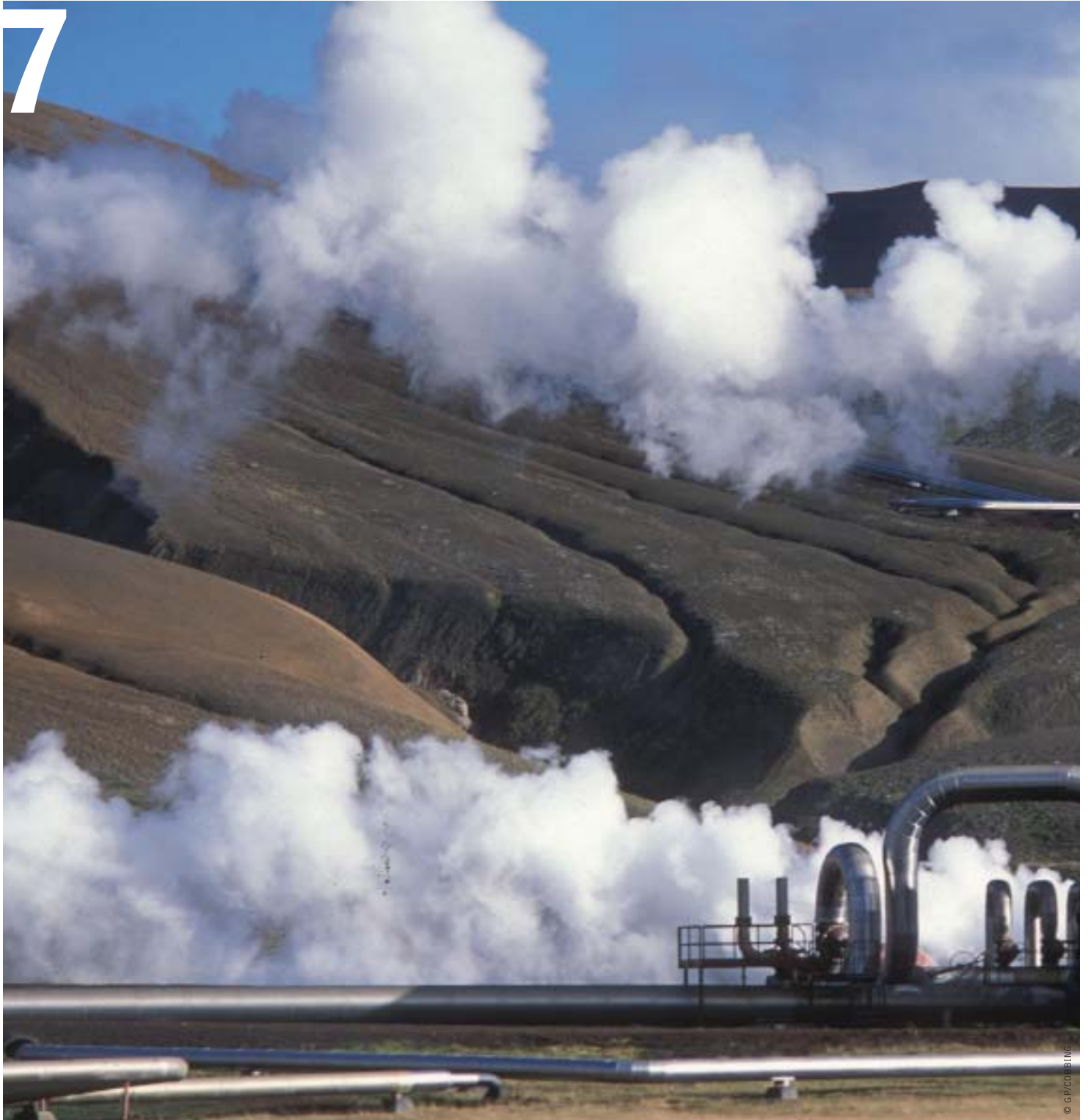


image ENERGY PLANT NEAR REYKJAVIK, ENERGY IS PRODUCED FROM THE GEOTHERMAL ACTIVITY.THE VOLCANIC ROCKS ARE VISIBLE BEHIND THE PLANT. NORTH WEST OF ICELAND.



This chapter describes the range of technologies available now and in the future to satisfy the world's energy demand. The energy [r]evolution scenario is focused on the potential for energy savings and renewable sources, primarily in the electricity and heat generating sectors. Although fuel use in transport is accounted for in the scenarios of future energy supply, no detailed description is given here of technologies, such as bio fuels for vehicles, which offer an alternative to the currently predominant oil.

fossil fuel technologies

The most commonly used fossil fuels for power generation around the world are coal and gas. Oil is still used where other fuels are not readily available, for example islands or remote sites, or where there is an indigenous resource. Together, coal and gas currently account for over half of global electricity supply.

coal combustion technologies

In a conventional coal-fired power station, pulverised or powdered coal is blown into a combustion chamber where it is burnt at high temperature. The hot gases and heat produced converts water flowing through pipes lining the boiler into steam. This drives a steam turbine and generates electricity. Over 90% of global coal-fired capacity uses this system. Coal power stations can vary in capacity from a few hundred megawatts up to several thousand.

A number of technologies have been introduced to improve the environmental performance of conventional coal combustion. These include coal cleaning (to reduce the ash content) and various 'bolt-on' or 'end-of-pipe' technologies to reduce emissions of particulates, sulphur dioxide and nitrogen oxide, the main pollutants resulting from coal firing apart from carbon dioxide. Flue gas desulphurisation (FGD), for example, most commonly involves 'scrubbing' the flue gases using an alkaline sorbent slurry, which is predominantly lime or limestone based.

More fundamental changes have been made to the way coal is burned to both improve its efficiency and further reduce emissions of pollutants. These include:

- **integrated gasification combined cycle:** Coal is not burnt directly but reacted with oxygen and steam to form a 'syngas' composed mainly of hydrogen and carbon monoxide, which is cleaned and then burned in a gas turbine to generate electricity and produce steam to drive a steam turbine. IGCC improves the efficiency of coal combustion from 38-40% up to 50%.
- **supercritical and ultrasupercritical:** These power plants operate at higher temperatures than conventional combustion, again increasing efficiency towards 50%.

- **fluidised bed combustion:** Coal is burned in a reactor comprised of a bed through which gas is fed to keep the fuel in a turbulent state. This improves combustion, heat transfer and recovery of waste products. By elevating pressures within a bed, a high-pressure gas stream can be used to drive a gas turbine, generating electricity. Emissions of both sulphur dioxide and nitrogen oxide can be reduced substantially.
- **pressurised pulverised coal combustion:** Mainly being developed in Germany, this is based on the combustion of a finely ground cloud of coal particles creating high pressure, high temperature steam for power generation. The hot flue gases are used to generate electricity in a similar way to the combined cycle system.

Other potential future technologies involve the increased use of coal gasification. Underground Coal Gasification, for example, involves converting deep underground unworked coal into a combustible gas which can be used for industrial heating, power generation or the manufacture of hydrogen, synthetic natural gas or other chemicals. The gas can be processed to remove CO₂ before it is passed on to end users. Demonstration projects are underway in Australia, Europe, China and Japan.

gas combustion technologies

Natural gas can be used for electricity generation through the use of either gas turbines or steam turbines. For the equivalent amount of heat, gas produces about 45% less carbon dioxide during its combustion than coal.

gas turbine plants use the heat from gases to directly operate the turbine. Natural gas fuelled turbines can start rapidly, and are therefore often used to supply energy during periods of peak demand, although at higher cost than baseload plants.

Particularly high efficiencies can be achieved through combining gas turbines with a steam turbine in combined cycle mode. In a combined cycle gas turbine (CCGT) plant, a gas turbine generator generates electricity and the exhaust gases from the gas turbine are then used to make steam to generate additional electricity. The efficiency of modern CCGT power stations can be more than 50%. Most new gas power plants built since the 1990s have been of this type.

At least until the recent increase in global gas prices, CCGT power stations have been the cheapest option for electricity generation in many countries. Capital costs have been substantially lower than for coal and nuclear plants and construction time shorter.

carbon storage technologies

Whenever coal or gas is burned, carbon dioxide (CO₂) is produced. Depending on the type of power plant, a large quantity of the gas will dissipate into the atmosphere and contribute to climate change. A coal power plant discharges roughly 720 grammes of carbon dioxide per kilowatt hour, a modern gas-fired plant releases about 370g CO₂/kWh. Some coal advocates are proposing a new technique for reducing the carbon dioxide released by power plants. In this scheme the CO₂ is separated, and then pumped underground. Both methods - capture and storage - have limitations. Even after employing proposed capture technologies, a residual amount of carbon dioxide - between 60 and 150g CO₂/kWh - will continue to be emitted.

carbon dioxide storage

CO₂ captured at the point of incineration has to be stored somewhere. Current thinking is that it can be trapped in the oceans or under the earth's surface at a depth of over 3,000 feet. As with nuclear waste, however, the question is whether this will just displace the problem elsewhere.

dangers of ocean storage

Ocean storage could result in greatly accelerated acidification (reduction of pH) of large areas and would be detrimental to a great many organisms, if not entire ecosystems, in the vicinity of injection sites. CO₂ disposed of in this way is likely to get back into the atmosphere in a relative short time. The oceans are both productive resources and a common natural endowment for this and future generations worthy of safekeeping. Given the diversity of other options available for dealing with CO₂ emissions, direct disposal of CO₂ to the ocean, sea floor, lakes and other open reservoir structures must be ruled out.

dangers of underground storage

Empty oil and gas fields are riddled with holes drilled during their exploration and production phases. These holes have to be sealed over. Normally special cement is used, but carbon dioxide is relatively reactive with water and attacks metals or cement, so that even sealed drilling holes present a safety hazard. To many experts the question is not if but when leakages will occur.

Because of the lack of experience with CO₂ storage, its safety is often compared to the storage of natural gas. This technology has been tried and tested for decades and is appraised by industry to be low risk. Greenpeace does not share this assessment. A number of serious leaks from gas storage installations have occurred around the world, sometimes requiring evacuation of nearby residents.

Sudden leakage of CO₂ can be fatal. Carbon dioxide is not itself poisonous, and is contained (approx. 0.04 per cent) in the air we breathe. But as concentrations increase it displaces the vital oxygen in the air. Air with concentrations of 7 to 8% CO₂ by volume causes death by suffocation after 30 to 60 minutes.

There are also health hazards when large amounts of CO₂ are explosively released. Although the gas normally disperses quickly after leaking, it can accumulate in depressions in the landscape or closed buildings, since carbon dioxide is heavier than air. It is equally

dangerous when it escapes more slowly and without being noticed in residential areas, for example in cellars below houses.

The dangers from such leaks are known from natural volcanic CO₂ degassing. Gas escaping at the Lake Nyos crater lake in Cameroon, Africa in 1986 killed over 1,700 people. At least 10 people have died in the Lazio region of Italy in the last 20 years as a result of CO₂ being released.

carbon storage and climate change targets

Can carbon storage contribute to climate change reduction targets? In order to avoid dangerous climate change, we need to reduce CO₂ globally by 50% in 2050. Power plants that store CO₂ are still being developed, however, and will not be widely available more than a decade. This means they will not make any substantial contribution towards protecting the climate until the year 2020 at the earliest.

