



Pathways to
Energy & climate change

2050



Pathways to 2050

Introduction

Pathways to 2050: Energy and Climate Change builds on the WBCSD's 2004 *Facts and Trends to 2050: Energy and Climate Change* and provides a more detailed overview of potential pathways to reducing CO₂ emissions.

The pathways shown illustrate the scale and complexity of the change needed, as well as the progress that has to be made through to 2050. Our "checkpoint" in 2025 gives a measure of this progress and demonstrates the urgency to act early to shift to a sustainable emissions trajectory.

The WBCSD has chosen to continue to illustrate the challenges associated with one particular trajectory, consistent with the discussion already presented in *Facts and Trends*. This document therefore looks closely at the changes needed to begin to stabilize CO₂ concentrations in the atmosphere at no more than 550-ppm (see glossary), which relates to the "9 Gt world" described in *Facts and Trends*. As such, and based upon simplified assumptions and extrapolations, we have made many choices, some arbitrary, to present this single illustrative story. It is neither a fully-fledged scenario nor does it recommend a target. Moreover, this document does not discuss policy definitions or options, topics that need to be dealt with separately.

Our principal sources of data for 2002 and 2025 references have been the IEA *World Energy Outlook* (IEA 2004) and the IEA *CO₂ Emissions From Fuel Combustion 1971-2002* (IEA 2003). While the projections we have made in *Pathways to 2050* also build on the findings of *Facts and Trends*, the reader may note some differences in the numbers presented in some areas. These are a result of improved data sources and some adjustments in our own calculation and transcription methods, but do not alter the key findings and outcomes.

This document is intended to stimulate dialogue and enhance mutual understanding of the issues. We hope many will share our own belief that widespread action must start now.



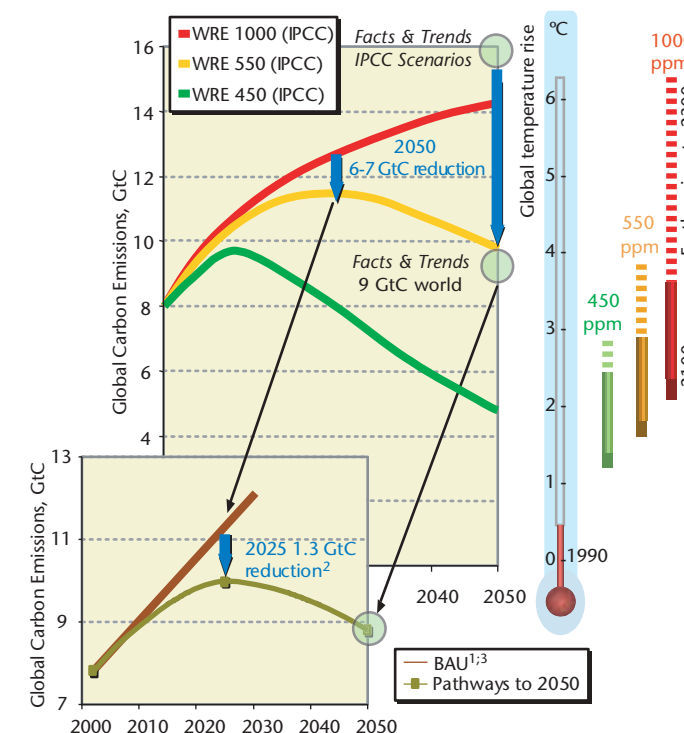
Facts and Trends to 2050
Energy and Climate Change

Pathways at a glance . . .

The IEA *World Energy Outlook Reference Scenario* (IEA 2004) projects a rise in global carbon emissions from 7.8 Gigatons of carbon (GtC) in 2002¹ to some 12 GtC by 2030. The IPCC scenarios used in *Facts and Trends* (WBCSD 2004a) indicated a rise to 15-16 GtC by 2050 if current trends are not altered.

Such emissions profiles put the world on a trajectory towards an atmospheric CO₂ concentration as high as 1,000 ppm, up from 370 ppm in 2000 and 280 ppm in pre-industrial times. The resulting temperature rise cannot be predicted with accuracy, but it might be as high as 3-4° Celsius by 2100 and up to 6° Celsius by 2300.

Figure 1: Emissions scenarios



Limiting atmospheric concentrations to around 550-ppm while still allowing carbon emissions to increase in the medium term requires a global downturn in emissions no later than 2030, followed by a continuing decline. By 2050, in contrast to a sharply rising demand for energy (at least double) over the same period, emissions must approximate today's levels.

Many pathways exist for such a journey, but all require significant changes in energy production and use in order to succeed and need major sectoral shifts, or megatrends. **Five principal megatrends have been identified.**

Megatrends

- 1. Power generation** – Emissions management moves upstream as electricity is increasingly the final energy carrier, displacing direct burning of fossil fuels in end use. 4
- 2. Industry and manufacturing** – Industry, together with power generation, has been the first major sector to respond to the challenges posed by climate change and to be impacted by climate change legislation. Further challenges will arise in developing countries with increasing energy demands. 6
- 3. Mobility** – As the desire for transport and travel increases, especially in developing countries, new technologies and behavioral changes are needed to achieve significant emissions reductions. 8
- 4. Buildings** – Buildings give rise, directly and indirectly, to as much as 40% of CO₂ emissions. New energy-efficient building designs and materials, coupled with renewable heating and electricity, are increasingly attractive, while appliances have to meet ever more stringent efficiency standards. 10
- 5. Consumer choices** – Society tends to think little of the CO₂ implications of simple everyday choices. Yet such choices are a key element in moving to a sustainable energy future. 12

Regional trends

Every country and region contributes to the changes required, either by modifying energy production and consumption habits developed over many years or by shifting to an alternative development pathway. Four economic regions are illustrated:

- USA & Canada** Efficiency and Growth 14
- EU-25** Broad Based Energy Infrastructure 16
- China** Low-Carbon, Coal-Based Economy 18
- Japan** Sustainable Energy Showcase 20

This selection does not imply that other countries are ignored or should remain passive. Rather, these areas exemplify trends that can yield significant results and benefit the global scene over the long term.

As illustrated in *Facts and Trends*, major transitions at the global level will take time to implement. By 2025, real signs of change must be apparent. New and innovative zero emissions technologies and processes must be commercialized and deployment started. By 2050 these must be in widespread everyday use and be part of an optimized energy mix.

Global Trends and Pathways

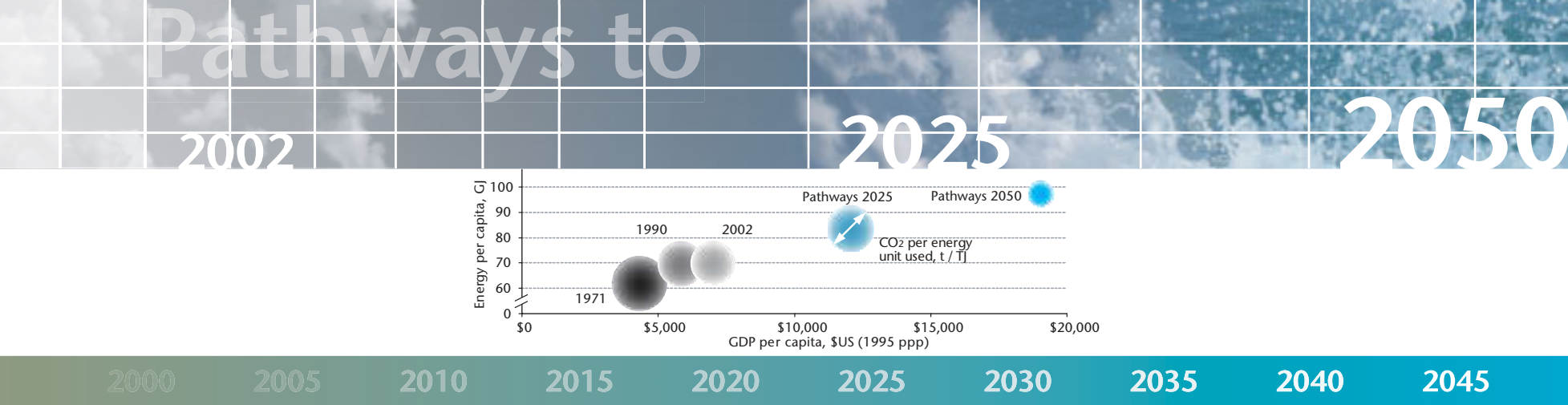


The challenge

A 550-ppm emissions trajectory is an ambitious undertaking in a rapidly developing world. It requires large-scale deployment of a wide range of technologies with high investment and complex choices, completely transforming energy production and use. Issues around energy security and affordability will also play a key role in this transformation process.

By 2050, the world must generate a dollar of GDP with only half the energy used in 2002, equivalent to an economic efficiency improvement of 1.5% per year, a rate of change 20% higher than that achieved in the last 30 years.

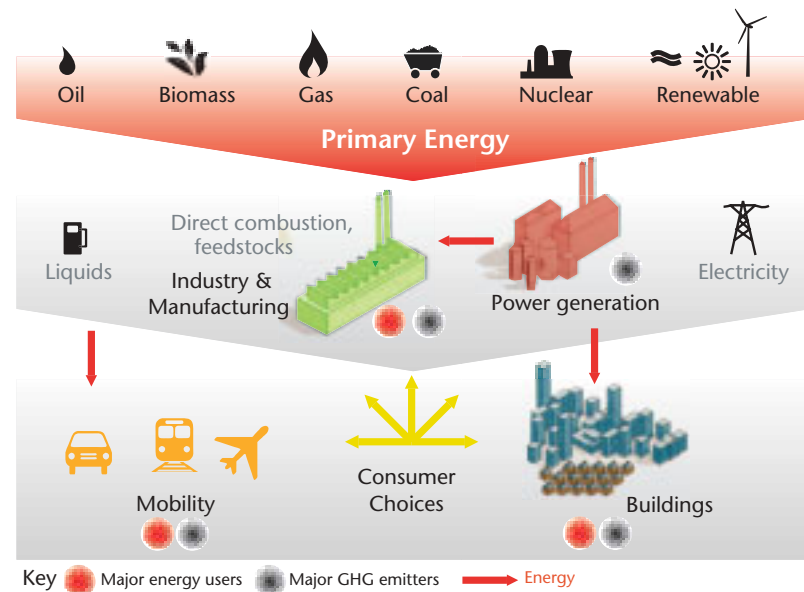
Additionally, each Tera-Joule of energy used must generate 45% less carbon emissions than in 2002, implying a 1.3% improvement in carbon intensity per year. This is equivalent to twice the global rate of decarbonization in the last 30 years.



Megatrends to 2050

Energy flows through the economy (see Figure 2) give an insight into the key areas that must be tackled. Five megatrends emerge that all have a major role to play in reshaping our energy systems, either as energy users, emitters, or both. They are power generation, industry & manufacturing, mobility, buildings and consumer choices. Figures 3 and 4 summarize the contributions of these megatrends to the energy and emissions "pathway" chosen, as well as how they relate to the IEA's Reference Scenario (IEA 2004).

Figure 2: Energy flows through the economy



Measuring Progress - The Kaya Identity

Facts and Trends showed that a strong alignment exists between energy and development, with GDP per capita and energy per capita rising in unison, albeit with some flattening of the relationship as economies mature and become more service oriented. Further dimensions are the carbon intensity of the energy used and population growth. The links between these factors are simply described by the *The Kaya Identity*. *Kaya* breaks down the main emissions driving forces, such that:

$$\text{CO}_2 \text{ emissions} = \text{people} \times \text{GDP/person} \times \text{energy/unit GDP} \times \text{CO}_2/\text{unit energy}$$

Only four factors govern the outcome:

- Population
 - Economic Prosperity
 - Energy Intensity
 - Carbon Intensity
- Number of people
GDP per person
Energy per unit of GDP (energy efficiency of the economy)
CO₂ per unit of energy (reflects the emissions from energy production end use)

In *Pathways to 2050*, the WBCSD chose the most referenced forecast for population growth (~9 billion by 2050, UNDESA) and extrapolated GDP growth patterns to 2050 based on IEA forecasts to 2030, but simplified to five groupings: very high (4.5%), high (3.5%), above (2.5%), medium (2%) and low (1.5%).

Figures 5 and 6 illustrate the extent of change needed in energy efficiency (represented by the position on the graph) and carbon intensity (represented by the size of the circles).

Figure 3: Levers for changing carbon intensity: direct CO₂ emissions by sector

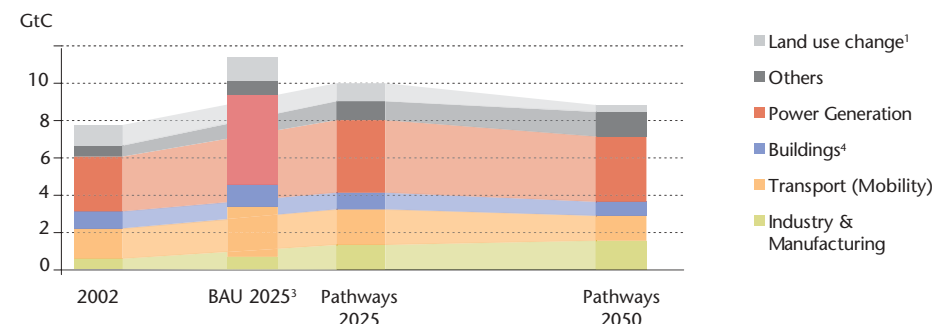
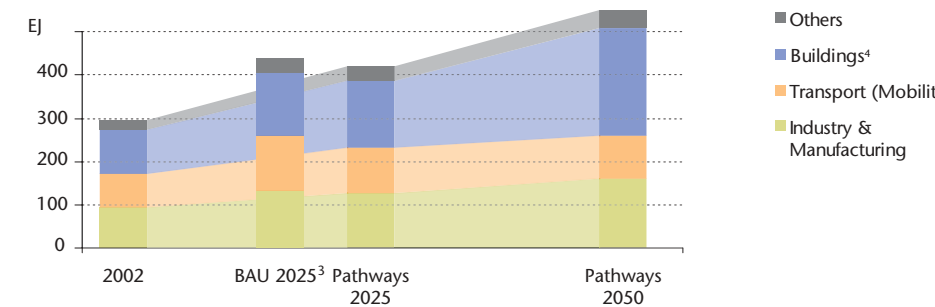
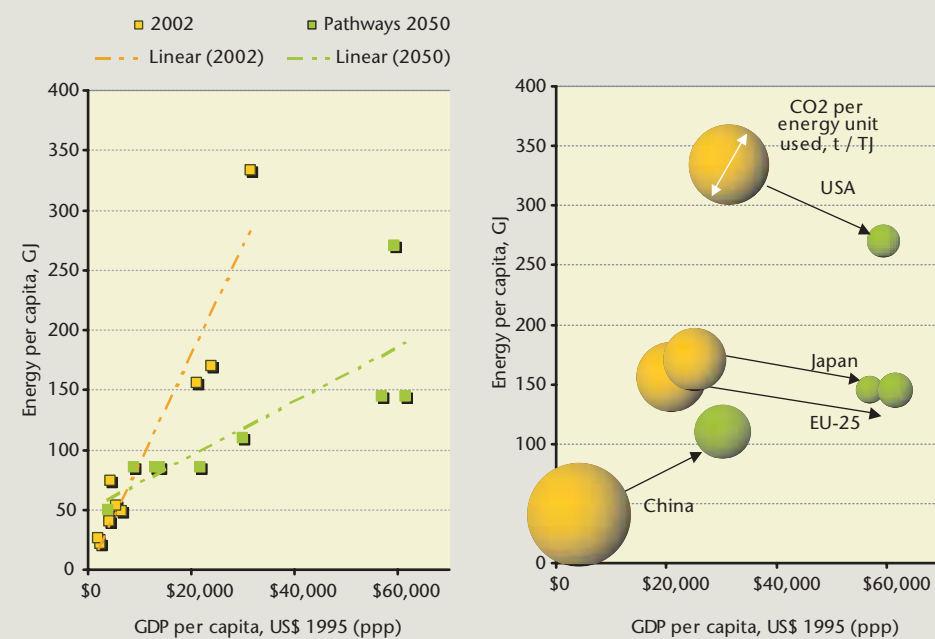


Figure 4: Levers for changing energy intensity: final energy consumption by sectors



Figures 5 and 6: Pathways to 2050



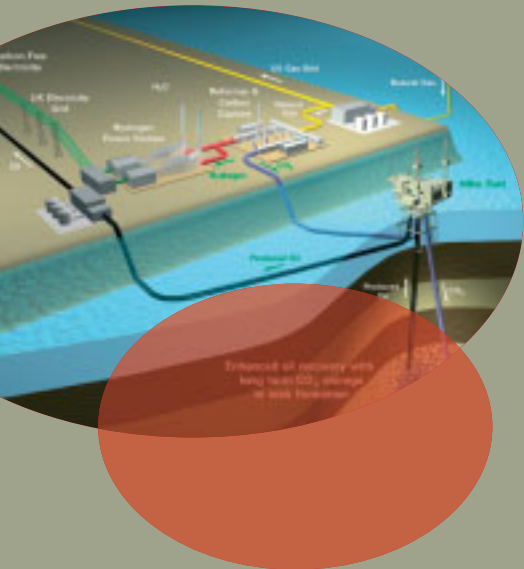
By 2050

Success is measured by secure, widespread access to affordable energy with global carbon emissions at or below 9 GtC per year and declining. In 2050 we have:

- > Transformed the power generation sector to deliver low carbon electricity from a wide variety of sources;
- > Further enhanced the efficiency of the manufacturing industry;
- > Created a sustainable mobility sector based on high efficiency vehicles, a broader range of fuel choices and a balance between private and mass transportation;
- > Achieved significant energy efficiency improvements in the building sector in order to partly counterbalance rising energy demand;
- > Raised awareness among all energy users of the choices they can make to deliver sustainable energy use.

This combination of options and pathways is only one of many that would deliver a 9 Gt world by 2050. Other pathways may be more acceptable or more cost effective. Considering the substantial investment associated with the changes needed, optimizing the use of financial resources will be a key consideration in policy development.

Megatrends Power Generation



The challenge

In this 9 Gt world, electricity demand rises to more than four times its 2002 level by 2050. This implies a growth rate close to that of GDP (as seen in recent decades). At the same time, power sector emissions can be no more than 25% higher than 2002 levels, which means a substantial reduction in carbon intensity.



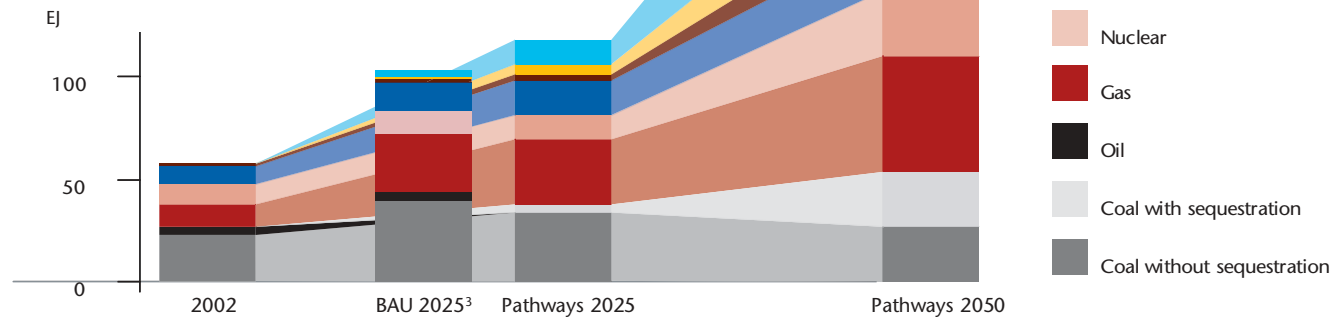
Today

- > In 2002, power and heat generation contributed around 40% of global CO₂ emissions from fuel combustion, with coal-fired power generation responsible for about 70% of this. During 2005, China built one large conventional coal-fired power plant almost every two weeks. Expected future capacity additions for China are enormous;
- > Natural gas is only half as CO₂ intensive as coal per unit of electricity generated. Continued high growth rates lead to increased import dependency for some countries and require the further development of capital-intensive infrastructure, such as liquid natural gas (LNG) terminals;
- > Nuclear power's safety record is improving, but concerns about weapons proliferation and issues with the public acceptance of waste disposal remain. Its capital costs can be particularly high in the case of uncertain regulatory outcomes;
- > Energy derived from biomass and waste represents a small but growing segment of the renewable

fuels option. CO₂ emissions from biomass-derived fuel combustion are classified as greenhouse gas neutral;

- > The economic viability of wind, wave or tidal as well as solar power capacity will continue to depend on consumer and government support for some time, even though wind is now nearing competitiveness in areas with favorable conditions. Generation from these sources can be unpredictable and intermittent, which typically demands extra investment in the transmission and distribution system, as well as back-up or storage capacity.

Figure 7: Electricity generation by fuel⁵



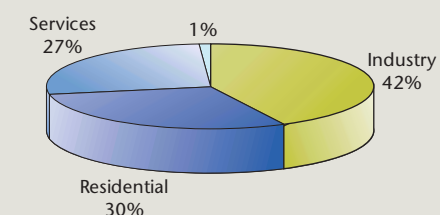
By 2025

- > Commercialization of Carbon Capture and Storage (CCS) has started with more than 100 coal-based CCS facilities in operation. However, CCS technology needs to prove its permanence and add value through enhanced oil recovery, coal bed methane technology or direct carbon value before gaining widespread acceptance;
- > Generation from biomass/waste and other renewables (excluding hydro) is multiplied by a factor of 18 compared with 2002 levels which is much higher than for example IEA reference forecasts (roughly a factor of 5).
- > Many nuclear plants currently operating are replaced, and an additional 30% of new capacity is installed;

Who consumes electricity?

The buildings (residential & services) and industry sectors together consume practically all of the world's electricity, with more than half used in buildings. Thus they are crucial in using electricity efficiently. There also is considerable potential to modernize our transmission and distribution infrastructure to avoid losses.

Figure 8: Shares of electricity consumption (2002)



The growing importance of electricity

Electricity use is already growing more quickly relative to other energy carriers as a result of the following trends:

- > Improvements in electrical applications, including automation, and a substitution of fossil fuels in end use;
- > Increasing numbers of electrical appliances;
- > Information technology and the Internet;
- > Continuous urbanization.

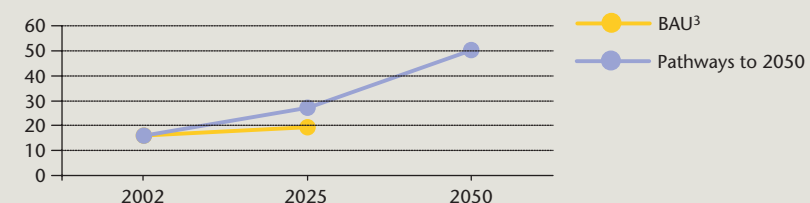
This could be further reinforced in a carbon-constrained world:

- > As a flexible energy carrier, electricity offers additional potential for carbon management;
- It can be generated from a variety of low and zero carbon sources and from large facilities with CCS;

○ At point of use, it produces no emissions. Emissions management increasingly becomes an upstream issue, and is not left to the final consumer;

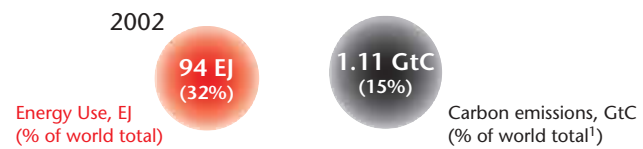
> Most new sources of renewable energy lend themselves mainly to electricity generation.

Figure 9: Share of electricity in final energy consumption

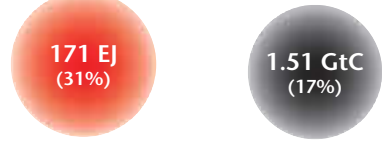


By 2050

- > Coal use grows by 50% compared to 2002 levels, and half the generation capacity uses CCS;
- > Natural gas is the largest fossil contributor to electricity generation at over triple the 2002 level;
- > Both coal and gas facilities run at significantly higher efficiency (including the use of combined heat and power (CHP) units), to decrease primary energy needs per unit of output;
- > Nuclear power, as a carbon-free energy resource and an important electricity base-load supply, grows at rates approaching those seen before 1990, to reach a level three-times higher in 2050 compared with 2002;
- > Hydropower more than doubles until 2050, meaning nearly all of the remaining potential is exploited;
- > Wind, geothermal, wave and tidal power increase nearly 160-fold from 2002, implying an 11% annual growth rate;
- > Sustained growth rates for solar are even higher, at around 20% per year.



Pathways 2050



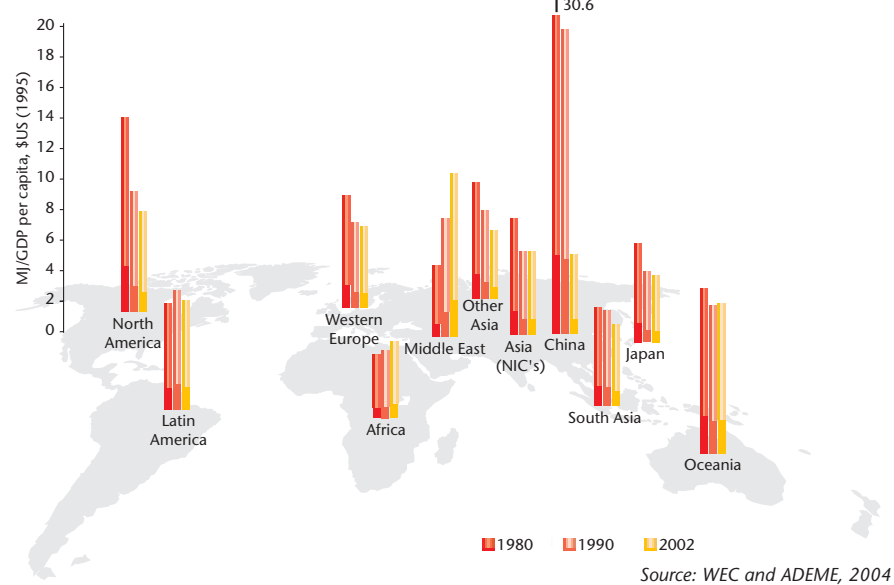
2000 2005 2010 2015 2020 2025 2030 2035 2040 2045

Today

The industry and manufacturing sector is supporting a diverse range of businesses, including petroleum refining, automobile production, cement, chemicals and metals smelting. Taken as a whole, this sector makes up 32% of the world's total energy consumption today.