Nor is CO₂ storage of any great help in attaining the goal of an 80% reduction by 2050 in OECD countries. If it does become available in 2020, most of the world's new power plants will have just finished being modernised. All that could then be done would be for existing power plants to be retrofitted and CO₂ captured from the waste gas flow. As retrofitting existing power plants is highly expensive, a high carbon price would be needed.

Employing CO₂ capture will also increase the price of electricity from fossil fuels. Although the costs of storage depend on a lot of factors, including the technology used for separation, transport and the kind of storage installation, experts from the UN Intergovernmental Panel on Climate Change calculate the additional costs at between 3.5 and 5.0 cents/kWh of power. Since modern wind turbines in good wind locations are already cost competitive with new build coal-fired power plants today, the costs will probably be at the top end. This means the technology would more than double the cost of electricity today.

conclusion

Renewable energy sources are already available, in many cases cheaper, and without the negative environmental impacts that are associated with fossil fuel exploitation, transport and processing. It is renewable energy together with energy efficiency and energy conservation – and NOT carbon capture and storage – that has to increase world-wide so that the primary cause of climate change – the burning of fossil fuels like coal, oil and gas – is stopped. Greenpeace opposes any CCS efforts which lead to:

- the undermining or threats to undermine existing global and regional regulations governing the disposal of wastes at sea (in the water column, at or beneath the seabed).
- continued or increasing finance to the fossil fuel sector at the expense of renewable energy and energy efficiency.
- the stagnation of renewable energy, energy efficiency and energy conversation improvements
- the promotion of this possible future technology as the only major solution to climate change, thereby leading to new fossil fuel developments – especially lignite and black coal-fired power plants, and the increase of emissions in the short to medium term



nuclear technologies

Generating electricity from nuclear power involves transferring the heat produced by a controlled nuclear fission reaction into a conventional steam turbine generator. The nuclear reaction takes place inside a core and surrounded by a containment vessel of varying design and structure. Heat is removed from the core by a coolant (gas or water) and the reaction controlled by a moderating element or “moderator”.

Across the world over the last two decades there has been a general slowdown in building new nuclear power stations. This has been caused by a variety of factors: fear of a nuclear accident, following the events at Three Mile Island, Chernobyl and Monju, increased scrutiny of economics and environmental factors, such as waste management and radioactive discharges.

nuclear reactor designs: evolution and safety issues

At the beginning of 2005 there were 441 nuclear power reactors operating in 31 countries around the world. Although there are dozens of different reactor designs and sizes, there are three broad categories either currently deployed or under development. These are:

generation I: Prototype commercial reactors developed in the 1950s and 1960s as modified or enlarged military reactors, originally either for submarine propulsion or plutonium production.

generation II: Mainstream reactor designs in commercial operation worldwide.

generation III: Generation III reactors include the so-called “Advanced Reactors”, three of which are already in operation in Japan, with more under construction or planned. About 20 different designs are reported to be under development¹⁴, most of them “evolutionary” designs developed from Generation II reactor types with some modifications, but without introducing drastic changes. Some of them represent more innovative approaches. According to the World Nuclear Association, reactors of Generation III are characterised by the following:

- a standardised design for each type to expedite licensing, reduce capital cost and construction time
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets
- higher availability and longer operating life, typically 60 years
- reduced possibility of core melt accidents
- minimal effect on the environment
- higher burn-up to reduce fuel use and the amount of waste
- burnable absorbers (“poisons”) to extend fuel life

To what extent these goals address issues of higher safety standards, as opposed to improved economics, remains unclear.

The **European Pressurised Water Reactor (EPR)** has been developed from the most recent Generation II designs to start operation in France and Germany¹⁵. Its stated goals are to improve safety levels - in particular, reduce the probability of a severe accident by a factor of ten, achieve mitigation of severe accidents by restricting their consequences to the plant itself, and reduce costs. Compared to its predecessors, however, the EPR displays several modifications which constitute a reduction of safety margins, including:

- The volume of the reactor building has been reduced by simplifying the layout of the emergency core cooling system, and by using the results of new calculations which predict less hydrogen development during an accident.
- The thermal output of the plant was increased by 15% relative to the French reactor by increasing core outlet temperature, letting the main coolant pumps run at higher capacity and modifying the steam generators.
- The EPR has fewer redundant trains in safety systems than a Germany Generation II reactor.

Several other modifications are hailed as substantial safety improvements, including a “core catcher” system to control a meltdown accident. Nonetheless, in spite of the changes being envisaged, there is no guarantee that the safety level of the EPR actually represents a significant improvement. In particular, reduction of the expected core melt probability by a factor of ten is not proven. Furthermore, there are serious doubts as to whether the mitigation and control of a core melt accident with the “core catcher” concept will actually work.

Finally, **generation IV** reactors are currently being developed with the aim of commercialisation in 20-30 years.

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renewable energy technologies

Renewable energy covers a range of natural sources which are constantly renewed and therefore, unlike fossil fuels and uranium, will never be exhausted. Most of them derive from the effect of the sun and moon on the earth's weather patterns. They also produce none of the harmful emissions and pollution associated with "conventional" fuels. Although hydroelectric power has been used on an industrial scale since the middle of the last century, the serious exploitation of other renewable sources has a more recent history.

solar power (photovoltaics)

There is more than enough solar radiation available all over the world to satisfy a vastly increased demand for solar power systems. The sunlight which reaches the earth's surface is enough to provide 2,850 times as much energy as we can currently use. On a global average, each square metre of land is exposed to enough sunlight to produce 1,700 kWh of power every year. The average irradiation in Europe is about 1,000 kWh per square metre, however, compared with 1,800 kWh in the Middle East.

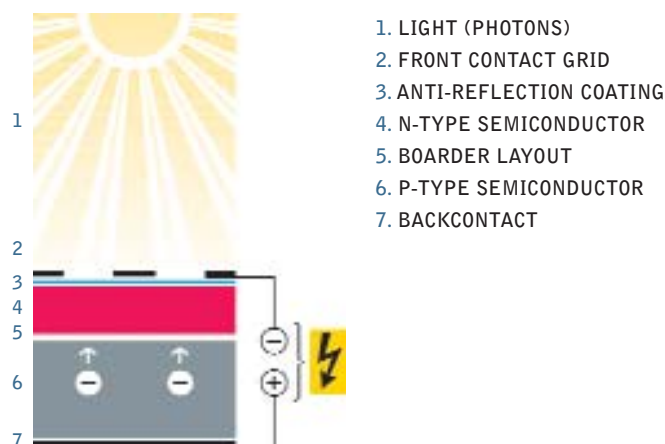
Photovoltaic (PV) technology involves the generation of electricity from light. The secret to this process is the use of a semiconductor material which can be adapted to release electrons, the negatively charged particles that form the basis of electricity. The most common semiconductor material used in photovoltaic cells is silicon, an element most commonly found in sand. All PV cells have at least two layers of such semiconductors, one positively charged and one negatively charged. When light shines on the semiconductor, the electric field across the junction between these two layers causes electricity to flow. The greater the intensity of the light, the greater the flow of electricity. A photovoltaic system does not therefore need bright sunlight in order to operate, and can generate electricity even on cloudy days. Solar PV is different from a solar thermal collecting system (see below) where the sun's rays are used to generate heat, usually for hot water in a house, swimming pool etc.

The most important parts of a PV system are the cells which form the basic building blocks, the modules which bring together large numbers of cells into a unit, and, in some situations, the inverters used to convert the electricity generated into a form suitable for everyday use. When a PV installation is described as having a capacity of 3 kWp (peak), this refers to the output of the system under standard testing conditions, allowing comparison between different modules. In central Europe a 3 kWp rated solar electricity system, with a surface area of approximately 27 square metres, would produce enough power to meet the electricity demand of an energy conscious household.

types of PV system

- **grid connected** The most popular type of solar PV system for homes and businesses in the developed world. Connection to the local electricity network allows any excess power produced to be sold to the utility. Electricity is then imported from the network outside daylight hours. An inverter is used to convert the DC power produced by the system to AC power for running normal electrical equipment.
- **grid support** A system can be connected to the local electricity network as well as a back-up battery. Any excess solar electricity produced after the battery has been charged is then sold to the network. This system is ideal for use in areas of unreliable power supply.
- **off-grid** Completely independent of the grid, the system is connected to a battery via a charge controller, which stores the electricity generated and acts as the main power supply. An inverter can be used to provide AC power, enabling the use of normal appliances. Typical off-grid applications are repeater stations for mobile phones or rural electrification. Rural electrification means either small solar home systems (SHS) covering basic electricity needs or solar mini grids, which are larger solar electricity systems providing electricity for several households.
- **hybrid system** A solar system can be combined with another source of power - a biomass generator, a wind turbine or diesel generator - to ensure a consistent supply of electricity. A hybrid system can be grid connected, stand alone or grid support.

figure 31: photovoltaics technology



concentrating solar power plants(CSP)

Concentrating solar power (CSP) plants, also called solar thermal power plants, produce electricity in much the same way as conventional power stations. The difference is that they obtain their energy input by concentrating solar radiation and converting it to high temperature steam or gas to drive a turbine or motor engine. Large mirrors concentrate sunlight into a single line or point. The heat created there is used to generate steam. This hot, highly pressurised steam is used to power turbines which generate electricity. In sun-drenched regions, CSP plants can guarantee large shares of electricity production.

Four main elements are required: a concentrator, a receiver, some form of transfer medium or storage, and power conversion. Many different types of system are possible, including combinations with other renewable and non-renewable technologies, but the three most promising solar thermal technologies are:

- **parabolic trough** Trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line. A thermal transfer fluid, such as synthetic thermal oil, is circulated in these tubes. Heated to approximately 400°C by the concentrated sun's rays, this oil is then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator, which can either be part of a conventional steam cycle or integrated into a combined steam and gas turbine cycle.

This is the most mature technology, with 354 MWe of plants connected to the Southern California grid since the 1980s and more than 2 million square metres of parabolic trough collectors installed worldwide.

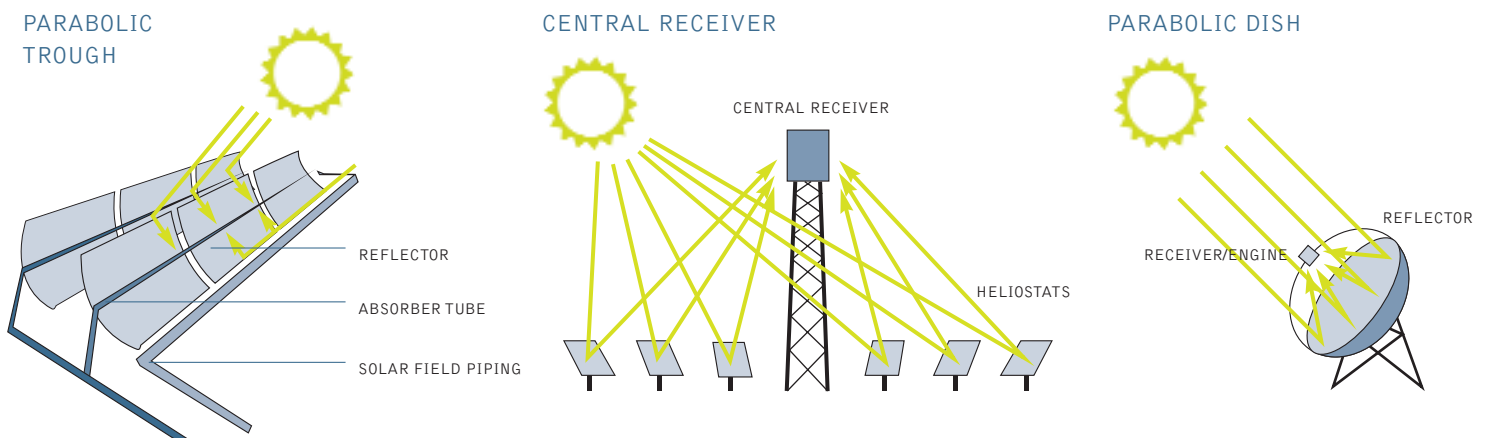
- **central receiver or solar tower** A circular array of heliostats (large individually tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation. To date, the heat transfer media demonstrated include water/steam, molten salts, liquid sodium and air. If pressurised gas or air is used at very high temperatures of about 1,000°C or more as the heat transfer medium, it can even be used to directly replace natural gas in a gas turbine, thus making use of the excellent efficiency (60%+) of modern gas and steam combined cycles.

After an intermediate scaling up to 30 MW capacity, solar tower developers now feel confident that grid-connected tower power plants can be built up to a capacity of 200 MWe solar-only units. Use of heat storage will increase their flexibility. Although solar tower plants are considered to be further from commercialisation than parabolic trough systems, they have good longer-term prospects for high conversion efficiencies. Projects are being developed in Spain, South Africa and Australia.

- **parabolic dish** A dish-shaped reflector is used to concentrate sunlight on to a receiver located at its focal point. The concentrated beam radiation is absorbed into the receiver to heat a fluid or gas (air) to approximately 750°C. This is then used to generate electricity in a small piston, Stirling engine or a micro turbine, attached to the receiver.

The potential of parabolic dishes lies primarily in decentralised power supply and remote, stand-alone power systems. Projects are currently planned in the United States, Australia and Europe.

figures 32 - 34: parabolic trough/central receiver or solar tower/parabolic dish technology



solar thermal collectors

Solar thermal collecting systems are based on a centuries-old principle: the sun heats up water contained in a dark vessel. Solar thermal technologies on the market now are efficient and highly reliable, providing energy for a wide range of applications - from domestic hot water and space heating in residential and commercial buildings to swimming pool heating, solar-assisted cooling, industrial process heat and the desalination of drinking water.

solar domestic hot water and space heating

Domestic hot water production is the most common application. Depending on the conditions and the system's configuration, most of a building's hot water requirements can be provided by solar energy. Larger systems can additionally cover a substantial part of the energy needed for space heating. There are two main types of technology:

- **vacuum tubes:** The absorber inside the vacuum tube absorbs radiation from the sun and heats up the fluid inside. Additional radiation is picked up from the reflector behind the tubes. Whatever the angle of the sun, the round shape of the vacuum tube allows it to reach the absorber. Even on a cloudy day, when the light is coming from many angles at once, the vacuum tube collector can still be effective.
- **flat panel:** This is basically a box with a glass cover which sits on the roof like a skylight. Inside is a series of copper tubes with copper fins attached. The entire structure is coated in a black substance designed to capture the sun's rays. These rays heat up a water and antifreeze mixture which circulates from the collector down to the building's boiler.

solar assisted cooling

Solar chillers use thermal energy to produce cooling and/or dehumidify the air in a similar way to a refrigerator or conventional air-conditioning. This application is well-suited to solar thermal energy, as the demand for cooling is often greatest when there is most sunshine. Solar cooling has been successfully demonstrated and large-scale use can be expected in the future.

figure 35: flat panel solar technology



wind power

Over the last 20 years, wind energy has become the world's fastest growing energy source. Today's wind turbines are produced by a sophisticated mass production industry employing a technology that is efficient, cost effective and quick to install. Turbine sizes range from a few kW to over 5,000 kW, with the largest turbines reaching more than 100m in height. One large wind turbine can produce enough electricity for about 5,000 households. State-of-the-art wind farms today can be as small as a few turbines and as large as several hundred MW.

The global wind resource is enormous, capable of generating more electricity than the world's total power demand, and well distributed across the five continents. Wind turbines can be operated not just in the windiest coastal areas but in countries which have no coastlines, including regions such as central Eastern Europe, central North and South America, and central Asia. The wind resource out at sea is even more productive than on land, encouraging the installation of offshore wind parks with foundations embedded in the ocean floor. In Denmark, a wind park built in 2002 uses 80 turbines to produce enough electricity for a city with a population of 150,000.

Smaller wind turbines can produce power efficiently in areas that otherwise have no access to electricity. This power can be used directly or stored in batteries. New technologies for using the wind's power are also being developed for exposed buildings in densely populated cities.

wind turbine design

Significant consolidation of wind turbine design has taken place since the 1980s. The majority of commercial turbines now operate on a horizontal axis with three evenly spaced blades. These are attached to a rotor from which power is transferred through a gearbox to a generator. The gearbox and generator are contained within a housing called a nacelle. Some turbine designs avoid a gearbox by using direct drive. The electricity output is then channelled down the tower to a transformer and eventually into the local grid.

Wind turbines can operate from a wind speed of 3-4 metres per second up to about 25 m/s. Limiting their power at high wind speeds is achieved either by "stall" regulation - reducing the power output - or "pitch" control - changing the angle of the blades so that they no longer offer any resistance to the wind. Pitch control has become the most common method. The blades can also turn at a constant or variable speed, with the latter enabling the turbine to follow more closely the changing wind speed.

The main design drivers for current wind technology are:

- high productivity at both low and high wind sites
- grid compatibility
- acoustic performance



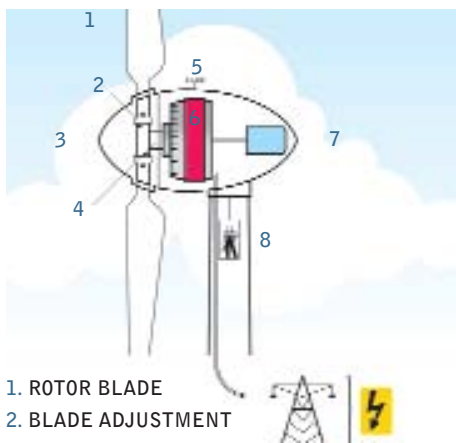
- aerodynamic performance
- visual impact
- offshore expansion

Although the existing offshore market is only 0.4% of the world's land-based installed wind capacity, the latest developments in wind technology are primarily driven by this emerging potential. This means that the focus is on the most effective ways to make very large turbines.

Modern wind technology is available for a range of sites - low and high wind speeds, desert and arctic climates. European wind farms operate with high availability, are generally well integrated with the environment and accepted by the public. In spite of repeated predictions of a levelling off at an optimum mid-range size, and the fact that wind turbines cannot get larger indefinitely, turbine size has increased year on year - from units of 20-60 kW in California in the 1980s up to the latest multi-MW machines with rotor diameters over 100 m. The average size of turbine installed around the world during 2005 was 1,282 kW, whilst the largest machine in operation is the Enercon E112, with a capacity of up to 6 MW. This is targeted at the developing offshore market.

This growth in turbine size has been matched by the expansion of both markets and manufacturers. More than 80,000 wind turbines now operate in over 50 countries around the world. The German market is the largest, but there has also been impressive growth in Spain, Denmark, India and the United States.

figure 36: wind turbine technology



1. ROTOR BLADE
2. BLADE ADJUSTMENT
3. NACELL
4. ROTOR SHAFT
5. WIND MEASUREMENT
6. GENERATOR
7. SYSTEM CONTROL
8. LIFT

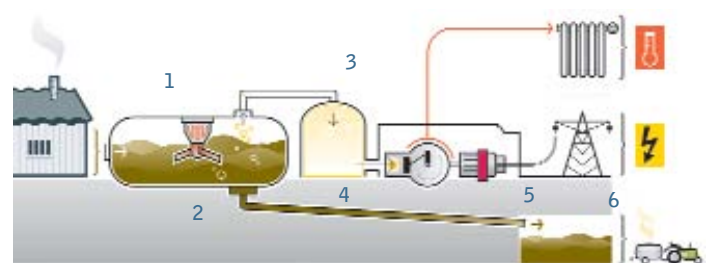
biomass energy

Biomass is a broad term used to describe material of recent biological origin that can be used as a source of energy. This includes wood, crops, algae and other plants as well as agricultural and forest residues. Biomass can be used for a variety of end uses: heating, electricity generation or as fuel for transportation. The term 'bio energy' is used for biomass energy systems that produce heat and/or electricity and 'bio fuels' for liquid fuels for transport. Biodiesel manufactured from various crops has become increasingly used as vehicle fuel, especially as the cost of oil has risen.

Biological power sources are renewable, easily stored, and, if sustainably harvested, CO₂ neutral. This is because the gas emitted during their transfer into useful energy is balanced by the carbon dioxide absorbed when they were growing plants.

Electricity generating biomass power plants work just like natural gas or coal power stations, except that the fuel must be processed before it can be burned. These power plants are generally not as large as coal power stations because their fuel supply needs to grow as near as possible to the power plant. Heat generation from biomass power plants can result either from utilising the heat produced in a Combined Heat and Power plant (CHP), piping the heat to nearby homes or industry, or through dedicated heating systems. Small heating systems using specially produced pellets made from waste wood, for example, can be used to heat single family homes instead of natural gas or oil.

figure 37: biomass technology



1. HEATED MIXER
2. CONTAINMENT FOR FERMENTATION
3. BIOGAS STORAGE
4. COMBUSTION ENGINE
5. GENERATOR
6. WASTE CONTAINMENT

biomass technology

A number of processes can be used to convert energy from biomass. These divide into thermal systems, which involve direct combustion of either solids, liquids or a gas via pyrolysis or gasification, and biological systems, which involve decomposition of solid biomass to liquid or gaseous fuels by processes such as anaerobic digestion and fermentation.

thermal systems

- **direct combustion** Direct combustion is the most common way of converting biomass to energy, for heat as well as electricity. Worldwide it accounts for over 90% of biomass generation. Technologies can be distinguished as either fixed bed, fluidised bed or entrained flow combustion. In fixed bed combustion, such as a grate furnace, primary air passes through a fixed bed, in which drying, gasification and charcoal combustion takes place. The combustible gases produced are burned after the addition of secondary air, usually in a zone separated from the fuel bed. In fluidised bed combustion, the primary combustion air is injected from the bottom of the furnace with such high velocity that the material inside the furnace becomes a seething mass of particles and bubbles. Entrained flow combustion is suitable for fuels available as small particles, such as sawdust or fine shavings, which are pneumatically injected into the furnace.
- **gasification** Biomass fuels are increasingly being used with advanced conversion technologies, such as gasification systems, which offer superior efficiencies compared with conventional power generation. Gasification is a thermochemical process in which biomass is heated with little or no oxygen present to produce a low energy gas. The gas can then be used to fuel a gas turbine or a combustion engine to generate electricity. Gasification can also decrease emission levels compared to power production with direct combustion and a steam cycle.
- **pyrolysis** Pyrolysis is a process whereby biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose. The products of pyrolysis always include gas ('biogas'), liquid ('bio-oil') and solid ('char'), with the relative proportions of each depending on the fuel characteristics, the method of pyrolysis and the reaction parameters, such as temperature and pressure. Lower temperatures produce more solid and liquid products and higher temperatures more biogas.

biological systems

These processes are suitable for very wet biomass materials such as food or agricultural wastes, including slurry.