The majority of this energy consumption takes place in developed countries due to their substantial industrial and manufacturing base. Although developing country manufacturing capacity is typically more energy intensive, recent developments show that this trend is now changing with many new facilities matching or exceeding the efficiency of those in developed countries.

Figure 10: Energy intensity of industry



Cement

There are several ways to produce cement, each using different amounts of energy. A modern dry process, which can use as little as 3,000 MJ/ton of clinker, is more efficient than a wet process (5,000-6,000 MJ/ton of clinker). Increasing the production of blended cement, which includes materials that do not require processing in the cement kiln (e.g., fly ash, slag), both reduces process CO2 emissions

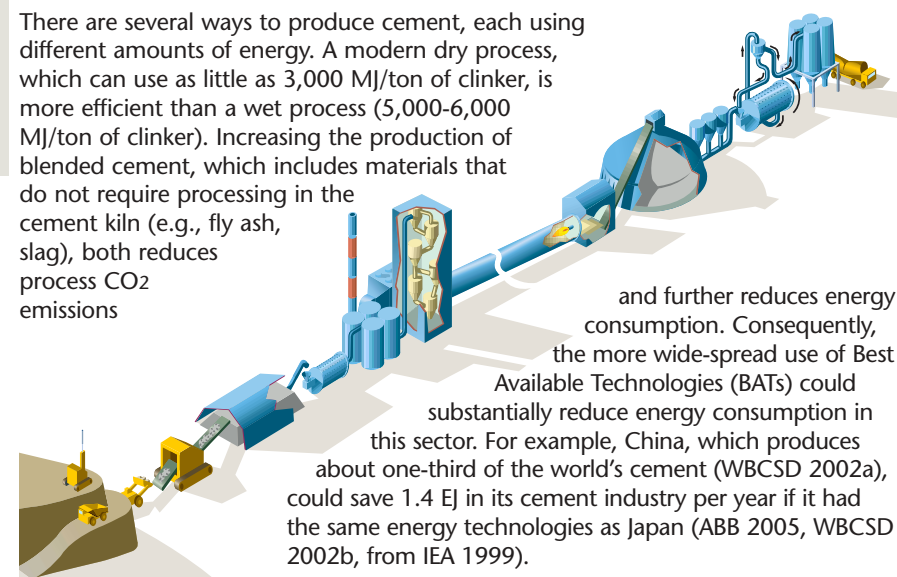
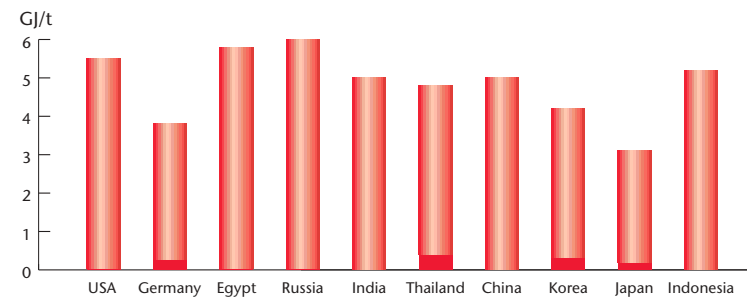


Figure 11: Primary energy intensity of cement production



By 2050

The industry and manufacturing sector substantially increases its output volumes to drive economic growth, especially in developing countries. To keep up with the megatrend, it:

- > Shifts towards electricity and biomass fuels;
- > Increases the deployment of BATs as a cost-effective emission and energy reduction option, which allows developing countries to leapfrog certain stages of technology development;
- > Further improves energy efficiency and fuel conservation;
- > Develops new low-energy and low-carbon technologies to address energy needs and requirements in a carbon-restricted world. To accomplish these breakthroughs, substantial amounts are invested in research and development.

The challenge

The industry and manufacturing sector is expected to consume more energy in the future due to rising population levels and continuing global economic growth. These developments need to be offset by significant energy efficiency improvements per unit of output and a shift towards lower carbon options.

Forest Products

The Forest Products industry is energy intensive but already generates some 50% of its own energy needs from biomass. The low-carbon pathway for the industry could include the following:

- > Capturing the carbon storage benefits of forest products through transparent reporting and quantification;
- > Improving energy efficiency at industry facilities through the use of breakthrough technologies in various processes;
- > Increasing the energy derived from pulp and paper and wood products biomass residuals by escalating the use of CHP systems and high

efficiency (pulping liquor) recovery boilers;

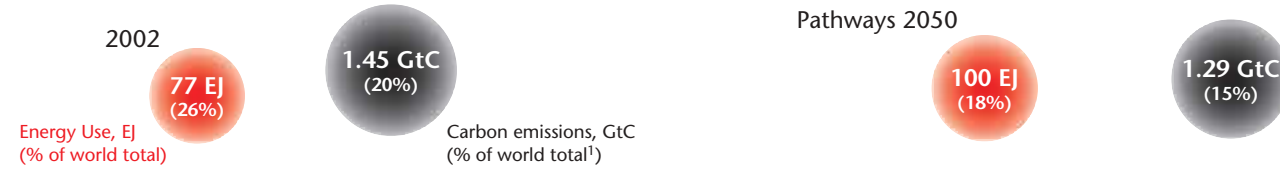
- > Expanding the managed forest sector to produce additional biomass fuels for society by investing in afforestation, reforestation, and forest restoration projects. The challenge is to mobilize the required capital investment, secure sufficient quantities of affordable biomass fuel, and finance the research required for increased forest productivity;
- > Raising the already high share of recovered paper (over half of all paper is recycled in many countries) to liberate more raw material and biomass for energy use.

Electric Motors

In the EU-15, electric motors in industry and manufacturing used about 24% of total electricity consumption in the year 2000 (European Copper Institute 2004). Significant energy savings can be achieved by applying more energy efficient electric motors. Economical electricity savings can be as high as 29%, with further savings in primary energy upstream at the power plant.

Even though some such projects can pay off relatively quickly for end users, a large part of the financial "savings" from efficiency improvements comes in the form of avoided expenditure on the supply side. Innovative incentive mechanisms are needed to capture these system benefits and to thereby realize more of the theoretical efficiency potential.

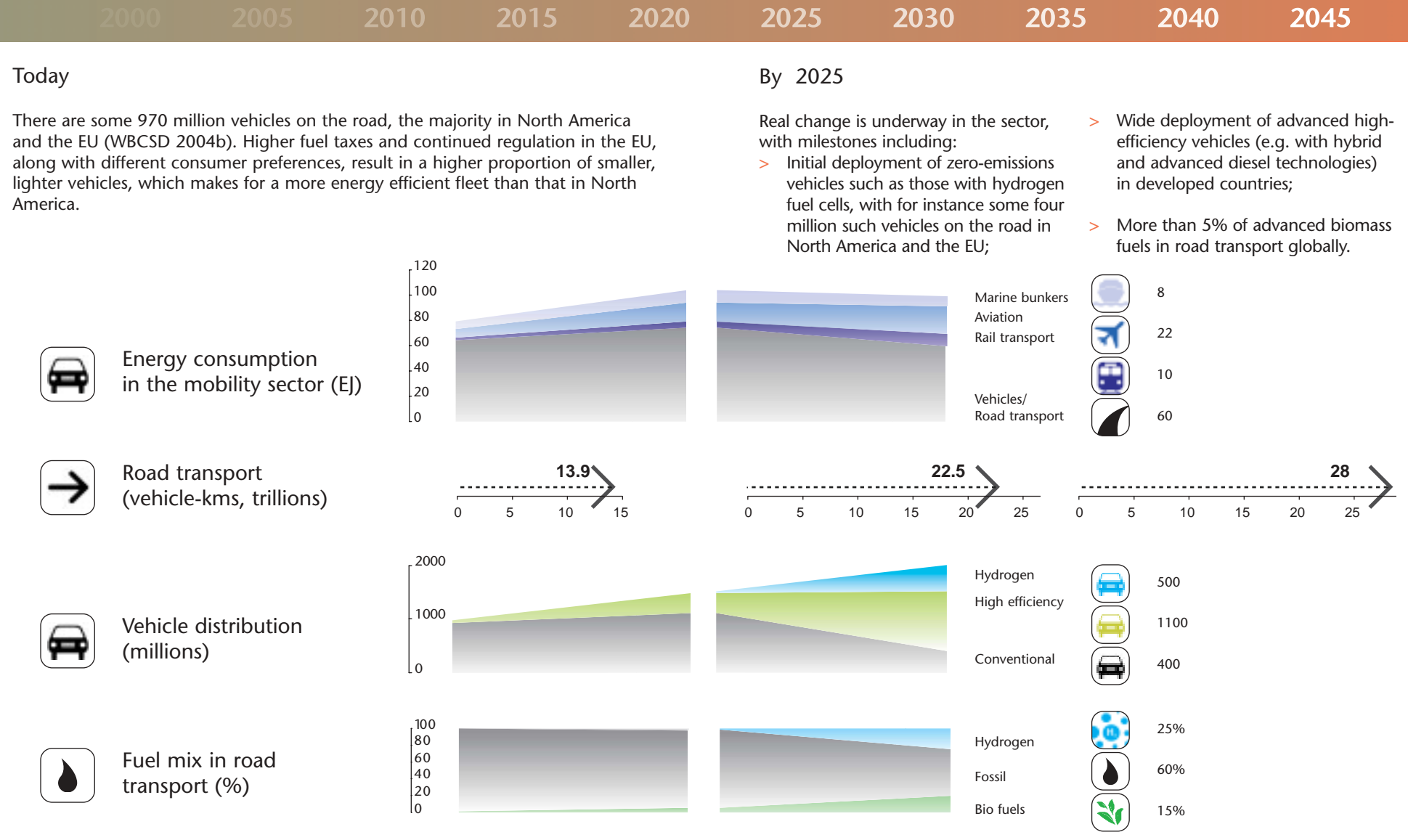
Pathways to 2050



The challenge

The mobility sector will not be sustainable if present trends continue. World transport activity is expected to more than double by 2050, making a megatrend shift in the mobility sector essential.

The world's vehicle stock rises to over two billion units, with an almost proportionate rise in total passenger kilometers traveled. Developing countries in particular are expected to experience sharp rises in vehicle numbers as their economic development continues.



Shifting towards low carbon technologies

Possible low-carbon technology options for the road transport sector include:

Biomass fuels

Biomass fuels for transport can be derived from agricultural crops and crop waste and from other biomatter such as harvested wood waste residuals. Their conversion includes fermentation to produce ethanol and various processes to produce synthetic and bio diesels. These fuels become part of the short-term natural carbon cycle and can be carbon neutral when using appropriate harvesting techniques. For example, the use of sugar to produce ethanol via fermentation is already a large-scale industry in Brazil.

Hydrogen

Hydrogen is an alternative energy carrier that is manufactured today from fossil fuels (principally natural gas). The carbon-free manufacture of hydrogen remains very expensive and involves energy transformation losses. In the longer term, innovative technologies (e.g. high temperature nuclear reactors or coal gasification with CCS) are needed. The hydrogen can then be consumed in a fuel cell producing electricity that then powers the vehicle.

Hybrids

Hybrids use two power sources to operate the vehicle. The second source is a battery that recovers waste energy from vehicle operation and then powers the vehicle during periods of low demand. During these periods the main power source (typically an internal combustion engine) shuts down, thus saving fuel.

Diesel

Although gasoline engines have improved, diesel remains more efficient due to the high compression ratios used within the engine. With the early issues around particulate emissions now being solved by new filters, and smoother operational performance, the technology has a great deal to offer in terms of efficiency gains. Europe for instance has embraced diesel over the last decade or so, a factor that has contributed to its relatively high vehicle fleet efficiency.

By 2050

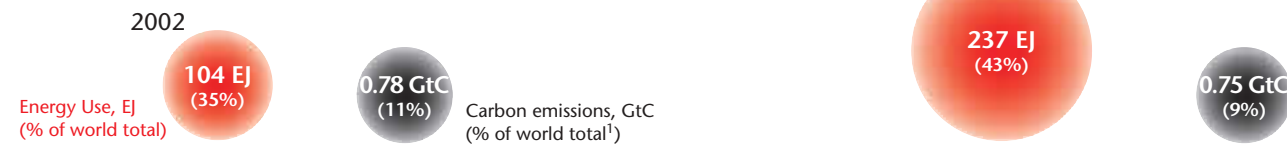
In a 2050 9 Gt world where the carbon emissions profile is dominated by power generation and direct burning of fuel, the overall emissions from the mobility sector have fallen by over 10% relative to 2002, with an even greater reduction achieved in road transport. These reductions are achieved by:

- > An increasing number of high-efficiency and hydrogen vehicles;
- > Shifting towards rail transport and biomass fuels.

Within the mobility megatrend lies the aviation sector, where capital stock turnover is slower than for road transport and no large-scale viable alternative to fossil-based fuels is being considered. As a result and with demand soaring, aviation emissions treble over the period, even with the introduction of high-efficiency airplanes.

A further shift to mass transportation offers considerable efficiency benefits. Rail transport can be up to seven times more efficient than a light duty vehicle (WBCSD 2004b). Japan in particular has embraced rail transport in a way that has become widely admired. Substantial investments are made worldwide to make this an efficient and attractive alternative to individual transport.





By 2050

Significant increases in energy consumption in this sector are caused by:

- > A switch to electricity along with changing development profiles and to power the higher number of appliances;
- > A growing service sector requiring commercial buildings;
- > The continued rise of the information economy;
- > A further shift from rural to urban living, especially in developing countries where this is typically linked to a rise in income levels.

Today

Energy consumed in buildings already represents more than a third of global consumption, and this share is increasing. The bulk of it is used in heating, air conditioning, lighting and appliances, depending on the surrounding climate.

Energy sources vary depending on development levels. Households in some developing countries still rely on biomass. In developed countries, energy for heating largely comes from oil and gas, causing most of today's carbon emissions from buildings. The use of electricity sharply rises with income.

Elements of new building design that can substantially reduce energy use or emissions

- > Ventilated double skin facades to reduce heating and cooling requirements;
- > "Low-E" glass coating to reduce the amount of heat absorbed from sunlight through the windows (windows with the reverse effect can be installed in colder climates);
- > Wood as a building material with advantageous insulation properties, which also stores carbon and is often produced with biomass energy;

Figure 12: USA service sector energy consumption by type (1999)

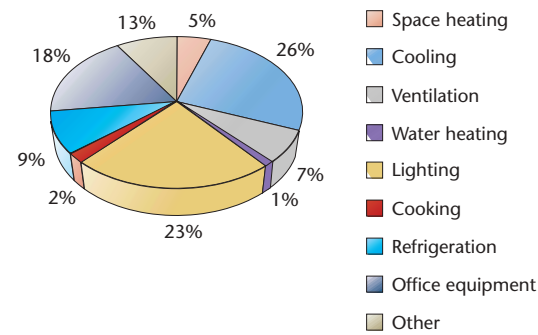
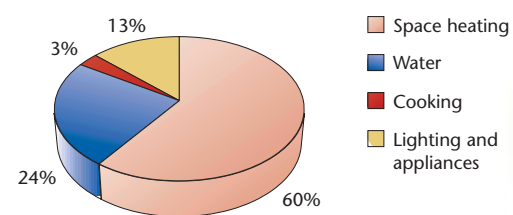
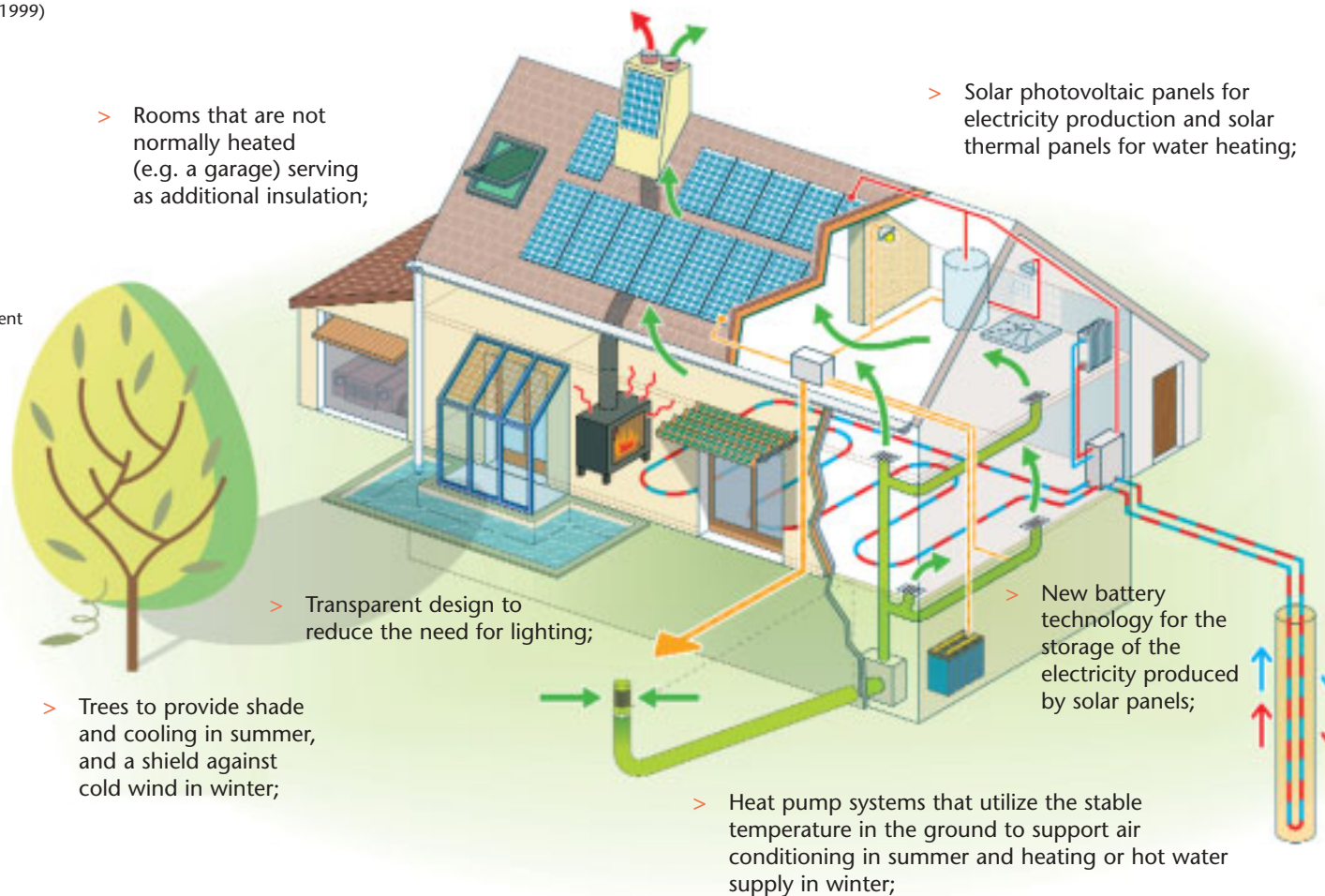
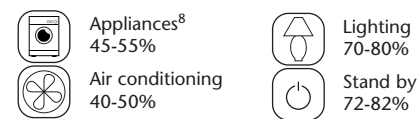


Figure 13: UK household energy consumption (2003)



Typical savings potential for different types of devices in use today, compared to the most efficient technology available:⁷



Energy efficiency

At the same time, substantial energy efficiency progress is made by continuous improvements in appliances, and new solutions for integrated building design. Some of these solutions need to be applied not only to most new builds, but also to the significant number of houses that exist today and will still be serving their purpose in 2050.

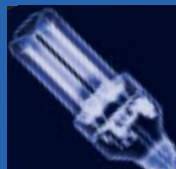
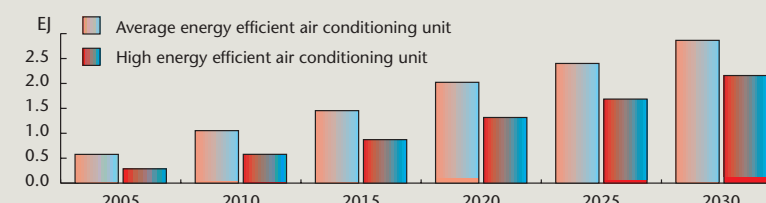


Illustration: Heat pumps in China

The installation of efficient heat pump-based air conditioning units instead of average air conditioning units in Chinese households would result in a savings of more than 15 EJ (including transmission & distribution losses) until 2030. This would translate into an energy savings of 0.5 EJ in 2010, which would equal about 1.1% of total Chinese energy consumption in that year, or, for comparison, about 20% of Germany's electricity consumption in the year 2002.

Figure 14: Energy consumption of the air conditioning units in selected years⁹



Megatrends Consumer Choices



The challenge

Our daily decisions, be it the setting on our thermostat, the choice between using a car or public transport, or even choosing a long-haul holiday destination against a regional one, influence energy use somewhere along the value chain.

A shift in consumer choices directly or indirectly affects the other megatrends due to the fact that it is consumption that ultimately drives economic activity. Since many small decisions can add up to make a tremendous difference, a megatrend shift in our consumption choices (lifestyle changes) can make an important contribution to a carbon-constrained world.



2000 2005 2010 2015 2020 2025 2030 2035 2040 2045

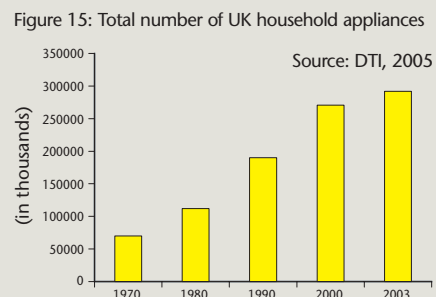
Carbon choices		Carbon choices	
The illustration below shows that consumers can greatly influence their own personal carbon footprint, directly and indirectly, simply by making different choices.		The illustration below shows that consumers can greatly influence their own personal carbon footprint, directly and indirectly, simply by making different choices.	
Icon	Description	Icon	Description
	A family of four Tons of carbon per year		A family of four Tons of carbon per year
	Detached house with oil heating: + extra air-conditioning + heated pool		Semi-detached house: with a ground source heat pump:
	But could install Insulation & double glazing Efficient lighting		And has installed Insulation & double glazing Efficient lighting
	And could Use A* appliances Adjust the thermostat Switch off lights/appliances		And also Uses A* appliances Adjusts the thermostat Switches off lights/appliances
	And could also install Solar panels for electricity and hot water		And also installs Solar panels for electricity and hot water
	Drives two cars SUV (15,000 miles) Sedan (10,000 miles)		Drives one car Hybrid (5,000 miles)
	Air travel ~15 short-haul ~8 long-haul		Air travel ~8 short-haul
	Waste But could recycle		Waste But recycles
Overall (excluding reduction options)		Overall	
9.65		0.85	

Source: BP 2005 and WBCSD adaptation

The Rise of the Appliance
The increasing number and use of home appliances has brought many benefits, but also a rise in energy use. In the UK household energy use for lighting and appliances has nearly doubled since 1971, driven by a quadrupling of the number of devices (see figure 15). Now, many appliances such as televisions, DVD-players or PCs continue to use energy when switched "off" to power built-in clocks, keep data and allow remote control access.

Some devices now consume more power on standby over their life than they do in actual operation. In the OECD, standby devices consume some 5-10% of residential electricity use. In

the USA, for example, this equates to the output from five 1 GW power stations per year. The "1-Watt Initiative" specifically aims to reduce stand-by consumption of appliances to below one Watt, from typical averages of 3-10 W. This initiative is widely supported.



The indirect route to a lower carbon footprint

Many choices that we make daily also have more indirect – but not necessarily smaller – impacts on value-chain emissions:

- > Recycling and reusing products such as plastic bags, cans made from aluminum, or glass bottles saves a great deal of the industrial energy required for their production;
- > Doing shopping online instead of physically driving to the store or using telecommuting and teleconferences instead of face-to-

face meetings reduces energy consumption by lowering the need to travel;

- > Purchasing local products rather than imported ones reduces the energy used in international freight transport (including aviation).

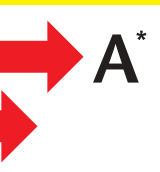
By 2050

Our society needs to have understood that all consumer choices influence the energy balance and affect the environment.

The energy and environment impact of such choices will need to become completely transparent and available so that informed decisions on the goods and services we use and the lifestyle options we seek can be made.

This will in turn encourage the development of products that offer a true low energy, low carbon value.

However, one cannot rely on consumers to act differently simply based on public appeals. More sustainable products need to be real alternatives, and ultimately consumers will need to see improved value to sway their decision in favor of more energy-efficient products and services.