- **anaerobic digestion** Anaerobic digestion means the breakdown of organic waste by bacteria in an oxygen-free environment. This produces a biogas typically made up of 65% methane and 35% carbon dioxide. Purified biogas can then be used both for heating or electricity generation.
- **fermentation** Fermentation is the process by which plants of high sugar and starch content are broken down with the help of micro-organisms to produce ethanol and methanol. The end product is a combustible fuel that can be used in vehicles.

Biomass power station capacities typically range up to 15 MW, but larger plants are possible of up to 400 MW capacity, with part of the fuel input potentially being fossil fuel, for example pulverised coal. The world's largest biomass fuelled power plant is located at Pietarsaari in Finland. Built in 2001, this is an industrial CHP plant producing steam (100 MWth) and electricity (240 MWe) for the local forest industry and district heat for the nearby town. The boiler is a circulating fluidised bed boiler designed to generate steam from bark, sawdust, wood residues, commercial bio fuel and peat.

A 2005 study commissioned by Greenpeace Netherlands concluded that it was technically possible to build and operate a 1,000 MWe biomass fired power plant using fluidised bed combustion technology and fed with wood residue pellets.¹⁶

reference

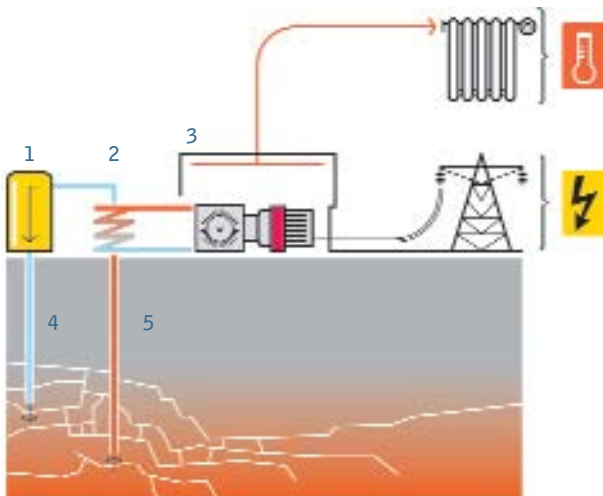
16 OPPORTUNITIES FOR 1,000 MWE BIOMASS-FIRED POWER PLANT IN THE NETHERLANDS", GREENPEACE NETHERLANDS, MARCH 2005

geothermal energy

Geothermal energy is heat derived from deep underneath the earth's crust. In most areas, this heat reaches the surface in a very diffuse state. However, due to a variety of geological processes, some areas, including the western part of the USA, west and central eastern Europe, Iceland, Asia and New Zealand are underlain by relatively shallow geothermal resources. These are classified as low temperature (less than 90°C), moderate temperature (90° - 150°C) and high temperature (greater than 150°C). The uses to which these resources can be put depends on the temperature. The highest temperature is generally used only for electric power generation. Current global geothermal generation capacity totals approximately 8,000 MW. Uses for low and moderate temperature resources can be divided into two categories: direct use and ground-source heat pumps.

Geothermal power plants use the earth's natural heat to vapourise water or an organic medium. The steam created powers a turbine which produces electricity. In New Zealand and Iceland, this technique has been used extensively for decades. In Germany, where it is necessary to drill many kilometres down to reach the necessary temperatures, it is only in the trial stages. Geothermal heat plants require lower temperatures and the heated water is used directly.

figure 38: geothermal technology



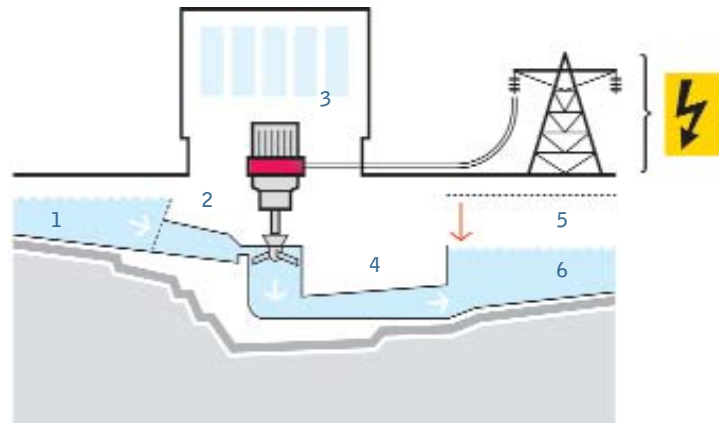
1. PUMP
2. HEAT EXCHANGER
3. GAS TURBINE & GENERATOR
4. DRILLING HOLE FOR COLD WATER INJECTION
5. DRILLING HOLE FOR WARM WATER EXTRACTION

hydro power

Water has been used to produce electricity for about a century. Today, around one fifth of the world's electricity is produced from hydro power. Large unsustainable hydroelectric power plants with concrete dams and extensive collecting lakes often have very negative effects on the environment, however, requiring the flooding of habitable areas. Smaller 'run-of-the-river' power stations, which are turbines powered by one section of running water in a river, can produce electricity in an environmentally friendly way.

The main requirement for hydro power is to create an artificial head so that water, diverted through an intake channel or pipe into a turbine, discharges back into the river downstream. Small hydro power is mainly 'run-of-the-river' and does not collect significant amounts of stored water, requiring the construction of large dams and reservoirs. There are two broad categories of turbines: impulse turbines (notably the Pelton) in which a jet of water impinges on the runner designed to reverse the direction of the jet and thereby extract momentum from the water. This turbine is suitable for high heads and 'small' discharges. Reaction turbines (notably Francis and Kaplan) run full of water and in effect generate hydrodynamic 'lift' forces to propel the runner blades. These turbines are suitable for medium to low heads, and medium to large discharges.

figure 39: hydro technology



1. INLET
2. SIEVE
3. GENERATOR
4. TURBINE
5. HEAD
6. OUTLET

ocean energy

tidal power

Tidal power can be harnessed by constructing a dam or barrage across an estuary or bay with a tidal range of at least 5 metres. Gates in the barrage allow the incoming tide to build up in a basin behind it. The gates then close so that when the tide flows out the water can be channelled through turbines to generate electricity. Tidal barrages have been built across estuaries in France, Canada and China but a mixture of high cost projections coupled with environmental objections to the effect on estuarial habitats has limited the technology's further expansion.

wave and tidal stream power

In wave power generation, a structure interacts with the incoming waves, converting this energy to electricity through a hydraulic, mechanical or pneumatic power take-off system. The structure is kept in position by a mooring system or placed directly on the seabed/seashore. Power is transmitted to the seabed by a flexible submerged electrical cable and to shore by a sub-sea cable.

Wave power converters can be made up from connected groups of smaller generator units of 100 – 500 kW, or several mechanical or hydraulically interconnected modules can supply a single larger turbine generator unit of 2 – 20 MW. The large waves needed to make the technology more cost effective are mostly found at great distances from the shore, however, requiring costly sub-sea cables to transmit the power. The converters themselves also take up large amounts of space. Wave power has the advantage of providing a more predictable supply than wind energy and can be located in the ocean without much visual intrusion.

There is no commercially leading technology on wave power conversion at present. Different systems are being developed at sea for prototype testing. These include a 50 kW PowerBuoy floating buoy device installed in Hawaii, a 750 kW Pelamis device, with linked semi-submerged cylindrical sections, operating in Scotland, a 300 kW underwater tidal current turbine operating in south-west England, a 150 kW seabed-mounted Stingray, also using tidal currents, and a 500 kW coastline wave energy generator operating on the island of Islay, Scotland. Most development work has been carried out in the UK.

energy efficiency

Energy efficiency often has multiple positive effects. For example, an efficient clothes washing machine or dishwasher uses less power and less water. Efficiency also usually provides a higher level of comfort. For example, a well-insulated house will feel warmer in the winter, cooler in the summer and be healthier to live in. An efficient refrigerator will make less noise, have no frost inside, no condensation outside and will probably last longer. Efficient lighting will offer you more light where you need it. Efficiency is thus really: 'more with less'.

Efficiency has an enormous potential. There are very simple steps a householder can take, such as putting additional insulation in the roof, using super-insulating glazing or buying a high-efficiency washing machine when the old one wears out. All of these examples will save both money and energy. But the biggest savings will not be found in such incremental steps. The real gains come from rethinking the whole concept, e.g. 'the whole house', 'the whole car' or even 'the whole transport system'. When you do this, surprisingly often energy needs can be cut back by four to ten times what is needed today.

Take the example of a house: by insulating the whole outer shell (from roof to basement) properly, which requires an additional investment, the demand for heat will be so low that you can install a smaller and cheaper heating system – offsetting the cost of the extra insulation. The result is a house that only needs one third of the energy without being any more expensive to build. By insulating even further and installing a high efficiency ventilation system, heating demand is reduced to one tenth. Thousands of these super-efficient houses have been successfully built in Europe over the last ten years. This is no dream for the future, but part of everyday life.

Here is another example: imagine you are the manager of an office. Throughout the hot summer months, air-conditioning pumps cold air on your staff's shoulders to keep them productive. As this is fairly expensive, you could ask a clever engineer to improve the efficiency of the cooling pumps. But why not take a step back instead and look at the whole system. If we first improve the building to keep the sun from heating the office like an oven, then install more energy-efficient computers, copiers and lights (which save electricity and generate less heat), and then install passive cooling systems such as ventilation at night – you may well find that the air-conditioning system is no longer necessary. Then, of course, if the building had been properly planned and built, you would not have bought the air-conditioner in the first place.



electricity

There is a huge potential to save electricity in a relatively short period of time. By simply switching off the standby mode and changing to energy efficient light bulbs, consumers would save electricity and money in every household. If the majority of households did this, several large power plants could be switched off almost immediately. The following table provides a brief overview of medium-term measures for industry and household appliances:

table 13: examples of electricity saving potential

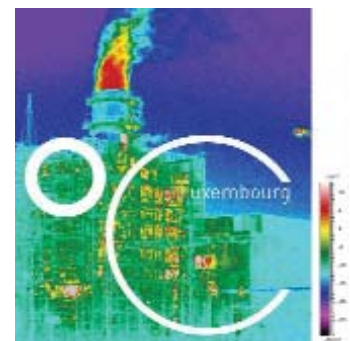
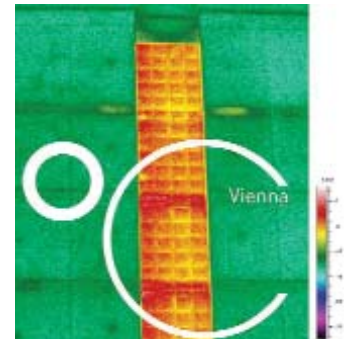
SECTOR	EFFICIENCY MEASURE	ELECTRICITY SAVINGS
Industry	Efficient motor systems	30-40%
	Higher aluminium recycling rate	35-45%
Other sectors	Efficient household appliances	30-80%
	Efficient office appliances	50-75%
	Efficient cooling systems	30-60%
	Efficient lighting	30-50%
	Reduced stand by losses	50-70%
	Reduced electricity use during non-office hours	up to 90%

source ECOFYS 2006, GLOBAL ENERGY DEMAND SCENARIOS

heating

Insulation and thermal design can dramatically reduce heat loss and help stop climate change. Energy demand for heating in existing buildings can be reduced on average by 30-50%. In new buildings it can be reduced by 90-95% using widely available and competitive technology and design.