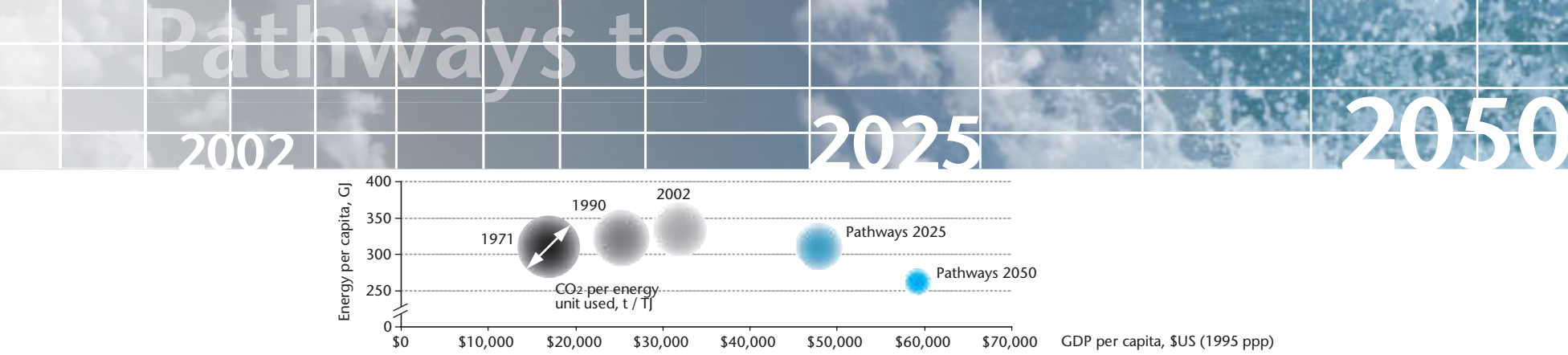
USA and Canada



The challenge

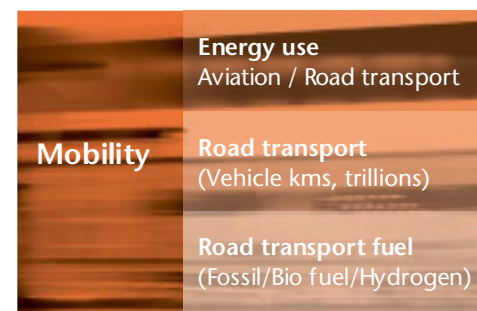
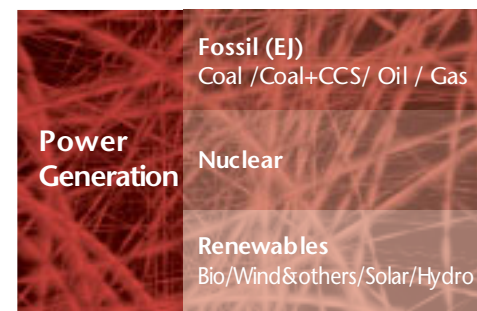
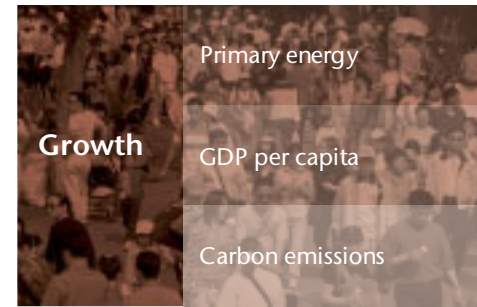
In 2002 the USA & Canada represented the world's largest economic unit, but also the most energy and carbon intensive on a per capita basis. This means that these economies face a dual challenge in contributing to a 550-ppm trajectory, as significant reductions in both energy intensity and carbon intensity must be achieved.

In 2050 the USA & Canada have carbon emissions of some 0.9 GtC, compared with 1.76 GtC in 2002.

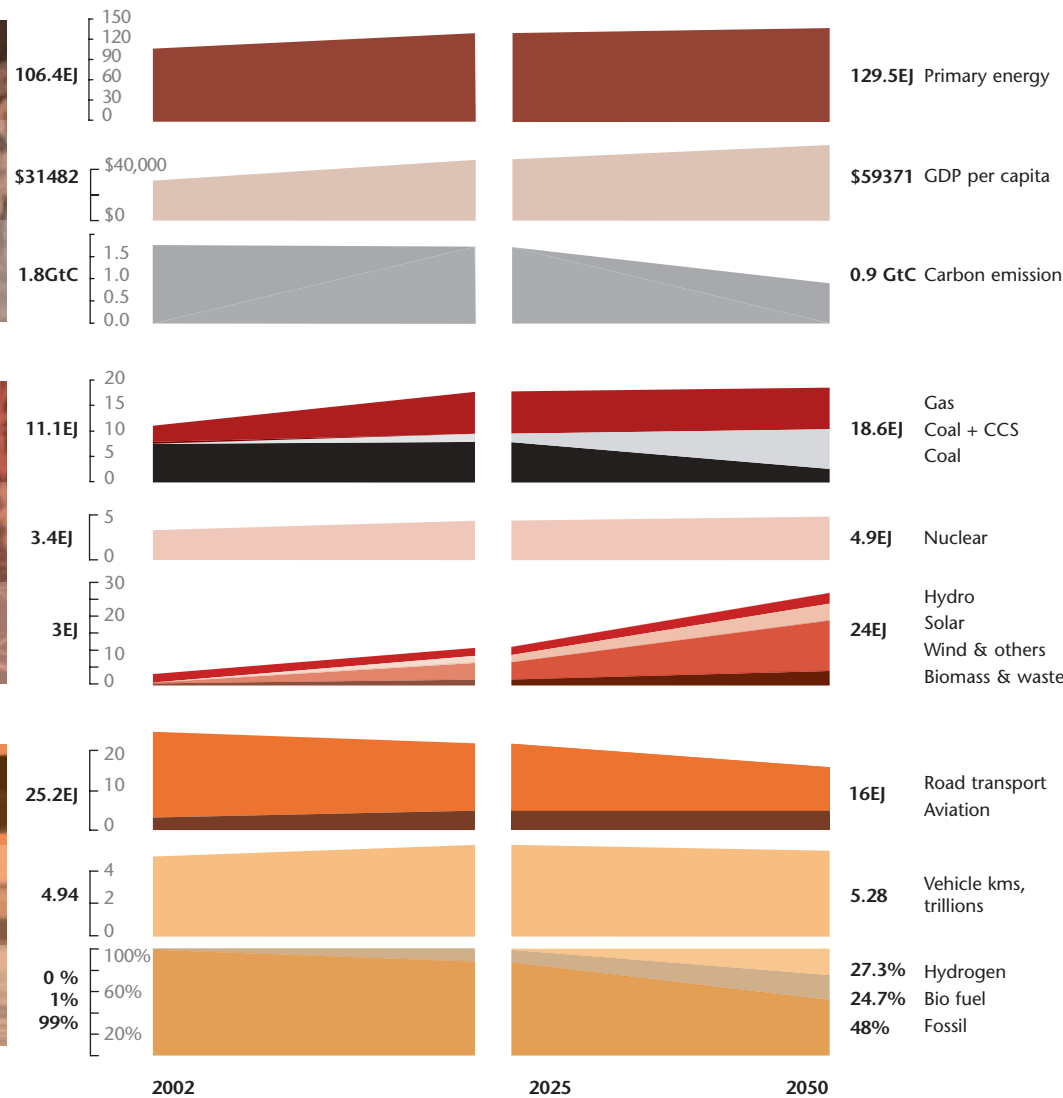


Today

Key indicators



By 2025



2025 milestones

- > Much improved public awareness of the impact of energy use;
- > Carbon emissions in decline particularly from the transport sector, down more than 10% from 2002;
- > Nuclear power capacity maintained at 2000 levels;
- > Over 70 coal-fired power stations with carbon capture and storage capability in operation;
- > Two million hydrogen powered vehicles on the road;
- > Biomass fuel use established and meeting over 10% of the vehicle fuel mix.

By 2050

Efficiency and Growth

The task facing USA & Canada is challenging. Developments through to 2050 are:

- > Primary energy demand close to flat, while maintaining robust economic growth and catering for a growing population;
- > A transformation in mobility infrastructure and fuels with a 100% improvement in vehicle efficiency, large scale use of biomass fuels and the growth of hydrogen fuel cell vehicles to more than one-quarter of the on-road fleet. This delivers a marked reduction in net transport emissions, in contrast to almost constant growth over the 20th century;
- > A restart in nuclear power growth yielding a 40% increase in capacity;
- > The deployment of CCS for coal-fired power generation, with three-quarters of facilities using the technology;
- > Large-scale use of renewables, especially wind and solar.



Exploring Economic Trade-offs

There are inevitable trade-offs between different future paths, which must be explored and managed. While such trade-offs exist in any economy and are a function of the energy market in operation, it is particularly important in the North American context due to the likely extent of reductions required.

From 1990 to 2002, economic efficiency improved by 1.4% per year, with only a small improvement in carbon intensity. If the goal is to stay on the indicated pathway to 2050, maintaining this slow decarbonization trend through to 2050

would require a 78% improvement in energy efficiency across the economy, or an improvement of over 3% per year.

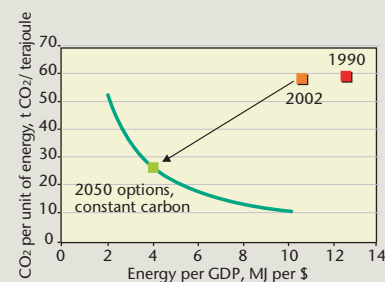


Figure 16: Energy & carbon intensity

Alternatively, with almost no improvement in energy efficiency, energy decarbonization must be some 80%, meaning an almost total renewable / nuclear / carbon sequestration based economy.

Tackling both energy efficiency and carbon intensity is necessary. To 2050, an energy efficiency improvement of about 2% per year is assumed for North America, which in turn requires a 1.4% per year reduction in carbon intensity (see figures 16 and 17). However, a smaller improvement in vehicle

efficiency could mean more need for biomass fuels or more requirements for carbon sequestration in the power

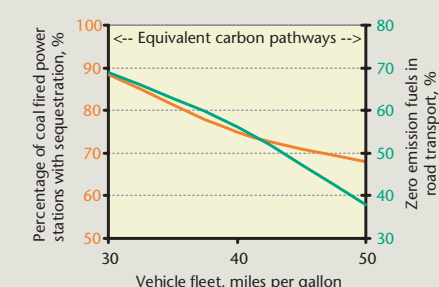


Figure 17: Strategies to offset vehicle efficiency changes

European Union

25 members



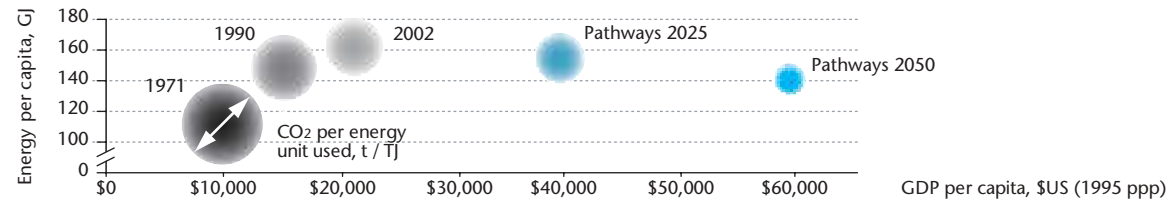
The challenge

The EU has transformed its energy infrastructure over the last 30 years, introducing natural gas, nuclear and more recently wind for power generation and broadening the fuel base for vehicles to include diesel and now biomass fuels. It has also led in the development of climate change policy, as seen with the introduction of emissions trading in 2005.

With these developments, the EU has decarbonized (CO₂ per TJ) its energy use by some 25% over the period, or 0.75% per year. But over the next 50 years, that rate of change needs to double.

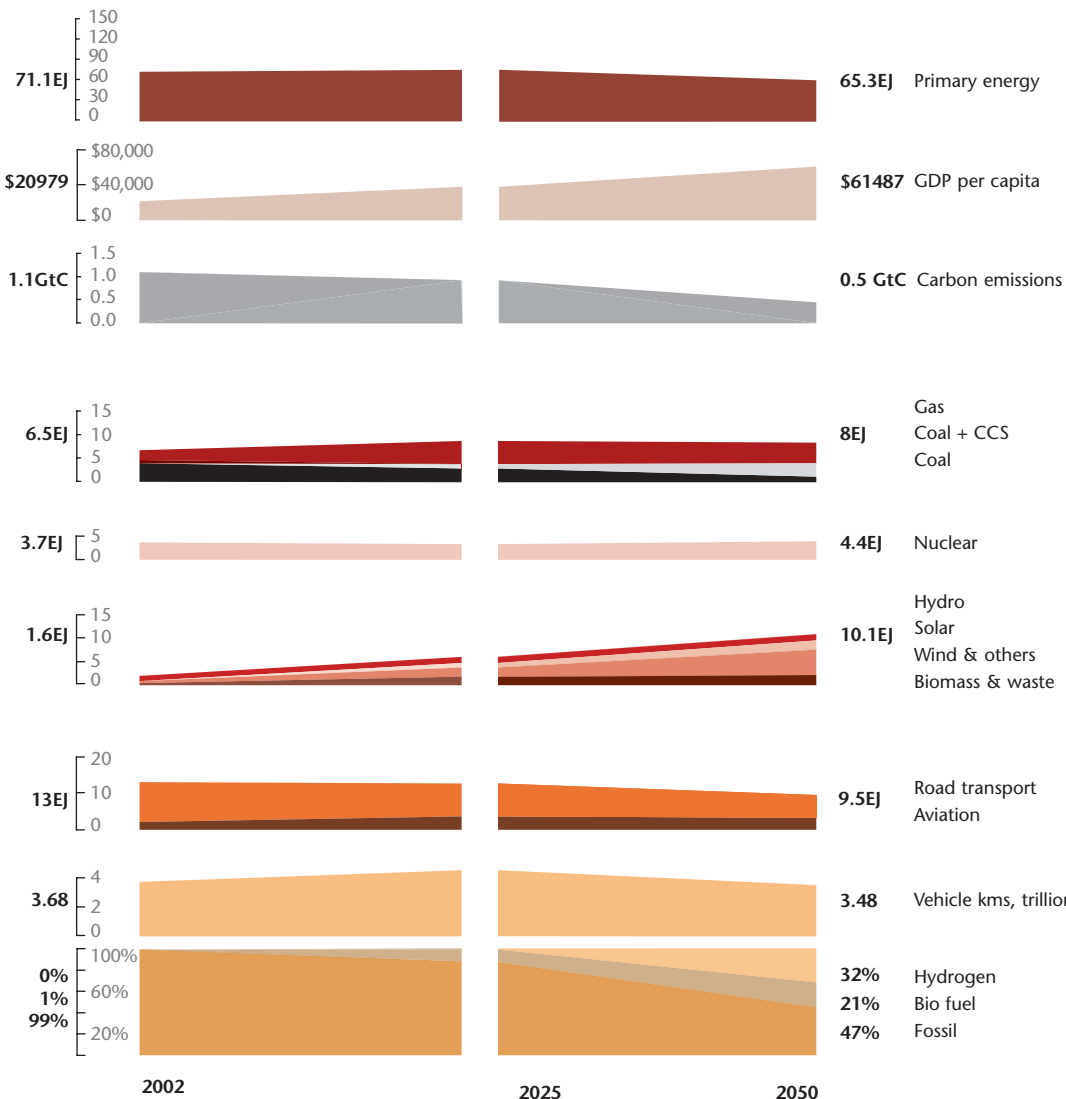
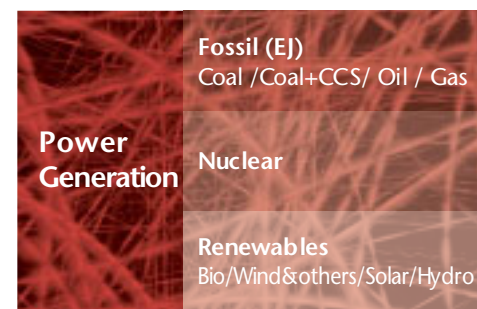
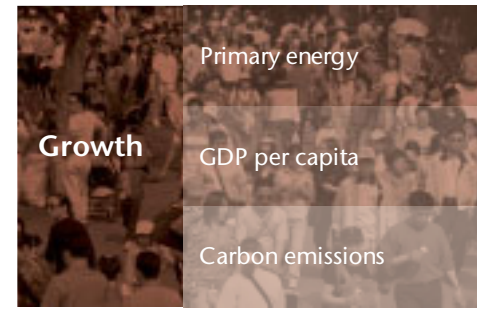
The transformation to come will need to be on a much larger scale than the one we have seen.

Pathways to 2025 2050



Today

Key indicators



2025 milestones

- > One quarter of all coal fired power generation capacity (some 30+ large generating stations) use carbon capture and storage, which means rapid commercialization of this technology;
- > Natural gas use grows by some 35% from 2002, mainly for power generation, bringing with it an increase in import dependency for several countries;
- > Nuclear power growth restarts, which means early clarification of public acceptance issues;
- > Renewable energy (wind and solar) grows substantially, with wind power alone being some 10-15 times the 2002 level. This means a consistent approach across the EU to renewables development;
- > Average on-the-road vehicle efficiency improves by nearly 50% and a zero emissions alternative (e.g. advanced biomass fuels or hydrogen from carbon free sources) has a strong foothold in the sector (at least 10% on-the-road).

By 2050

Broad based energy infrastructure

By 2050 EU energy infrastructure could be very different from today. Developments through to 2050 include:

- > An overall reduction in primary energy demand, through energy efficiency measures;
- > Electricity becomes the dominant end-use energy source, eclipsing the position of petroleum today;
- > A shift from a predominance of oil and gas to a broad based energy mix, including nuclear;
- > A fuel shift in the vehicle sector to a mix of gasoline-diesel / biofuel / hydrogen;
- > Large-scale use of renewables, especially wind and solar.

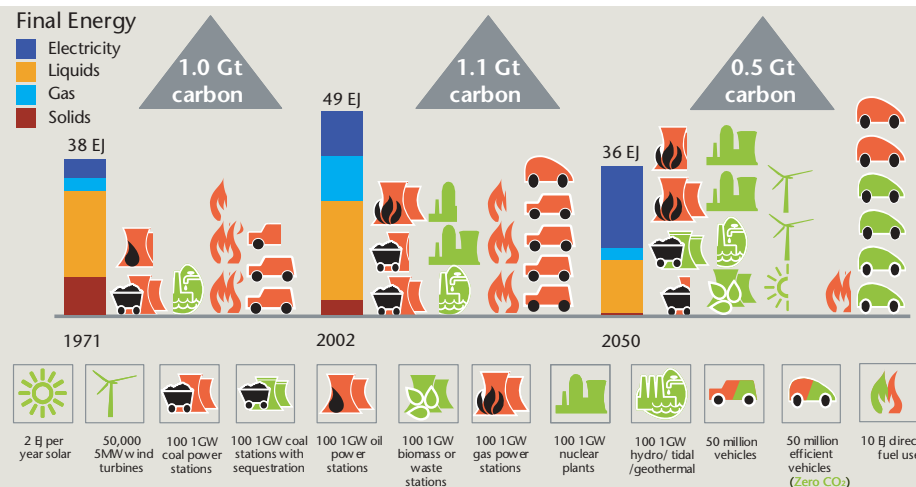


Figure 18: Energy infrastructure in the EU-25

Decarbonizing Europe

Energy changes (see figures 18 & 19) have been considerable since 1971, giving the EU one of the fastest and most consistent decarbonization trends.

But the scale of change in the next 50 years will eclipse even the changes seen so far, with new industries developing, focused on renewable power generation, advanced biomass fuels, hydrogen based transport and carbon sequestration. Final energy demand will need to decline and shift strongly to electricity.

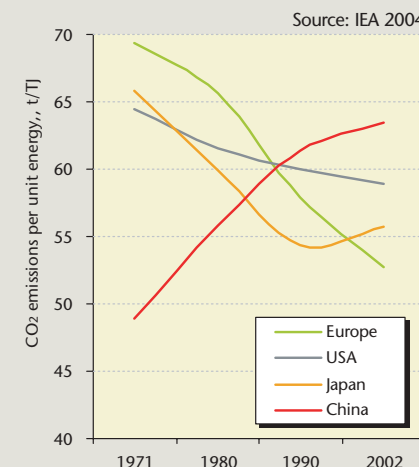


Figure 19: CO₂ intensities in key regions

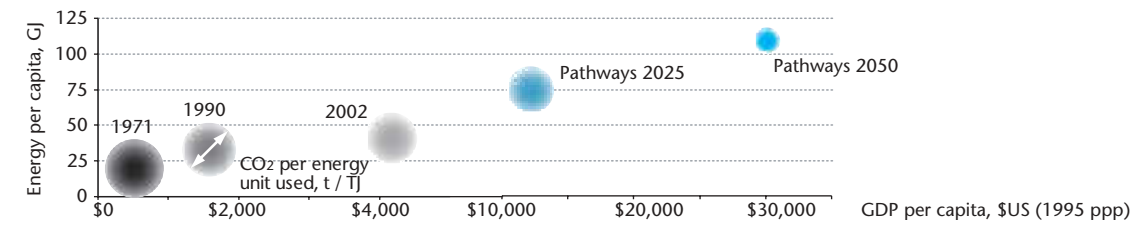


Pathways to 2050

2002

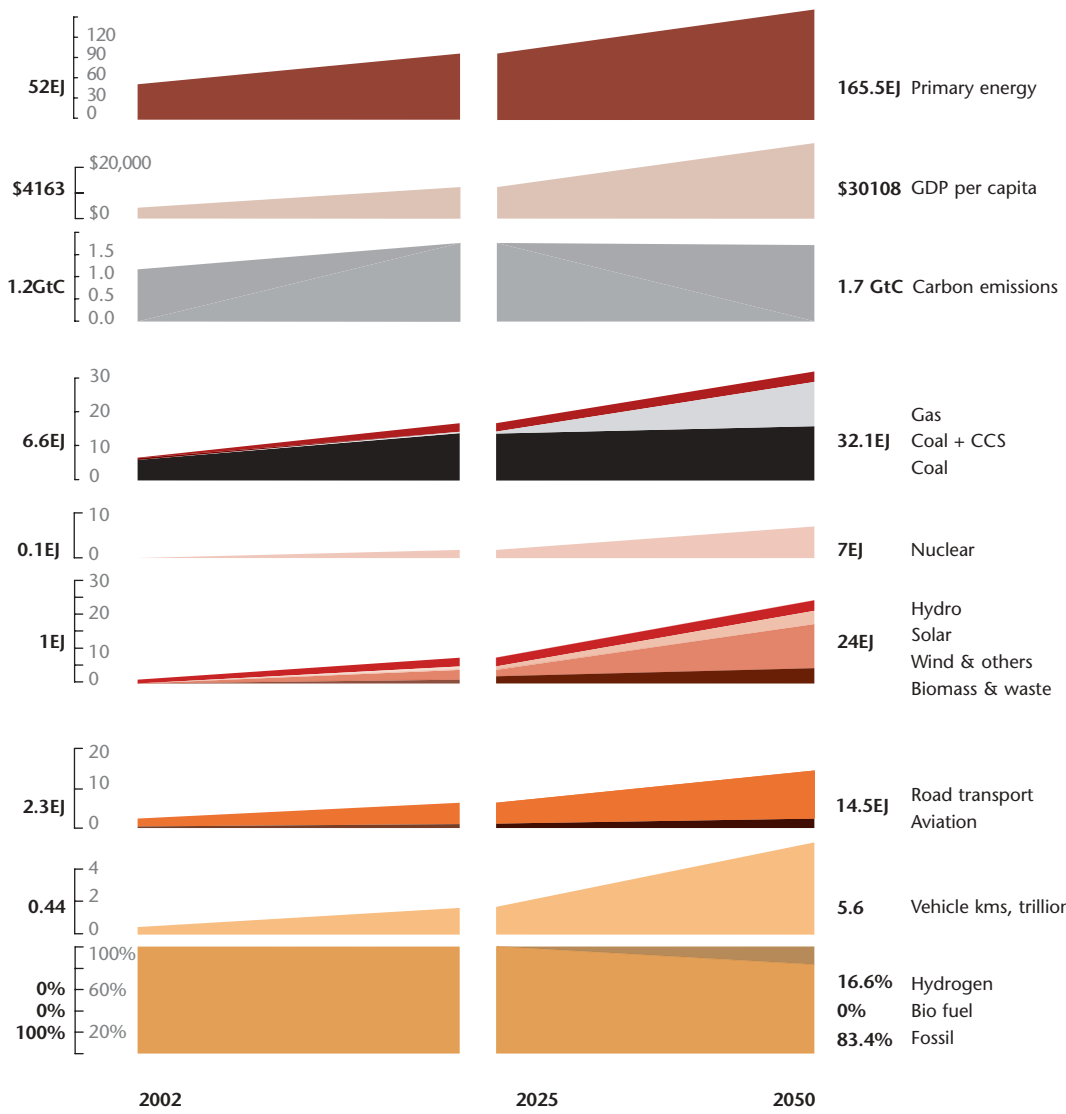
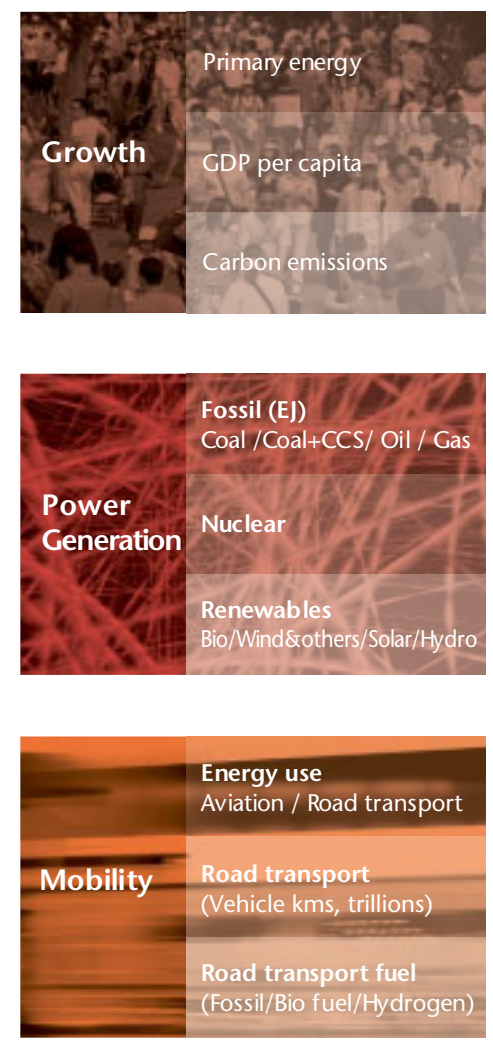
2025

2050



Today

Key indicators



2025 milestones

- > Coal gasification, ideally coupled with carbon capture and storage, in place as the standard for new coal fired power generation, with no further traditional combustion generating plants being built;
- > Tough energy-efficiency standards in place and in use for new homes, buildings and factories;
- > A nearly 10 fold expansion of nuclear power capacity against 2002 levels;
- > Establishment of viable wind and solar businesses in the power generation sector;
- > Continued tightening of the 2004 vehicle efficiency standards to a fleet average of 6 to 6.7 l/100 km (with an on road target of 6 l/100 km for all vehicles by 2050) and the first hydrogen infrastructure under development in specific sectors (e.g. buses and taxis).