Heat losses can be easily detected with thermographic photos (see example below). A thermographic camera shows details the eye cannot detect. Parts of the building that have a higher surface temperature than the rest appear in yellow and red. This means that in these areas heat is leaking through gaps and poor insulating materials, and valuable energy is being lost. This results both in damage to the environment through a waste of energy resources and to unnecessary costs for home owners and tenants. Typical weak points are window panes and frames and thin walls below windows, where radiators are commonly positioned and insulation should be optimal.



images 1. VIENNA AM SCHÖPFWERK RESIDENTIAL ESTATE. AS WELL AS LOSSES OF HEAT ENERGY THROUGH THE WINDOWS THERE ARE DIVERSE HEAT BRIDGES IN THE FABRIC OF THE BUILDING. **2.** LUXEMBOURG TWINERG GAS POWER PLANT. THE PLUME OF WASTE GAS IS NORMALLY NOT VISIBLE. THE THERMOGRAM SHOWS THE WASTE OF ENERGY THROUGH THE CHIMNEY.

energy efficiency in the energy [r]evolution Scenario

A range of options has been considered in this study for reducing the demand for energy in the period up to 2050. The analysis focuses on best practice technologies. The scenario assumes continuous innovation in the field of energy efficiency, so that best practice technologies keep improving. The table below shows those which have been applied in the three sectors – industry, transport and households/services. A few examples are elaborated here.

table 14: energy efficiency measures

SECTOR	REDUCTION OPTION
Industry	
General	Efficient motor systems
General	Heat integration/pinch analysis
General	Improved process control
Aluminium	Increase secondary aluminium
Iron and steel	Blast furnace - coal injection
Iron and steel	BOF (Basic Oxygen Furnace) gas + heat recovery
Iron and steel	Thin slab casting
Chemical industry	Membrane product separation
Transport	
Passenger cars	Efficient passenger cars (hybrid fuel)
Freight	Efficient freight vehicles
Buses	Efficient buses
Others	
Households & services	Efficient electric appliances
Services	Efficient cooling equipment
Households & services	Efficient lighting
Households & services	Reduce stand-by losses
Households & services	Improved heat insulation
Services	Reduce electricity use during non-office hours
Agriculture & non-specified others	Energy efficiency improvement

industry

Approximately 65% of electricity consumption by industry is used to drive electric motor systems. This can be reduced by employing variable speed drives, high efficiency motors and using efficient pumps, compressors and fans. The savings potential is up to 40%.

The production of primary aluminium from alumina (which is made out of bauxite) is a very energy-intensive process. It is produced by passing a direct current through a bath with alumina dissolved in a molten cryolite electrode. Another option is to produce aluminium out of recycled scrap. This is called secondary production. Secondary aluminium uses only 5 to 10% of the energy demand for primary production because it involves remelting the metal instead of an electrochemical reduction process. If recycling increases from 22% of aluminium production in 2005 to 60% in 2050 this would save 45% of current electricity use.

transport

Use of hybrid vehicles (electric/combustion) and other efficiency measures could reduce energy consumption in passenger cars by up to 80% in 2050.

households/services

Energy use by household appliances such as washing machines, dishwashers, TVs and refrigerators can be reduced by 30% using the best available options and by 80% with advanced technologies. Energy use by office appliances can be reduced by 50-75% through a combination of power management and energy efficient computer systems.

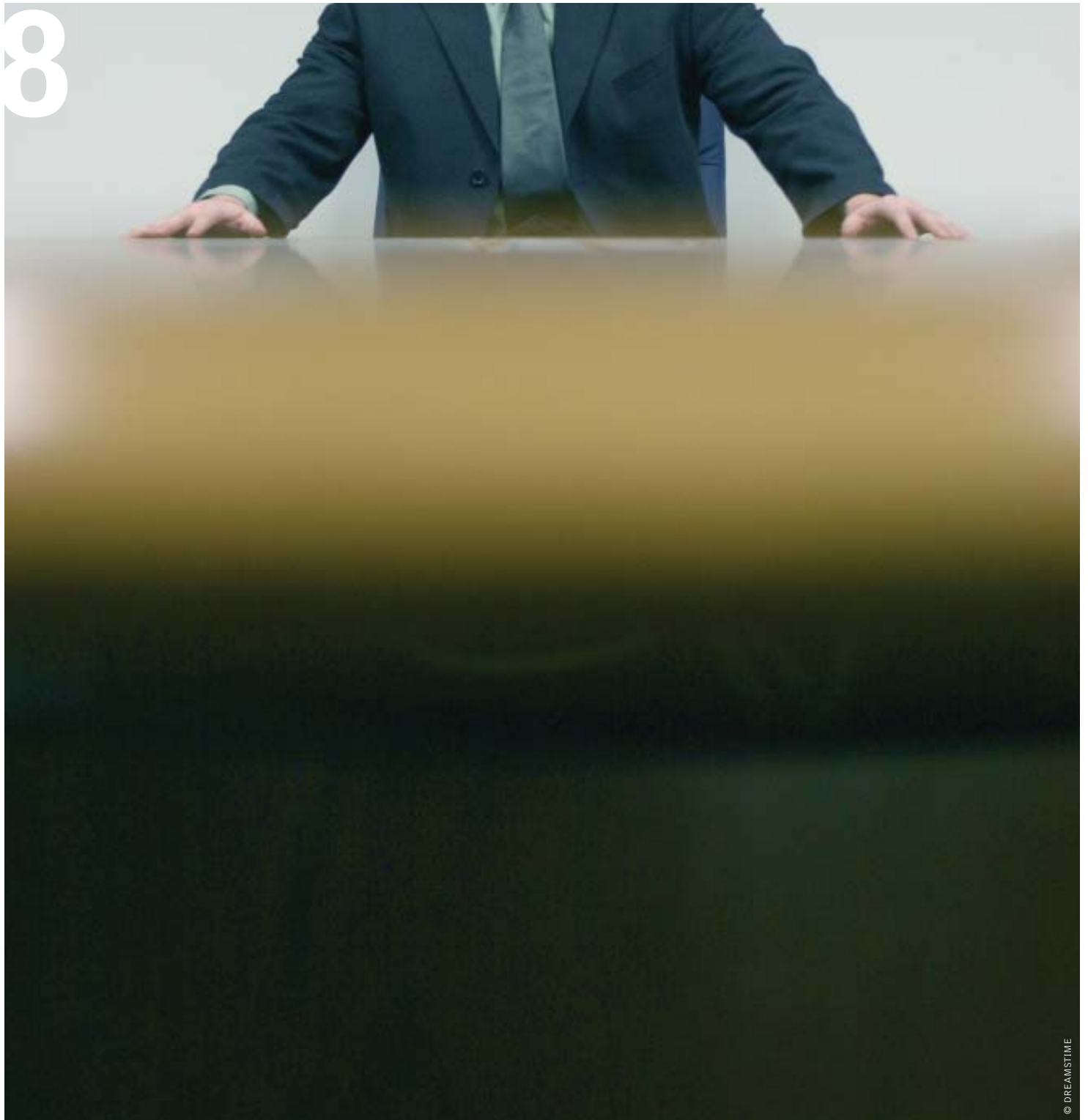
Use of stand-by mode for appliances is on average responsible for 5-13% of electricity use by households in OECD countries. Replacement of existing appliances by those with the lowest losses would reduce standby power consumption by 70%.

Better building design and effective heat insulation could save up to 80% of the average heat demand for buildings.

policy recommendations

"...CONTRIBUTE TO SUSTAINABLE ECONOMIC GROWTH, HIGH QUALITY JOBS, TECHNOLOGY DEVELOPMENT, GLOBAL COMPETITIVENESS AND INDUSTRIAL AND RESEARCH LEADERSHIP."

8



At a time when governments around the world are in the process of liberalising their electricity markets, the increasing competitiveness of renewable energy should lead to higher demand. Without political support, however, renewable energy remains at a disadvantage, marginalised by distortions in the world's electricity markets created by decades of massive financial, political and structural support to conventional technologies and the failure to internalise environmental and social costs in price of energy. Developing renewables will therefore require strong political and economic efforts, especially through laws that guarantee stable tariffs over a period of up to 20 years.

At present new renewable energy generators have to compete with old nuclear and fossil fuelled power stations which produce electricity at marginal costs because consumers and taxpayers have already paid the interest and depreciation on the original investments. Political action is needed to overcome these distortions and create a level playing field.

The following is an overview of current political frameworks and barriers that need to be overcome in order to unlock renewable energy's great potential to become a major contributor to global energy supply. In the process it would also contribute to sustainable economic growth, high quality jobs, technology development, global competitiveness and industrial and research leadership.

renewable energy targets

In recent years, as part of their greenhouse gas reduction policies as well as for increasing security of energy supply, an increasing number of countries have established targets for renewable energy. These are either expressed in terms of installed capacity or as a percentage of energy consumption. Although these targets are not often legally binding, they have served as an important catalyst for increasing the share of renewable energy throughout the world, from Europe to the Far East to the USA.

A time horizon of just a few years is not long enough in the electricity sector where the investment horizon can be up to 40 years. Renewable energy targets therefore need to have short, medium and long term steps and must be legally binding in order to be effective. They should also be supported by mechanisms such as the "feed-in tariff". In order for the proportion of renewable energy to increase significantly, targets must be set in accordance with the local potential for each technology (wind, solar, biomass etc) and according to the local infrastructure, both existing and planned.