By 2050

Low-carbon, coal-based economy

Developments by 2050 include the following:

- > A heavy reliance on coal for power generation, but with nearly 50% of that capturing and storing the carbon dioxide;
- > A large-scale renewable infrastructure for power generation, with wind power as the largest single source (some 200,000 5 MW turbines);
- > A nuclear generation industry equivalent in size to that in the EU and North America combined today;
- > A high efficiency vehicle fleet of some 350 million units, achieving the equivalent of 6 l/100 km. Gasoline and diesel are the predominant fuel, but hydrogen has a significant foothold;
- > Sustainable biomass practices throughout the economy;
- > Energy efficiency in the economy higher than in the best developed countries today.

The challenge

As China progresses rapidly, it is looking to its vast coal resources to power its energy-hungry economy – for power generation, liquid transport fuels and chemical feedstock. But coal is a CO₂ intensive energy source, producing twice the CO₂ emissions as natural gas per kWh of electricity and many times the CO₂ of a conventional refinery for each ton of refined petroleum product when used to produce liquid transport fuels.

China should aim to keep CO₂ emissions well below 2 GtC (compared to 1.2 GtC in 2002), even as energy use triples through to 2050.

While many of today's developed countries must manage a large infrastructure legacy and its related efficiency issues, China is in a unique position as much of its infrastructure is being built for the first time.

Gasification – a future option for coal

Gasification differs from combustion in that instead of burning, most of the carbon-containing feedstock is chemically broken apart by the gasifier's heat and pressure, setting into motion chemical reactions that produce "syngas." Syngas is primarily hydrogen and carbon monoxide.

Syngas can be burned as fuel in a combustion turbine that drives an electric generator. Hot air and exhaust heat from the combustion turbine are also used, giving significant efficiency improvements (eventually approaching 60% as the

technology matures vs. 33-38% in a conventional coal plant).

Clean syngas can also be used as a source of hydrogen that can be separated from the gas stream and used as a transport fuel.

An important advantage of gasification-based energy systems is that as oxygen is used in the gasifier (rather than air), the carbon dioxide produced by the process is in a concentrated gas stream, making it much easier and less expensive to separate and capture.

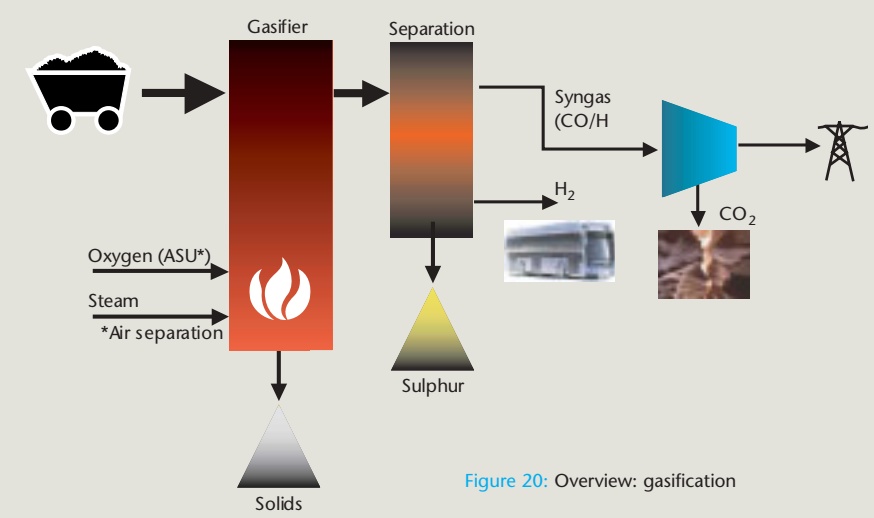


Figure 20: Overview: gasification



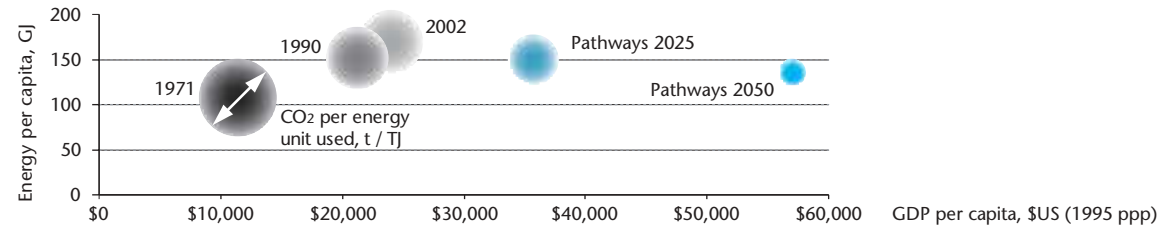
The challenge

With little in the way of natural resources and a heavy dependence on imported energy, Japan has become one of the world's most efficient economies. In doing so, it is now also one of the most innovative.

As such, Japan has the opportunity to become a showcase economy for sustainable energy, eliminating dependency on oil imports and instead relying on more widely available gas, nuclear and renewable power from sources such as biomass & waste, wind and solar.

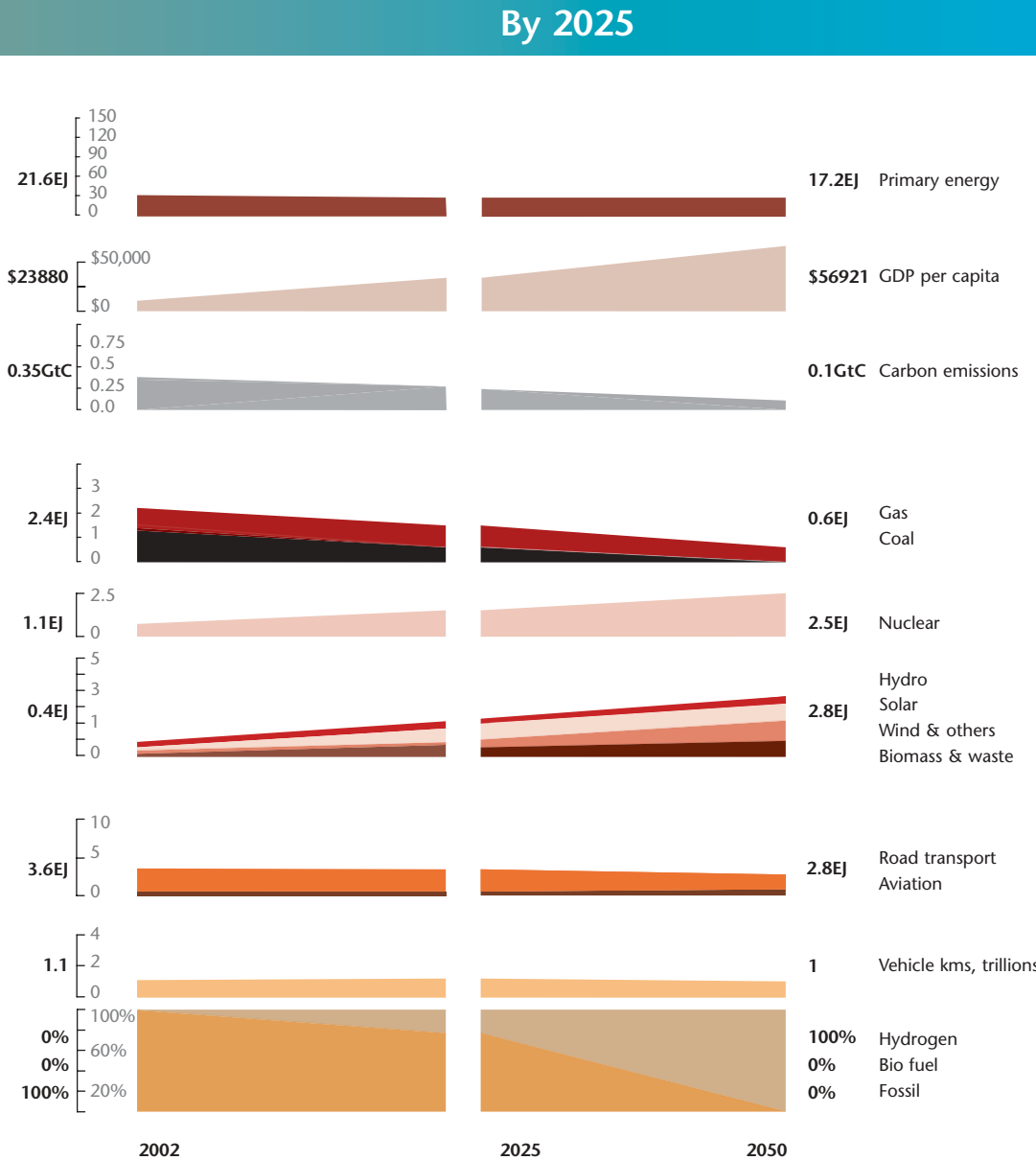
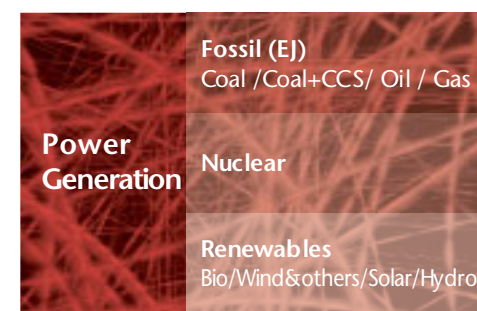
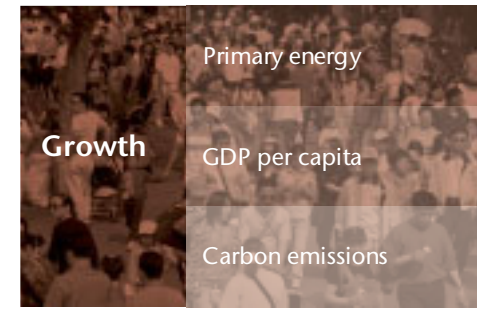
Emissions could fall from 0.35 GtC in 2002, to 0.23 GtC by 2025 and 0.1 GtC by 2050. On such a pathway, Japan would maintain its position as one of the world's most efficient economies and at the same time become the most carbon efficient industrialized economy.

Pathways to 2025 2050



Today

Key indicators



2025 milestones

- > A reduction of 50% or more in the use of coal for power generation;
- > Sustained growth re-established in the nuclear sector, which has faced public acceptance issues in recent years;
- > A large-scale solar industry, with the commercial application of thin-film based roofing and building-cladding materials (see below) well underway;
- > Commercial hydrogen generation and distribution and application in transport established, with fuel market share heading through 20%;
- > Energy use per unit of GDP at or below 4.2 MJ/\$, in contrast to 7 MJ/\$ in 2002.

By 2050

Sustainable energy showcase economy

Major changes in Japan's energy infrastructure and use patterns by 2050 include:

- > Completion of the gradual phase-out of coal-fired power generation and a reduction in power generation from natural gas, substantial improvement in generation efficiencies and the development of advanced carbon sequestration techniques using geochemical reaction;
- > Nuclear power generation at double to triple 2002 levels;
- > Development of a large-scale renewable power sector based on biomass, wind and particularly distributed solar generation;
- > A rapid shift in vehicle fuel from petroleum to hydrogen, generated from carbon free sources (e.g. renewable or nuclear power);



Developing and Showcasing Low Emission Technologies

Thin film solar technology

Solar energy costs lie in the range of 20 to 40 cents per kWh, well above the consumer electricity price. But this price range could be seriously challenged by a new generation of solar technology – flexible sheets of tiny solar cells. The technology could result in thin rolls of highly efficient light-collecting plastics spread across rooftops or built into building materials.

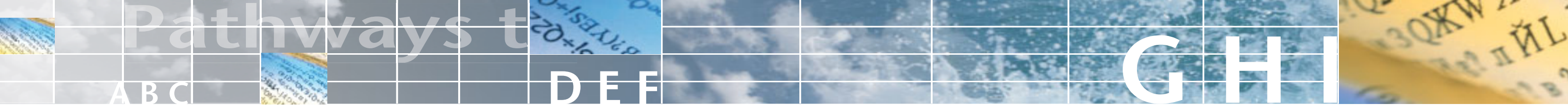
For Japan to produce 1.5 EJ of electricity from solar by 2050 (as much as its coal fired power generation in 2002) using such technology requires most rooftops to be covered.



Hydrogen Based Transport

Companies in Japan are actively developing and demonstrating the building blocks for a hydrogen based transport system. A hydrogen refuelling station in Tokyo has already been opened. Automobile manufacturers are active in the development of advanced fuel, high-efficiency vehicles, as demonstrated by their recent unveiling of hydrogen fuel cell hybrid vehicles.





Glossary

■ AIM

Scenarios from the Asian Pacific Integrated Model (AIM) from the National Institute of Environmental Studies in Japan – see “IPCC Scenarios” below.

■ BAT

Best available technology

■ Biomass & waste

Biomass and waste includes forest and mill residues, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes. Such materials can be burned to produce energy, gasified to produce a feedstock for various fuels or after enzyme hydrolysis to convert the cellulose into sugars, fermented and distilled into ethanol fuel.

■ Carbon dioxide (CO₂)

The principal gaseous product from the combustion of hydrocarbons such as natural gas, oil and coal. CO₂ exists naturally in the atmosphere and it is a greenhouse gas, but its concentration has been rising over the last century. This publication concentrates on reducing carbon dioxide emissions, representing around three quarters of all greenhouse gases (see “Greenhouse Gases”).

■ Carbon Capture and Storage (CCS)

A long-term alternative to emitting carbon dioxide to the atmosphere is capturing and storing it. Geological carbon storage involves the injection of CO₂ into subsurface geological formations. If the CO₂ source is not of sufficient purity, separation must take place first.

■ CO₂ Concentration

The amount of CO₂ in the atmosphere at any given time, typically measured in parts per million (ppm). In this publication CO₂ concentration means CO₂ only and does not include other greenhouse gases.

■ Dry process/wet process

The cement industry uses both dry and wet processes in making cement. The older wet process uses water slurry for mixing and grinding raw materials. The modern, dry process uses dry grinding equipment. The dry process is more thermally efficient as there is no energy lost in evaporating unneeded water.

■ Facts and Trends

The WBCSD 2004 publication *Facts and Trends to 2050: Energy & Climate Change*, used as a reference throughout this document.

■ Final energy

The energy actually used in vehicles, homes, offices and factories. For many consumers final energy is electricity, gasoline and natural gas for cooking and heating.

■ GDP

Gross Domestic Product, a measure of the size of the economy.

■ Gigatons

A ton is a weight measurement. A gigaton is equivalent to one billion tons.

■ Gigatons of Carbon (GtC)

Carbon emissions to the atmosphere are very large, so we measure them in gigatons. One Gt CO₂ in the atmosphere is equivalent to 0.27 GtC

■ Greenhouse Gases (GHGs)

Gases in the earth’s atmosphere that absorb and re-emit infrared radiation thus allowing the atmosphere to retain heat. These gases occur through both natural and human-influenced processes. The major GHG is water vapor. Other primary GHGs include carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF₆).

■ Heat pump

A heat pump is an electrical device, which takes heat from one location and transfers it to another. A typical refrigerator is a type of heat pump since it removes heat from an interior space and then rejects that heat outside. Heat pumps can work in either direction (i.e. they can take heat out of an interior space for cooling, or put heat into an interior space for heating purposes).

■ IEA

International Energy Agency, an intergovernmental body committed to advancing security of energy supply, economic growth and environmental sustainability through energy policy cooperation. A principal publication produced by IEA is the *World Energy Outlook* (WEO).

■ IPCC

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

■ IPCC scenarios

The IPCC developed four narrative storylines to describe potential pathways and encompass different demographic, social, economic, technological, and environmental developments. Importantly, the storylines do not include specific climate initiatives such as the implementation of the Kyoto Protocol. Each scenario then represents a specific quantitative interpretation of one of the storylines. See *Facts and Trends* (WBCSD 2004a) for more details.

■ Joule, MegaJoules (MJ), GigaJoules (GJ), TeraJoules (TJ) and ExaJoules (EJ)

A joule is a measure of energy use, but being a small amount, must be expressed in very large numbers when discussing global energy. A MegaJoule is one million joules, a GigaJoule is one billion joules (1 followed by 9 zeroes), a TeraJoule is 1 followed by 12 zeroes while an ExaJoule is 1 followed by 18 zeroes. One ExaJoule is 278 billion kWh, or 278 thousand GWh, or the equivalent of 32.1 GW power plants running for one year. Also see <http://www.iea.org/Textbase/stats/unit.asp> for conversion factors.

■ Kaya Identity

A simple relationship known as the Kaya Identity breaks down the main emissions driving forces as multiplicative factors on one side of an equation, against CO₂ emissions on the other, such that: CO₂ emissions = people x GDP/person x energy/unit GDP x CO₂/unit energy

■ Land use change

Land use changes take place when a piece of land is permanently modified from its current state, for example, the transformation of a forest into cropland. Land use changes affect the overall carbon emission level when they alter the ability of the vegetation and the soil to absorb carbon emissions. Deforestation is part of land use change.

■ Low-E glass coating

Low-emittance (Low-E) coating are microscopically thin, virtually invisible, metal or metallic oxide layers deposited on a window or skylight glazing surface primarily to reduce the U-factor by suppressing radiative heat flow (Source: <http://www.efficientwindows.org/lowe.cfm>).

■ Marine bunkers

The term “marine bunkers” is used to refer to the fuel combusted inside marine vessels, typically a residue (heavy fuel oil) from the oil refining industry.

■ NICs

Newly Industrialized Countries

■ Parts per million (ppm)

Parts (molecules) of a substance contained in a million parts of another substance. In this document “ppm” is used as a volumetric measure to express the amount of carbon dioxide in the atmosphere at any time.

■ Pathways 2025

Figures for the *Pathways 2025* case are WBCSD extrapolations and estimates reflecting a world that is roughly on the same path as that indicated by the WRE 550 ppm stabilization scenario.

■ Pathways 2050

Figures for the *Pathways 2050* case are WBCSD extrapolations and estimates reflecting a world that emits no more than 9 GtC in 2050.

■ PPP (Purchasing Power Parity)

The rate of currency conversion that equalizes the purchasing power of different currencies of a fixed basket of traded and non-traded goods and services and yield a widely based measure of standard of living.

■ Primary energy

The total energy available from our natural resources, such as renewable, uranium, coal, oil and natural gas, assuming 100% efficient use of those resources.

■ Stabilization

The long-term balanced concentration of CO₂ in the atmosphere. CO₂ constantly migrates from the atmosphere to the oceans, to plant and animal life and then back to the atmosphere where a balanced concentration has been maintained for thousands of years. Following a change in the balance due to additional emissions, a new balance, or stabilization, may take centuries to establish itself.

■ Watt, KiloWatts (KW), MegaWatts (MW), GigaWatts (GW) and Watt-Hour (Wh)

A watt is a measure of the rate of energy use, and is equivalent to a joule per second. A MegaWatt is one million watts, a GigaWatt is one billion watts. Power generation is typically expressed in watt-hours (Wh), which is the supply or use of one watt for a period of one hour. Households express energy use in kilowatt-hours (kWh). An appliance that requires 1000 watts to operate and is left on for one hour consumes one kilowatt-hour of electricity. See also “Joule”.

■ Wind and others

The category Wind and others includes the power generating renewable energy sources wind, tidal, wave and geothermal.

■ World Energy Outlook Reference Scenario

This is an energy scenario developed by the IEA, published most recently in the *World Energy Outlook* (2004). This scenario provides an outlook, under “Business As Usual” assumptions and developments, of the energy future up to 2030.

■ WRE

Wigley, Richels, and Edmonds; refers to the article published by these three authors in 1996: “Economic and Environmental Choices in the Stabilization of Atmospheric CO₂ Concentrations.” *Nature* 379(6562):240-243.

Principal references and sources

ABB 2005:	ABB Review, "Special Report: ABB in China"
BP 2005:	Carbon footprint calculator, http://www.bp.com/carbonfootprint
Department of Trade and Industry (DTI) 2005:	Energy Consumption in the UK
Deutsche Energie Agentur (DENA) 2005:	http://www.eu-label.de
Energy Plus 2004:	http://www.energy-plus.org
European Copper Institute 2004:	Energy Efficient Motor Driven Systems
IEA 1999:	The Reduction of Greenhouse Gas Emissions from the Cement Industry
IEA 2003:	CO ₂ emissions from fuel combustion 1971-2001
IEA 2004:	World Energy Outlook 2004
IPCC 2000:	Emissions scenarios: A special report of working group III of the Intergovernmental Panel on Climate Change
National Energy Foundation 2005:	http://www.nef.org.uk
Natural Resources Canada 2005:	Energy use data handbook
UN 2003:	World population 2002
United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) 2002:	Guidebook on Promotion of Sustainable Energy Consumption: Consumer Organization and Efficient Energy Use in the Residential Sector
WBCSD 2002a:	Toward a Sustainable Cement Industry: Environment, Health, and Safety Performance Improvement
WBCSD 2002b:	Trends, Challenges, and Opportunities in China's Cement Industry
WBCSD 2004a:	Facts and trends to 2050: Energy and Climate Change
WBCSD 2004b:	Mobility to 2030: Meeting the challenges to sustainability
WEC and ADEME 2004:	Energy Efficiency: A worldwide review
WRI 2005:	Climate Analysis Indicators Tool (http://cait.wri.org)

NOTES

1 IEA figures on CO₂ emissions exclude emissions from land use change, but these are included here (e.g. 1GtC in 2000), and are derived from the category "non-fossil CO₂" in IPCC (2000). Error margins in land use change estimates can be high (see also WRI 2005). All emissions figures quoted in this publication exclude non-CO₂ greenhouse gases, which represented around a quarter of total GHG emissions in the year 2000 (WRI 2005).

2 For the overall emissions figure in *Pathways 2025*, we have taken the difference between the WRE 1000 ppm scenario and the 550 ppm scenario in 2025, and subtracted this from the IEA reference case emissions in 2025.

3 BAU (for "Business As Usual") refers to the IEA Reference Scenario from the World Energy Outlook 2004 (IEA 2004). As the WEO does not provide a 2025 data point, we have assumed a mid-point value between those provided by the IEA for 2020 and 2030.

4 The IEA does not provide a data category for buildings. We have assumed our category "buildings" to comprise the categories "residential" and "commercial & public services" from the IEA online database (IEA Energy Information Centre, <http://www.iea.org/Textbase/subjectqueries/index.asp>).

5 EJ quantities given in Figure 7 do not include heat generation, to be consistent with IEA figures on electricity generation (before T&D losses). Power generation figures in individual country sections include heat generation.

6 In Figure 7, as well as the power generation charts in the country sections, "Wind & Others" refers to wind, wave, tidal and geothermal capacity.

7 WBCSD calculations from: Deutsche Energie Agentur (DENA) 2005, Natural Resources Canada 2005, Energy Plus 2004, Department of Trade and Industry (DTI) 2005, National Energy Foundation 2005, United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) 2002, as well as sources mentioned in note 9.

8 Includes: Washing machines, tumble dryers, refrigerators, freezers, dishwashers, ovens.

9 Source: Tokyo Electric Power Company (TEPCO) and WBCSD calculations based on data from: China Statistical Yearbook 2000, Energy Research Institute of the State Development and Planning Commission (China), The Energy Conservation Center (Japan), Industrial Structure Council, Ministry of Economy, Trade and Industry (Japan), Nippon Foundation (Japan), National Bureau of Statistics of China, and Japan Electric Power Information Center.

About the WBCSD

The World Business Council for Sustainable Development (WBCSD) is a coalition of 175 international companies united by a shared commitment to sustainable development via the three pillars of economic growth, ecological balance and social progress. Our members are drawn from more than 30 countries and 20 major industrial sectors. We also benefit from a Global Network of 50+ national and regional business councils and partner organizations.

Our mission is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

Our objectives include:

Business Leadership - to be a leading business advocate on sustainable development.

Policy Development - to participate in policy development to create the right framework conditions for business to make an effective contribution towards sustainable development.

The Business Case - to develop and promote the business case for sustainable development.

Best Practice - to demonstrate the business contribution to sustainable development solutions and share leading edge practices among members.

Global Outreach - contribute to a sustainable future for developing nations and nations in transition.

Energy and Climate Focus Area

Co-chairs
Anne Lauvergeon (AREVA)
Eivind Reiten (Norsk Hydro)

Working group

representatives from 75 member companies and 12 regional BCSDs

Our warmest thanks to all members of the Energy and Climate working group for their contribution to this brochure.

Project director	Laurent Corbier	(WBCSD)
Lead author	David Hone	(Shell)
Co-authors	Simon Schmitz, Lorenz Koch	(WBCSD)
Design	Michael Martin	(WBCSD)
Editor	Danielle Carpenter Sprungli	(WBCSD)

Photo credits

Page 4	Miller Field, carbon capture	BP
Page 7	Dry-process cement plant	R. Rivet
Page 9	Exhibition vehicles	Michelin
Page 11	Swiss Re, Tower in London	Swiss Re
Page 11	Energy efficient house	Baudorre, Meulien
		L'Expansion
Page 20	Solar facade	Shell

Copyright
ISBN
Printer

© WBCSD, November 2005
2-940240-83-3
Atar Roto Presse SA, Switzerland
Printed on paper containing 50% recycled content and 50 % from mainly certified forests (FSC and PEFC). 100 % chlorine free. ISO 14001 certified mill.

Disclaimer

This brochure is released in the name of the WBCSD. Like other WBCSD publications, it is the result of a collaborative effort by members of the secretariat and executives from several member companies. A wide range of members reviewed drafts, thereby ensuring that the document broadly represents the majority view of the WBCSD membership. It does not mean, however, that every member company agrees with every word.

Ordering publications

WBCSD, c/o Earthprint Limited
Tel: (44 1438) 748111
Fax: (44 1438) 748844
wbcسد@earthprint.com
Publications are available at:
www.wbcسد.org
www.earthprint.com



A publication of the WBCSD Facts and Trends series