In recent years the wind and solar power industries have shown that it is possible to maintain a growth rate of 30 to 35% in the renewables sector. In conjunction with the European Photovoltaic Industry Association, the European Solar Thermal Power Industry Association and the European Wind Energy Association¹⁷, Greenpeace and EREC have documented the development of those industries from 1990 onwards and outlined a prognosis for growth up to 2020.

reference

17 SOLAR GENERATION (EPIA), CONCENTRATED SOLAR THERMAL POWER - NOW! (GREENPEACE), WINDFORCE 12 (EWEA), GLOBAL WIND ENERGY OUTLOOK 2006, GWEC



demands for the energy sector

Greenpeace and the renewables industry have a clear agenda for changes that need to be made in energy policy to encourage a shift to renewable sources. The main demands are:

- Phase out all subsidies for fossil and nuclear energy and internalise external costs
- Establish legally binding targets for renewable energy
- Provide defined and stable returns for investors
- Guarantee priority access to the grid for renewable power generators
- Strict efficiency standards for all energy consuming appliances, buildings and vehicles

Conventional energy sources receive an estimated \$250-300 billion¹⁸ in subsidies per year worldwide, resulting in heavily distorted markets. The Worldwatch Institute estimates that total world coal subsidies are \$63 billion, whilst in Germany alone the total is \$21 billion, including direct support of more than \$85,000 per miner. Subsidies artificially reduce the price of power, keep renewable energy out of the market place and prop up non-competitive technologies and fuels. Eliminating direct and indirect subsidies to fossil fuels and nuclear power would help move us towards a level playing field across the energy sector. The 2001 report of the G8 Renewable Energy Task Force argued that “re-addressing them [subsidies] and making even a minor re-direction of these considerable financial flows toward renewables, provides an opportunity to bring consistency to new public goals and to include social and environmental costs in prices.” The Task Force recommended that “G8 countries should take steps to remove incentives and other supports for environmentally harmful energy technologies, and develop and implement market-based mechanisms that address externalities, enabling renewable energy technologies to compete in the market on a more equal and fairer basis.”

Renewable energy would not need special provisions if markets were not distorted by the fact that it is still virtually free for electricity producers (as well as the energy sector as a whole) to pollute. Subsidies to fully mature and polluting technologies are highly unproductive. Removing subsidies from conventional electricity would not only save taxpayers’ money. It would also dramatically reduce the need for renewable energy support.

This is a fuller description of what needs to be done to eliminate or compensate for current distortions in the energy market.

1. removal of energy market distortions

A major barrier preventing renewable energy from reaching its full potential is the lack of pricing structures in the energy markets that reflect the full costs to society of producing energy. For more than a century, power generation was characterised by national monopolies with mandates to finance investments in new production capacity through state subsidies and/or levies on electricity bills. As many countries are moving in the direction of more liberalised electricity markets, these options are no longer available, which puts new generating technologies, such as wind power, at a competitive disadvantage relative to existing technologies. This situation requires a number of responses.

internalisation of the social and environmental costs of polluting energy

The real cost of energy production by conventional energy includes expenses absorbed by society, such as health impacts and local and regional environmental degradation - from mercury pollution to acid rain – as well as the global negative impacts from climate change. Hidden costs include the waiving of nuclear accident insurance that is too expensive to be covered by the nuclear power plant operators. The Price- Anderson Act, for instance, limits the liability of US nuclear power plants in the case of an accident to an amount of up to US\$ 98 million per plant, and only 15 million per year per plant, with the rest being drawn from an industry fund for up to US\$ 10 billion – an after that taxpayer pays¹⁹. Environmental damage should as a priority be rectified at source. Translated into energy generation that would mean that, ideally, production of energy should not pollute and that it is the energy producers’ responsibility to prevent it. If they do pollute they should pay an amount equal to the damage the production causes to society as a whole. The environmental impacts of electricity generation can be difficult to quantify, however. How do we put a price on lost homes on Pacific Islands as a result of melting icecaps or on deteriorating health and human lives?

An ambitious project, funded by the European Commission - ExternE – has tried to quantify the true costs, including the environmental costs, of electricity generation. It estimates that the cost of producing electricity from coal or oil would double and that from gas would increase by 30% if external costs, in the form of damage to the environment and health, were taken into account. If those environmental costs were levied on electricity generation according to their impact, many renewable energy sources would not need any support. If, at the same time, direct and indirect subsidies to fossil fuels and nuclear power were removed, the need to support renewable electricity generation would seriously diminish or cease to exist.

reference

18 UNDP REPORT

19 [HTTP://EN.WIKIPEDIA.ORG/WIKI/PRICE-ANDERSON_NUCLEAR_INDUSTRIES_INDEMNITY_ACT](http://en.wikipedia.org/wiki/Price-Anderson_nuclear_industries_indemnity_act)

introduce the “polluter pays” principle

As with the other subsidies, external costs must be factored into energy pricing if the market is to be truly competitive. This requires that governments apply a “polluter pays” system that charges the emitters accordingly, or applies suitable compensation to non-emitters. Adoption of polluter pays taxation to electricity sources, or equivalent compensation to renewable energy sources, and exclusion of renewables from environment-related energy taxation, is essential to achieve fairer competition in the world’s electricity markets.

2. electricity market reform

Renewable energy technologies could already be competitive if they had received the same attention as other sources in terms of R&D funding and subsidies, and if external costs were reflected in power prices. Essential reforms in the electricity sector are necessary if new renewable energy technologies are to be accepted on a larger scale. These reforms include:

removal of electricity sector barriers

Complex licensing procedures and bureaucratic hurdles constitute one of the most difficult obstacles faced by renewable energy projects in many countries. A clear timetable for approving projects should be set for all administrations at all levels. Priority should be given to renewable energy projects. Governments should propose more detailed procedural guidelines to strengthen the existing legislation and at the same time streamline the licensing procedure for renewable energy projects.

A major barrier is the short to medium term surplus of electricity generating capacity in many OECD countries. Due to over-capacity it is still cheaper to burn more coal or gas in an existing power plant than to build, finance and depreciate a new renewable power plant. The effect is that, even in those situations where a new technology would be fully competitive with new coal or gas fired power plants, the investment will not be made. Until we reach a situation where electricity prices start reflecting the cost of investing in new capacity rather than the marginal cost of existing capacity, support for renewables will still be required to level the playing field.

Other barriers include the lack of long term planning at national, regional and local level; lack of integrated resource planning; lack of integrated grid planning and management; lack of predictability and stability in the markets; no legal framework for international bodies of water; grid ownership by vertically integrated companies and a lack of long-term R&D funding.

There is also a complete absence of grids for large scale renewable energy sources, such as offshore wind power or concentrating solar power (CSP) plants; weak or non-existent grids onshore; little recognition of the economic benefits of embedded/distributed generation; and discriminatory requirements from utilities for grid access that do not reflect the nature of the renewable technology.

The reforms needed to address market barriers to renewables include:

- Streamlined and uniform planning procedures and permitting systems and integrated least cost network planning;
- Fair access to the grid at fair, transparent prices and removal of discriminatory access and transmission tariffs;
- Fair and transparent pricing for power throughout a network, with recognition and remuneration for the benefits of embedded generation;
- Unbundling of utilities into separate generation and distribution companies;
- The costs of grid infrastructure development and reinforcement must be carried by the grid management authority rather than individual renewable energy projects;
- Disclosure of fuel mix and environmental impact to end users to enable consumers to make an informed choice of power source.

priority grid access

Rules on grid access, transmission and cost sharing are very often inadequate. Legislation must be clear, especially concerning cost distribution and transmission fees. Renewable energy generators should be guaranteed priority access. Where necessary, grid extension or reinforcement costs should be borne by the grid operators, and shared between all consumers, because the environmental benefits of renewables are a public good and system operation is a natural monopoly.

support mechanisms for renewables

The following section provides an overview of the existing support mechanisms and experiences of their operation. Support mechanisms remain a second best solution for correcting market failures in the electricity sector. However, introducing them is a practical political solution to acknowledge that, in the short term, there are no other practical ways to apply the polluter pays principle.

Overall, there are broadly speaking two types of incentive to promote deployment of renewable electricity. Others exist for renewable heating, but the experiences in this sector are unfortunately not as long as in the electricity sector. These are Fixed Price Systems where the government dictates the electricity price (or premium) paid to the producer and lets the market determine the quantity, and Renewable Quota Systems (in the USA referred to as Renewable Portfolio Standards) where the government dictates the quantity of renewable electricity and leaves it to the market to determine the price. Both systems create a protected market against a background of subsidised, depreciated conventional generators whose external environmental costs are not accounted for. Their aim is to provide incentives for technology improvements and cost reductions, leading to cheaper renewables that can compete with conventional sources in the future.



The main difference between quota based and price based systems is that the former aims to introduce competition between electricity producers. However, competition between technology manufacturers, which is the most crucial factor in bringing down electricity production costs, is present regardless of whether government dictates prices or quantities. Prices paid to wind power producers are currently higher in many European quota based systems (UK, Belgium, Italy) than in fixed price or premium systems (Germany, Spain, Denmark).

fixed price systems

Fixed price systems include investment subsidies, fixed feed-in tariffs, fixed premium systems and tax credits.

investment subsidies are capital payments usually made on the basis of the rated power (in kW) of the generator. It is generally acknowledged, however, that systems which base the amount of support on generator size rather than electricity output can lead to less efficient technology development. There is therefore a global trend away from these payments, although they can be effective when combined with other incentives.

fixed feed-in tariffs (FITs), widely adopted in Europe, have proved extremely successful in expanding wind energy in Germany, Spain and Denmark. Operators are paid a fixed price for every kWh of electricity they feed into the grid. In Germany the price paid varies according to the relative maturity of the particular technology and reduces each year to reflect falling costs. The additional cost of the system is borne by taxpayers or electricity consumers.

The main benefit of a FIT is that it is administratively simple and encourages better planning. Although the FIT is not associated with a formal Power Purchase Agreement, distribution companies are usually obliged to purchase all the production from renewable installations. Germany has reduced the political risk of the system being changed by guaranteeing payments for 20 years. The main problem associated with a fixed price system is that it does not lend itself easily to adjustment – whether up or down - to reflect changes in the production costs of renewable technologies.

fixed premium systems, sometimes called an “environmental bonus” mechanism, operate by adding a fixed premium to the basic wholesale electricity price. From an investor perspective, the total price received per kWh is less predictable than under a feed-in tariff because it depends on a constantly changing electricity price. From a market perspective, however, it is argued that a fixed premium is easier to integrate into the overall electricity market because those involved will be reacting to market price signals. Spain is the most prominent country to have adopted a fixed premium system.

tax credits, as operated in the US and Canada, offer a credit against tax payments for every kWh produced. In the United States the market has been driven by a federal Production Tax Credit (PTC) of approximately 1.8 cents per kWh. It is adjusted annually for inflation.

renewable quota systems

Two types of renewable quota systems have been employed - tendering systems and green certificate systems.

tendering systems involve competitive bidding for contracts to construct and operate a particular project, or a fixed quantity of renewable capacity in a country or state. Although other factors are usually taken into account, the lowest priced bid invariably wins. This system has been used to promote wind power in Ireland, France, the UK, Denmark and China.

The downside is that investors can bid an uneconomically low price in order to win the contract, and then not build the project. Under the UK's NFFO (Non-Fossil Fuel Obligation) tender system, for example, many contracts remained unused. It was eventually abandoned. If properly designed, however, with long contracts, a clear link to planning consent and a possible minimum price, tendering for large scale projects could be effective, as it has been for offshore oil and gas extraction in Europe's North Sea.

tradable green certificate (TGC) systems operate by offering “green certificates” for every kWh generated by a renewable producer. The value of these certificates, which can be traded on a market, is then added to the value of the basic electricity. A green certificate system usually operates in combination with a rising quota of renewable electricity generation. Power companies are bound by law to purchase an increasing proportion of renewable input. Countries which have adopted this system include the UK, Sweden and Italy in Europe and many individual states in the US, where it is known as a Renewable Portfolio Standard.

Compared with a fixed tender price, the TGC model is more risky for the investor, because the price fluctuates on a daily basis, unless effective markets for long-term certificate (and electricity) contracts are developed. Such markets do not currently exist. The system is also more complex than other payment mechanisms.

Which one out of this range of incentive systems works best? Based on past experience it is clear that policies based on fixed tariffs and premiums can be designed to work effectively. However, introducing them is not a guarantee for success. Almost all countries with experience in mechanisms to support renewables have, at some point in time, used feed-in tariffs, but not all have contributed to an increase in renewable electricity production. It is the design of a mechanism, in combination with other measures, that determines its success.

It is too early to draw final conclusions on the potential impacts of the full range of policy options available since more complex systems, such as those based on tradable green certificates, are still at an experimental phase. More time and experience are needed to draw credible conclusions on their ability to attract investments and deliver new capacity. The choice of framework at a national level also depends on the culture and history of the individual countries, the stage of development for renewables and the political will to produce results.

appendix

BREAKDOWN OF THE GLOBAL ENERGY SCENARIO BY WORLD REGION

OECD north america

development of energy demand

population: The population of OECD North America will increase from 425 million now to 585 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 2.1% per year, leading to a fivefold increase by 2050. Per capita GDP will remain one of the highest in the world, almost triple the global average.

energy intensity: Under the reference scenario, energy intensity will reduce by 1.1% per year, leading to a reduction in final energy demand per unit of GDP of about 40% between 2003 and 2050. Under the energy [R]evolution scenario, energy intensity will fall by 70%.

final energy demand: Under the reference scenario, energy demand will increase by more than 60% from the current 70,000 PJ/a to 114,000 PJ/a in 2050. Under the energy [R]evolution scenario, there will be a steady decrease to 56,000 PJ/a in 2050, half of projected consumption under the reference scenario.

electricity demand: Under the energy [R]evolution scenario, efficiency measures will result in electricity demand of about 3,400 TWh/a by 2050. Compared to the reference scenario, this would avoid the generation of 4,400 TWh/a.

heat demand: Under the energy [R]evolution scenario, a steep decline in demand for heating will mean that, compared to the reference scenario, the consumption of 15,000 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [R]evolution scenario, renewable energy sources will cover almost 50% of primary energy demand by 2050, an increase from 6% now.

electricity generation: Under the energy [R]evolution scenario, renewables will generate about 80% of electricity supply by 2050, an increase from 16% now. Growing from the current output of 195 GW, a renewable generating capacity of 1,150 GW will by then produce 23,700 TWh/a.

heat supply: Under the energy [R]evolution scenario, renewables will satisfy 60% of heating supply by 2050, an increase from 9% now. The CHP share will be more than 20%.

development of CO₂ emissions

CO₂ emissions will increase by 40% up to 2050 under the reference scenario. Under the energy [R]evolution scenario they will decrease from 6,600 million tonnes to 1,800 million tonnes. Annual per capita emissions will drop from 15.6 t to 3.0 t.

future costs of electricity generation

The growth in renewables under the energy [R]evolution scenario will increase the costs of electricity generation compared to the reference scenario by around 0.4 cents/kWh in 2020 up to 1.8 cents/kWh in 2050.

latin america

development of energy demand

population: The population of Latin America will grow slowly compared to other developing regions, increasing to 630 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 2.9% per year, leading to a quadrupling by 2050. Per capita GDP will still be below the world average and just one third of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 0.4% per year, leading to a reduction in final energy demand per unit of GDP of about 20% between 2003 and 2050. Under the energy [R]evolution scenario, energy intensity will fall by more than 50%.

final energy demand: Under the reference scenario, energy demand will more than triple from the current 14,000 PJ/a to 45,000 PJ/a in 2050. Under the energy [R]evolution scenario, there will be a much slower increase to 25,000 PJ/a in 2050, just over half of projected consumption under the reference scenario.

electricity demand: Under the energy [R]evolution scenario, energy efficiency measures will result in electricity demand of about 1,900 TWh/a by 2050. Compared to the reference scenario this will avoid the generation of 1,400 TWh/a.

heat demand: Under the energy [R]evolution scenario, demand for heating will remain relatively stable. Compared to the reference scenario, the consumption of 6,800 PJ/a will still be avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [R]evolution scenario, renewable energy sources will cover 65% of primary energy demand by 2050, an increase from 27% now.

electricity generation: Under the energy [R]evolution scenario, renewables will generate 90% of electricity supply by 2050, an increase from 70% now. Growing from a current output of 130 GW, a renewable generating capacity of 660 GW will by then produce 2,070 TWh/a.

heat supply: Under the energy [R]evolution scenario, renewables will satisfy 70% of heating supply by 2050, an increase from 36% now.

development of CO₂ emissions

CO₂ emissions will increase by a factor of four up to 2050 under the reference scenario. Under the energy [R]evolution scenario they will decrease from 800 million tonnes to 440 million tonnes. Annual per capita emissions will drop from 1.8 t to 0.7 t. Whereas today the power sector is the largest source of CO₂ emissions, it will contribute less than 15% of the total in 2050.

future costs of electricity generation

The growth in renewables under the energy [R]evolution scenario will decrease the costs of electricity generation compared to the reference scenario by around 1.5 cents/kWh in 2020 and up to 3.5 cents/kWh by 2050.



OECD europe

development of energy demand

population: The population of OECD Europe will peak at almost 550 million in about 2030. After that it will decrease to 510 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 1.7% per year, leading to a tripling by 2050. Per capita GDP will remain one of the highest in the world, more than double the global average.

energy intensity: Under the reference scenario, energy intensity will reduce by 1.1% per year, leading to a reduction in final energy demand per unit of GDP of about 40% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by almost 75%.

final energy demand: Under the reference scenario, energy demand will increase by more than 30% from the current 50,000 PJ/a to 68,000 PJ/a in 2050. Under the energy [r]evolution scenario, there will be a steady decrease to 41,000 PJ/a in 2050, two thirds of projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, electricity demand is expected to increase up to 2040, then fall to about 3,300 TWh/a by 2050. Compared to the reference scenario, efficiency measures therefore avoid the generation of 1,100 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be almost halved. Compared to the reference scenario, the consumption of 13,000 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover 50% of primary energy demand by 2050, an increase from 7% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 80% of electricity supply by 2050, an increase from 18% now. Growing from a current output of 160 GW, a renewable generating capacity of 865 GW will by then produce 2,500 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 50% of heating supply by 2050, an increase from 10% now. The CHP share will be more than 20%.

development of CO₂ emissions

CO₂ emissions will increase by one third up to 2050 under the reference scenario. Under the energy [r]evolution scenario they will decrease from 3,900 million tonnes to 1,200 million tonnes. Annual per capita emissions will drop from 7.4 t to 2.3 t.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will increase the costs of electricity generation compared to the reference scenario by around 0.5 cents/kWh between 2010 and 2030. Because of lower CO₂ intensity, costs will then start to decrease, falling by 2050 to 0.7 cents/kWh below those in the reference scenario.

africa

development of energy demand

population: The population of Africa will triple to 1,840 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 3.6% per year. By 2050 it will have increased fivefold. Per capita GDP will still only be a tenth of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 1% per year, leading to a reduction in final energy demand per unit of GDP of about 40% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall even further.

final energy demand: Under the reference scenario, energy demand will triple from the current 17,000 PJ/a to 54,000 PJ/a in 2050. Under the energy [r]evolution scenario, demand will grow much slower to reach 35,000 PJ/a by 2050, double today's figure but one third less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 2,000 TWh/a by 2050. Compared to the reference scenario, this will avoid the generation of 1,100 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be reduced. Compared to the reference scenario, the consumption of 8,600 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover 60% of primary energy demand by 2050, an increase from 47% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 55% of electricity supply by 2050, an increase from 17% now. Growing from a current output of 25 GW, a renewable generating capacity of 480 GW will by then produce 1,500 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 88% of heating supply by 2050, an increase from 78% now. Traditional biomass will be replaced by more efficient modern technologies.

development of CO₂ emissions

Whilst CO₂ emissions will increase "by a factor five" under the reference scenario, under the energy [r]evolution scenario they will be restricted to a 60% increase from their 2003 level of 750 million tonnes to 1,100 million tonnes by 2050. Annual per capita emissions will fall from 0.9 t to 0.6 t. Whilst the power sector will still the largest source of CO₂ emissions in 2050, it will also register the largest reduction.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will decrease costs compared to the reference scenario by 2 cents/kWh in 2020 and by about 3 cents/kWh in 2050.

appendix - *continued*

BREAKDOWN OF THE GLOBAL ENERGY SCENARIO BY WORLD REGION

middle east

development of energy demand

population: The population of the Middle East will double to 350 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 2.6% per year. By 2050 it will have increased by a factor of four. Per capita GDP will still only be a fifth of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 0.9% per year, leading to a reduction in final energy demand per unit of GDP of about 50% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by almost 60%.

final energy demand: Under the reference scenario, energy demand will more than double from the current 11,000 PJ/a to 25,000 PJ/a in 2050. Under the energy [r]evolution scenario, demand will grow much slower, to reach 15,000 PJ/a by 2050, a third more than today but 40% less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 1,000 TWh/a by 2050. Compared to the reference scenario, this will avoid the generation of 500 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be reduced. Compared to the reference scenario, the consumption of 4,700 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover 50% of primary energy demand by 2050, an increase from 1% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 86% of electricity supply by 2050, an increase from 3% now. Growing from a current output of 7 GW, a renewable generating capacity of 450 GW will by then produce 1,400 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 67% of heating supply by 2050, an increase from 1% now.

development of CO₂ emissions

Whilst CO₂ emissions will double under the reference scenario, under the energy [r]evolution scenario they will decrease from their 2003 level of 1,000 million tonnes to 480 million tonnes by 2050. Annual per capita emissions will fall from 5.5 t to 1.4 t. Whilst the power sector is now the largest source of CO₂ emissions, it will only account for only a fifth in 2050.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will decrease costs compared to the reference scenario by 1 cent/kWh in 2020 and by about 9 cents/kWh in 2050.

transition economies

development of energy demand

population: The population of the Transition Economies will reduce from 345 million now to 285 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 3.2% per year. By 2050 it will have increased by a factor of five. Per capita GDP will be about half of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 1.8% per year, leading to a reduction in final energy demand per unit of GDP of about 60% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by almost 80%.

final energy demand: Under the reference scenario, energy demand will more than double from the current 27,000 PJ/a to 51,000 PJ/a in 2050. Under the energy [r]evolution scenario, demand is expected to remain stable at current levels up to 2050, 50% less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 1,900 TWh/a by 2050. Compared to the reference scenario, this will avoid the generation of 640 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be reduced. Compared to the reference scenario, the consumption of 13,600 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover 60% of primary energy demand by 2050, an increase from 4% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 80% of electricity supply by 2050, an increase from 18% now. Growing from a current output of 90 GW, a renewable generating capacity of 635 GW will by then produce 1,900 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 60% of heating supply by 2050, an increase from 3% now. The CHP share will be more than 20%.

development of CO₂ emissions

While CO₂ emissions will increase by one third under the reference scenario, under the energy [r]evolution scenario they will decrease from their 2003 level of 2,700 million tonnes to 700 million tonnes by 2050. Annual per capita emissions will fall from 7.8 t to 2.5 t. With a share of 30% of total CO₂ emissions in 2050, the power sector will fall behind transport as the largest source.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will decrease costs compared to the reference scenario by about 1.8 cents/kWh in 2050.



south asia

development of energy demand

population: The population of South Asia is expected to grow to 2,200 million by 2050, 25% of the world total.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 3.9% per year. By 2050 it will have increased by a factor of six. Per capita GDP will still be only 20% of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 2% per year, leading to a reduction in final energy demand per unit of GDP of about 40% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by almost 80%.

final energy demand: Under the reference scenario, energy demand will more than double from the current 19,000 PJ/a to 47,000 PJ/a in 2050. Under the energy [r]evolution scenario, there will be a slower increase to 29,000 PJ/a in 2050, 50% more than today's figure but 40% less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 2,400 TWh/a by 2050. Compared to the reference scenario, this will avoid the generation of 1,000 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be reduced. Compared to the reference scenario, the consumption of 10,000 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover 50% of primary energy demand by 2050, an increase from 40% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 60% of electricity supply by 2050, an increase from 15% now. Growing from a current output of 31 GW, a renewable generating capacity of 600 GW will by then produce 1,700 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 70% of heating supply by 2050, a similar proportion to now, although traditional biomass will increasingly be replaced by more efficient technologies, in particular solar collectors and geothermal energy.

development of CO₂ emissions

CO₂ emissions will increase fourfold by 2050 under the reference scenario. Under the energy [r]evolution scenario they will remain at the 2003 level of about 1,000 million tonnes. Annual per capita emissions will only fall slightly from 0.8 t to 0.5 t. Although its share will decrease, the power sector will remain the largest source of CO₂ emissions in South Asia, contributing 50% of the total in 2050.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will decrease costs compared to the reference scenario by about 1 cent/kWh from 2020, increasing to 2 cents/kWh in 2050.

east asia

development of energy demand

population: The population of East Asia is expected to grow to 800 million by 2050, although its expansion will stabilise after 2040.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 3.2% per year. By 2050 it will have increased by a factor of 4.5. Per capita GDP will still be about a quarter of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 1.1% per year, leading to a reduction in final energy demand per unit of GDP of about 40% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by almost 70%.

final energy demand: Under the reference scenario, energy demand will more than double from the current 15,000 PJ/a to 39,000 PJ/a in 2050. Under the energy [r]evolution scenario, there will be a steady increase to 23,000 PJ/a in 2050, 50% more than today's figure but 40% less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 1,800 TWh/a by 2050. Compared to the reference scenario, this will avoid the generation of 1,000 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be reduced. Compared to the reference scenario, the consumption of 5,000 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover almost half of primary energy demand by 2050, an increase from 23% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 70% of electricity supply by 2050, an increase from 14% now. Growing from a current output of 29 GW, a renewable generating capacity of 560 GW will by then produce 1,600 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 80% of heating supply by 2050, an increase from 50% now.

development of CO₂ emissions

CO₂ emissions will increase fourfold by 2050 under the reference scenario. Under the energy [r]evolution scenario they will fall from the 2003 level of about 1,000 million tonnes to 830 million tonnes. Annual per capita emissions will only fall slightly from 1.7 t to 0.9 t. Whilst the power sector is today the largest source of CO₂ emissions in East Asia, it will contribute less than 30% in 2050.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will decrease costs compared to the reference scenario by about 1.5 cents/kWh from 2020, increasing to 3 cents/kWh in 2050.

appendix - *continued*

BREAKDOWN OF THE GLOBAL ENERGY SCENARIO BY WORLD REGION

china

development of energy demand

population: The population of China will peak at 1,460 million in about 2030. After that it will decrease to 1,400 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 4.1% per year, the highest growth of all the world regions. By 2050 it will have increased seven-fold. Per capita GDP will still be about half of that in Europe or North America.

energy intensity: Under the reference scenario, energy intensity will reduce by 2.3% per year, leading to a reduction in final energy demand per unit of GDP of about 65% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by almost 80%.

final energy demand: Under the reference scenario, energy demand will more than double from the current 35,000 PJ/a to 81,000 PJ/a in 2050. Under the energy [r]evolution scenario, there will be a steady increase to 53,000 PJ/a in 2050, 50% more than today's figure but a third less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 6,300 TWh/a by 2050. Compared to the reference scenario, this will avoid the generation of 1,200 TWh/a.

heat demand: Under the energy [r]evolution scenario, demand for heating will be reduced. Compared to the reference scenario, the consumption of 12,500 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover 33% of primary energy demand by 2050, an increase from 20% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate 50% of electricity supply by 2050, an increase from 15% now. Growing from a current output of 84 GW, a renewable generating capacity of 1,300 GW will by then produce 4,000 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 43% of heating supply by 2050, an increase from 35% now. The CHP share will be more than 30%.

development of CO₂ emissions

CO₂ emissions will triple by 2050 under the reference scenario. Under the energy [r]evolution scenario they will remain stable at the 2003 level of about 3,300 million tonnes. Annual per capita emissions will only fall slightly from 2.5 t to 2.3 t. The increasing electricity supply, the power sector will remain the largest source of CO₂ emissions in China, accounting for 50% in 2050.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will hardly increase costs and they will fall to almost 1 cent/kWh below those in the reference scenario by 2050.

OECD pacific

development of energy demand

population: The population of OECD Pacific will peak in 2020 at about 200 million and then decrease to 180 million by 2050.

GDP: The PPP adjusted Gross Domestic Product is expected to grow on average by 1.8% per year, leading to a fivefold increase by 2050. Per capita GDP is increasing strongly, making this the leading world region by 2050.

energy intensity: Under the reference scenario, energy intensity will reduce by 1.0% per year, leading to a reduction in final energy demand per unit of GDP of about 40% between 2003 and 2050. Under the energy [r]evolution scenario, energy intensity will fall by 75%.

final energy demand: Under the reference scenario, energy demand will increase by more than 40% from the current 21,000 PJ/a to 30,000 PJ/a in 2050. Under the energy [r]evolution scenario, energy demand will peak in 2010, then fall back to 17,300 PJ/a by 2050, which is about 85% of today's figure and 40% less than projected consumption under the reference scenario.

electricity demand: Under the energy [r]evolution scenario, efficiency measures will result in electricity demand of about 1,600 TWh/a by 2050. Compared to the reference scenario, this would avoid the generation of 800 TWh/a.

heat demand: Under the energy [r]evolution scenario, a steep decline in demand for heating will mean that, compared to the reference scenario, the consumption of 4,900 PJ/a is avoided through efficiency gains.

development of energy supply

primary energy supply: Under the energy [r]evolution scenario, renewable energy sources will cover one third of primary energy demand by 2050, an increase from 3% now.

electricity generation: Under the energy [r]evolution scenario, renewables will generate about 70% of electricity supply by 2050, an increase from 10% now. Growing from the current output of 60 GW, a renewable generating capacity of 410 GW will by then produce 1,130 TWh/a.

heat supply: Under the energy [r]evolution scenario, renewables will satisfy 60% of heating supply by 2050, an increase from 4% now.

development of CO₂ emissions

CO₂ emissions will increase by 20% up to 2050 under the reference scenario. Under the energy [r]evolution scenario they will decrease from 1,900 million tonnes to 700 million tonnes. Annual per capita emissions will drop from 9.4 t to 3.8 t.

future costs of electricity generation

The growth in renewables under the energy [r]evolution scenario will increase the costs of electricity generation compared to the reference scenario up to 2030, but by 2050 they will be 1 cent/kWh lower.

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
<i>CHP by producer</i>						
Main activity 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	37	42	48	53	58
Import RES	5	6	6	7	8	9
Export	24	29	33	37	41	45
Distribution losses	285	321	344	361	345	352
Own consumption electricity	293	33	354	372	356	362
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	28	16	18	19	19
Gas	185	198	268	209	189	175
Oil	65	55	50	28	19	16
Nuclear	103	107	107	98	92	86
Biomass	4	5	6	7	8	9
Hydro	81	87	85	85	84	83
Wind	5	15	37	74	84	93
PV	0	0	1	2	4	7
Geothermal	3	4	4	5	6	6
Solar thermal power plants	0	1	1	2	3	4
Ocean energy	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
<i>CHP by producer</i>						
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	245	318	262	242	227
Oil	69	58	53	31	21	19
Nuclear	103	107	107	98	92	86
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	18	19	21	22	23
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	16	39	78	91	104
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

PJA	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
RES share	4.5%	5.0%	5.3%	5.9%	6.4%	6.5%

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 heating¹⁾	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	4,042
Solar collectors	54	56	71	87	102	121
Geothermal	39	31	36	39	41	47
Total heat supply¹⁾	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: co₂ 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	2,132	2,257	2,578	2,726	3,117
Lignite	115	231	124	127	121	120
Gas	243	266	367	289	261	256
Oil	81	68	62	35	23	20
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
Co₂ 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
Co₂ 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
Co₂ emissions per capita (t/capita)	19	21	21	21	20	21

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 heating¹⁾	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 supply¹⁾	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)	8.4%	12.9%	26.5%	41.2%	55.2%	64.3%
'Efficiency' savings (compared to Ref.)	0	4,620	8,050	10,466	13,209	16,079

table 21: co₂ 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	1,395	788	335	208	76
Lignite	115	93	77	36	0	0
Gas	243	271	300	285	205	102
Oil	81	62	21	13	3	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
Co₂ 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
Co₂ 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
Co₂ emissions per capita (t/capita)	19	16	12	8	6	4
'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
<i>CHP by producer</i>						
Main activity 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	30	30	30	30	30
Import RES	5	6	13	17	20	24
Export	24	24	24	24	24	24
Distribution losses	285	255	254	247	243	224
Own consumption electricity	293	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	9.5%	14.5%	32.0%	54.6%	66.0%	79.1%
'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	10	5	0	0
Gas	185	202	219	207	149	70
Oil	65	50	17	10	2	0
Nuclear	103	73	50	0	0	0
Biomass	4	6	8	8	8	8
Hydro	81	90	102	115	122	128
Wind	5	29	205	358	404	464
PV	0	2	26	89	119	146
Geothermal	3	5	8	11	12	13
Solar thermal power plants	0	1	5	21	36	49
Ocean energy	0	1	4	6	10	17
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
<i>CHP by producer</i>						
Main activity 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	33	240	474	569	675
Share of fluctuating RES	0.70%	4.20%	26.60%	46.70%	55.70%	63.80%
RES share	13.1%	19.4%	42.7%	63.4%	73.1%	83.9%

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
RES share	4.5%	7.7%	15.4%	27.4%	38.0%	47.5%
'Efficiency' savings (compared to Ref.)	0	20,573	39,734	58,078	70,805	87,502

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